CROATIAN ACADEMY OF ENGINEERING

JUBILEE ANNUAL 2017-2018
OF THE CROATIAN ACADEMY OF ENGINEERING

Published by:
Croatian Academy of Engineering – HATZ
28 Kačić Street, PO Box 59, HR-10001 Zagreb, Republic of Croatia

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ISSN 1332-3482

Jubilee Annual 2017-2018 of the Croatian Academy of Engineering
Jub. Ann. 2017-2018 Croat. Acad. Eng.

Proof-reader:
Miroslav Horvatić, MA

Pre-press:
Vladimir Pavlić, BSc (GRAPA, Ltd., Zagreb)

Press:
Tiskara Zelina, Ltd., Sveti Ivan Zelina

Circulation:
450 books, 50 CDs

CROATIAN ACADEMY OF ENGINEERING

Jub. Ann. 2017-2018 Croat. Acad. Eng. ISSN 1332-3482

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ACADEMIA SCIENTIARUM TECHNICARUM CROATICA MCMXCIII

CAETS

Euro-CASE

Zagreb, 2018

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ABOUT THE ACADEMY

Editorial

Dear readers,

On January 19, 1993, 25 years ago, the Croatian Academy of Engineering was founded as a scientific organization which brings together distinguished scientists from Croatia and abroad in the fields of technological and biotechnological sciences with the status of an independent scientific association.

It is certainly necessary to note how the Academy developed its activities over the past 25 years in various ways and in various forms in order to have an objective and consistent trace of its activities now and in the future.

It is customary for the Academy to present the appropriate form of its activities in the annuals of the Academy, which are issued yearly in Croatian or English. So, Annual 2016 of the Croatian Academy of Engineering was published in which our members in their papers deal with the current burning topic entitled "The State and the Future of Technical and Biotechnical Sciences in Croatia in the 21st Century" which certainly contributed to considerations and decisions related to the future of science and economy.

You now have in front of you our Annual 2017 - 2018 in English under the title "Annual 2017 – 2018 of the Croatian Academy of Engineering" with the subtitle "Twenty Five Years of the Croatian Academy of Engineering". The significant aim of this edition is to make a contribution to marking the 25th anniversary of our Academy through the organizational and historical review of activities over the past years and to make you familiar with the type and membership of the Academy.

In addition to the informative presentation of the activities, an insight into the part of our members' scientific work is given so that the Annual also contains a series of recent original papers of some of our members, giving the Academy additional scientific value.

Following this introductory part, dear reader, we would like you to get acquainted with the organization and history of the Academy and to see the detailed organization of our Academy that has evolved over the last years.

Particular emphasis should be put on a large number of organizational units which cover the diversity of as large a number of imagined activities of the Academy as possible.

Of course, this diverse activity requires a series of normative acts that cover these activities and are coordinated with the relevant legal regulations.

Therefore, the Annual presents a brief description of our normative acts with special reference to the Statute of the Academy.

Three comprehensive papers are dedicated to the twenty-five-year history of the Croatian Academy of Engineering described through the memories of the previous historical presidents, which gives the additional authenticity and quality of the presentation of work and events associated with the life of the Academy.

As the Academy has been establishing connections with the international science community since its beginnings, especially in the technical fields, there is a rich activity of the Academy in that sense.

The membership in Euro-CASE (the European Council of Applied Sciences and Engineering) and CAETS (International Council of Academies of Engineering and Technological Sciences, where we take active participation in their work, provide a special support for this connection.

Particularly important are also agreements on cooperation with academies from other countries. A more detailed description of these co-operations is presented in the paper 'International Cooperation of the Croatian Academy of Engineering in the period 1997-2018'. We have paid special attention to marking this twenty-fifth year of the Academy, which lasts throughout 2018 in various ways, especially through scientific and professional meetings that will contribute to the wider community as well. The details of this marking are described below in '2018 - Celebrating 25 Years of Progress of the Croatian Academy of Engineering' and I am inviting the readers to participate in interesting events (www.hatz.hr).

In its ranks the Academy has a large number of prominent members who are widely recognized in our scientific and social community and have received significant acknowledgments for their work and contribution to the reputation of the academic community. It certainly deserves to be especially emphasized, so the following chapter “National Awards and Decorations of the Members of the Croatian Academy of Engineering 1993-2018" and "Recipients of the Awards of the Academy 2002-2018" brings a list of our members who are the winners of social awards and decorations, and especially of traditional awards made by our Academy for years.

It is an opportunity for our readers of the Jubilee Annual to get acquainted with our members and their number in the special chapter 'Members of the Academy in 2018 (Full Members of the Academy, Elected Members of the Academy, Emeriti of the Academy and Associates of the Academy in 2018', 'Honorary Members of the Academy in 2018', 'Deceased Members of the Academy (all categories) 1993-2018'. The current list of all the categories of our members that we are proud of is given. For historical reasons it is necessary to pay homage to our unfortunately deceased members since the foundation of the Academy until this day.

As the Academy maintains cooperation with the rest of the scientific community, and especially with the economy, the next chapter 'Supporting Members of the Academy in 2018' also presents our current corporate members in the category of supporting members of the Academy, whom we are particularly grateful for their contribution to the regular work of the Academy .

In 2017 the current leadership, i.e. the Governing Board, was elected, whose mandate lasts up to 2021. As this jubilee year falls within the scope of this mandate, we have found it desirable to present a shortened election program of work of the new Governing Board to give the reader an insight into the current activities of the Academy as presented at the end of the first part of the Annual in 'A Short Overview of the Work of the Governing Board of the Croatian Academy of Engineering 2017-2021'.

The specific feature of scientific work of our elected members is a productive scientific publication in various editions at home and abroad. Therefore, we asked our members to submit their original unpublished scientific papers for this Jubilee Annual. The Editorial Board selected about sixteen papers from various technical fields for publication in the second part of this Annual. I believe that after reading these papers of our members in co-authorship with other prominent scientists you will acquire some new useful scientific knowledge in the area of technical and biotechnical sciences. We are especially grateful to the authors and their associates for their contribution which in our opinion contributes to increasing the reputation of our Academy.

In order to become more familiar with the scope of the activities of our members whose quality and number we are proud of, the last part of the Annual presents in the form of 'Who is Who' in our Academy, as we have done earlier, the basic information about our members and the reader will surely then gain the impression of the significance of the Croatian Academy of Engineering today.

Finally, as the Editorial Board, we apologize in advance for any unintended oversights, inaccuracies or incompleteness that may have happened in such a demanding edition, and I express my special gratitude to all the contributors to this monograph.

Editor in Chief
Prof. *Vladimir Andročec*, Ph.D.

Organization of the Croatian Academy of Engineering

Rogale, D.

Vice-President of the Academy

Croatian Academy of Engineering has a complex internal organization that has been changed and improved during the existence of the Academy. In this way its efficiency has been ensured and increased. The organization has a very clear organizational scheme and hierarchical structure, its bodies and holders of tasks. The organizational structure in the mandate of the Governing Board of the Academy 2013-2017 has changed to a lesser extent in the new mandate 2017-2021 and is shown in Figure 1.

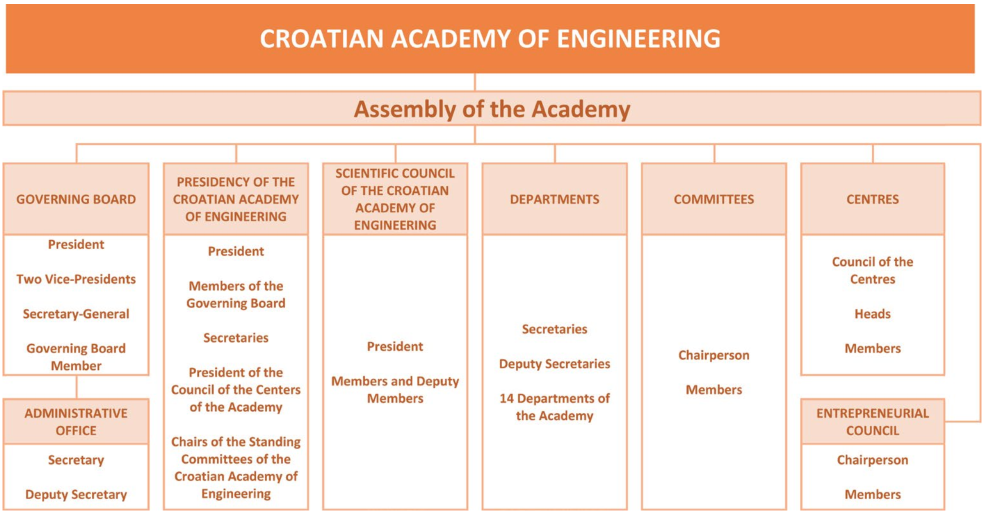


Fig. 1 – Basic organizational structure of the Croatian Academy of Engineering

The above figure also shows the newly established Entrepreneurial Council of the Academy as an advisory board.

Assembly of the Academy

The Statute of the Academy stipulates that the Assembly is the highest body of the Academy, Fig. 2, constituted of all categories of members and chaired by the President of the Academy.

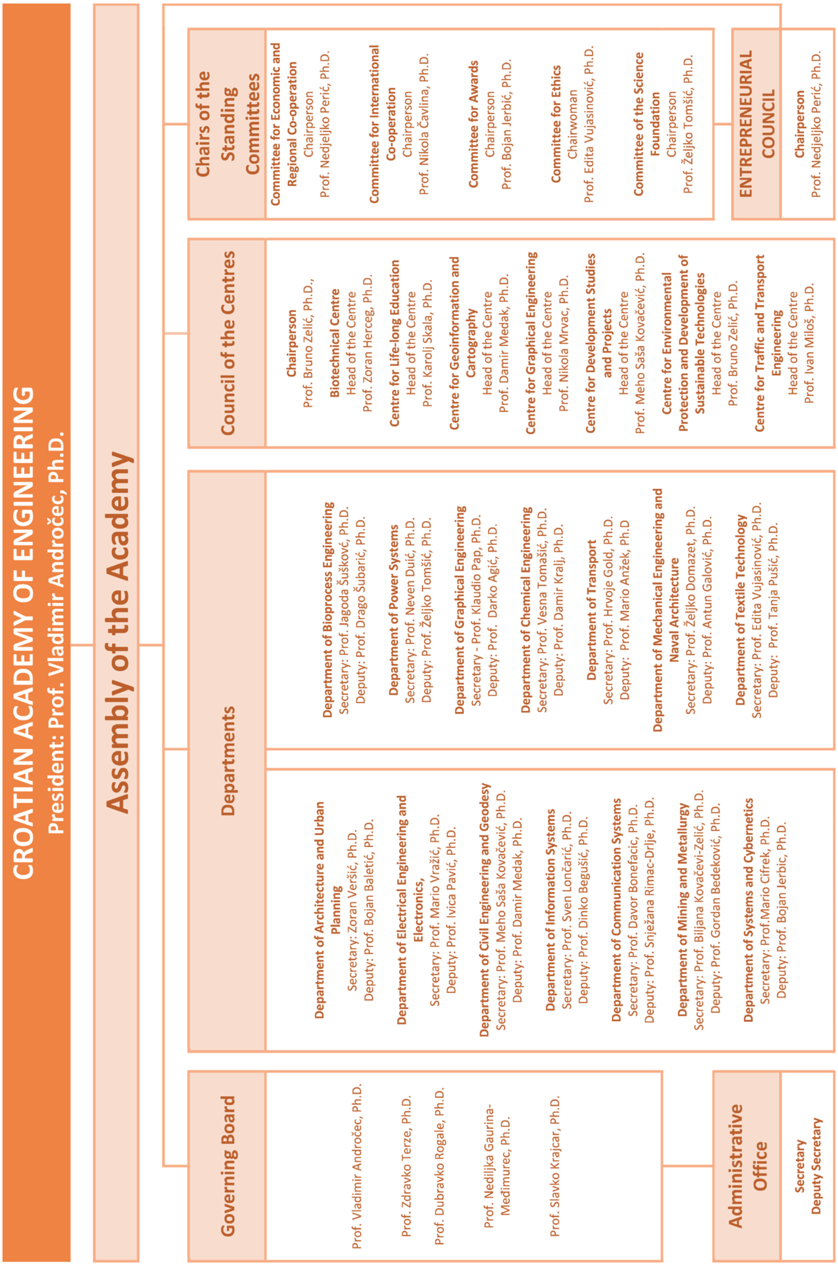


Fig. 2 – Organizational structure of the Academy with all constituent elements and the leadership elected for 2017-2021 mandate

The above figure lists the names of the members of the Governing Board elected for the 2017-2021 mandate, the names of all 14 Academy Departments and their Secretaries and Deputy Secretaries, the Council of Centers, Chairperson of the Council and the names of the centers and their Chairpersons.

In addition, the names of the Committees and their Chairpersons and the newly established Entrepreneurial Council with its Chairperson are also listed.

Governing Board

The Governing Board of the Academy consists of the President, two Vice-Presidents, the Secretary-General of the Academy and Governing Board Member. The mandate of the elected members of the Governing Board lasts 4 years, Fig. 3.

The President of the Academy presides over the Governing Board.

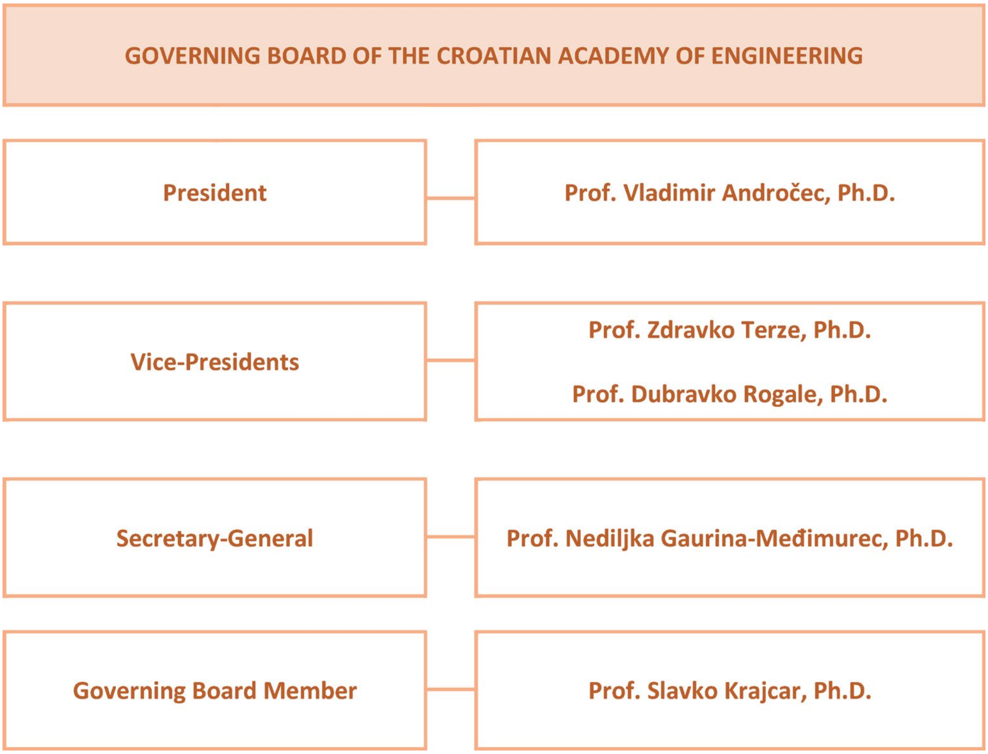


Fig. 3 – Organization of the Governing Board of the Croatian Academy of Engineering 2017-2021

President of the Academy represents the Academy, presides over the Assembly, convenes the meetings of the Assembly, Presidency and Governing Board, chairs them and supervises decision making and execution of decisions. President of the Academy acts on behalf of the Academy and manages its financial affairs. President of the Academy may assign particular areas of his/her authority to the Vice-Presidents and Secretary-General. President of the Academy promotes activities of the Academy in administrative structures and in collaboration with industry in Croatia, and according to the program of the Academy in cooperation with foreign countries. President of the Academy is elected for a term of four years with the possibility of reelection for another consecutive mandate.

Vice-Presidents of the Academy carry out tasks under the authority entrusted to them by the President of the Academy. One Vice-President of the Academy is responsible for monitoring and coordinating the work with the Departments of the Academy, and the second Vice-President of the Academy is responsible for the execution of the program, i.e. projects of the Academy, activities of the Standing Committees and monitoring the work of the Science Fund of the Academy. Vice-Presidents are elected for a term of four years with the possibility of reelection for another consecutive mandate.

Secretary-General of the Academy organizes the work of the Professional Services of the Academy, prepares and organizes meetings of bodies, drafts decisions and documents of the Academy, coordinates the work of the bodies of the Academy, supervises the execution of the decisions made by the Academy, performs all tasks entrusted to him/her by the Assembly, the Presidency, the Governing Board and the President of the Academy. Secretary-General of the Academy is elected for a term of four years with the possibility of reelection for another consecutive mandate.

Presidency of the Academy

The Presidency of the Academy is executive body of the Assembly.

The Presidency of the Academy consists of the President of the Academy, two Vice-Presidents of the Academy, the Secretary-General of the Academy, one member of the Governing Board, Secretaries of Departments of the Academy, President of the Council of the Centers of the Academy and the Chairpersons of Committees of the Academy, Fig. 4. The mandate of the Presidency lasts 4 years.

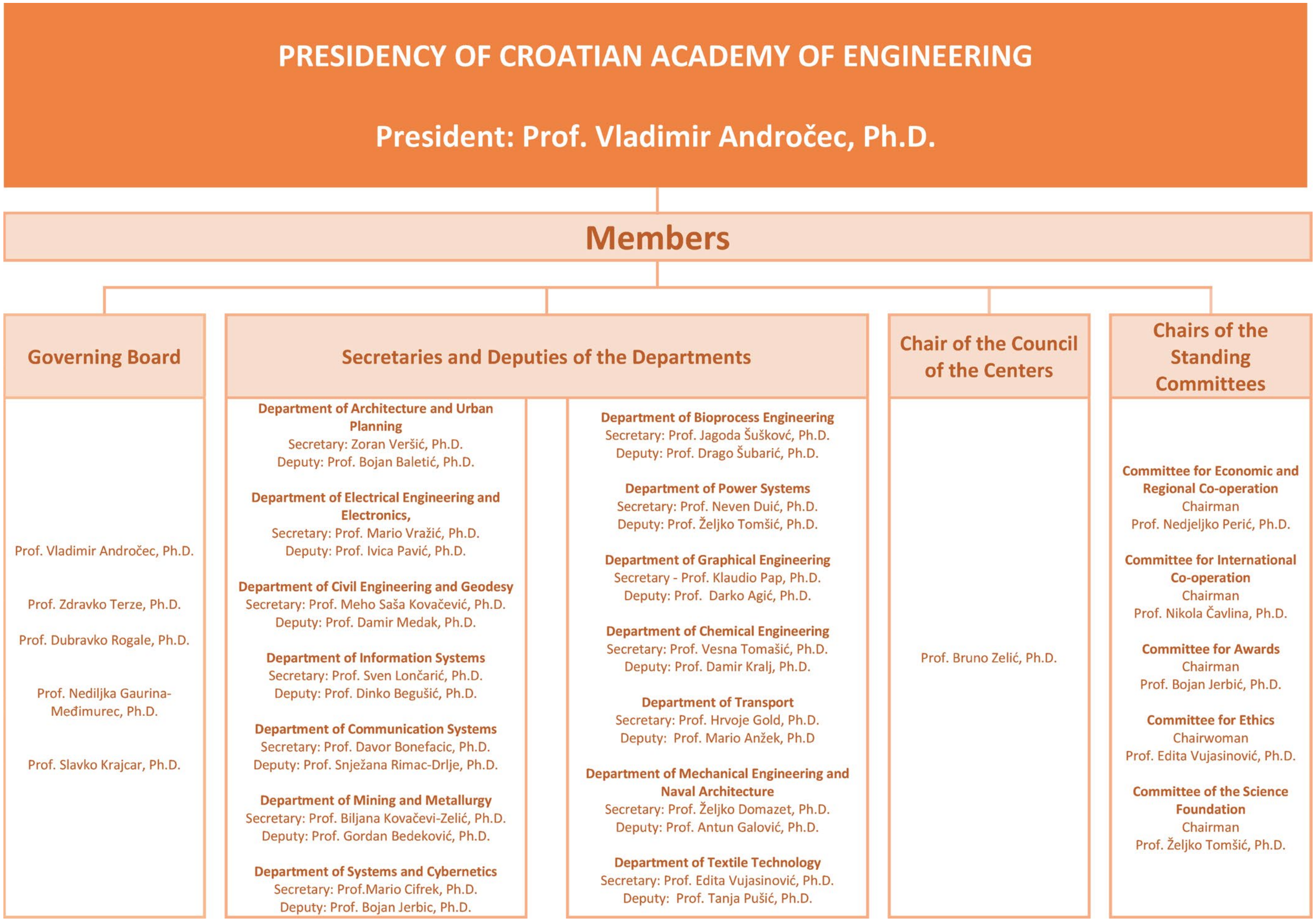


Fig. 4 – Presidency of the Croatian Academy of Engineering 2017-2021

Meetings of the Presidency are held as required, six times a year as a rule. Fig. 4 shows the structure of the Presidency and the members elected for the 2017-2021 mandate.

Scientific Council of the Academy

Scientific Council of the Academy is a scientific body of the Academy. Scientific Council of the Academy consists of the representatives of each Department (one per Department) and Chairperson of the Scientific Council, Fig. 5. Members of the Scientific Council of the Academy shall be elected from among members of the Academy and Members Emeriti of the Academy by Departments for a period of four years with the possibility of reelection. Fig. 5 lists the names of the members of the Scientific Council and their Deputies for the 2017-2021 mandate.

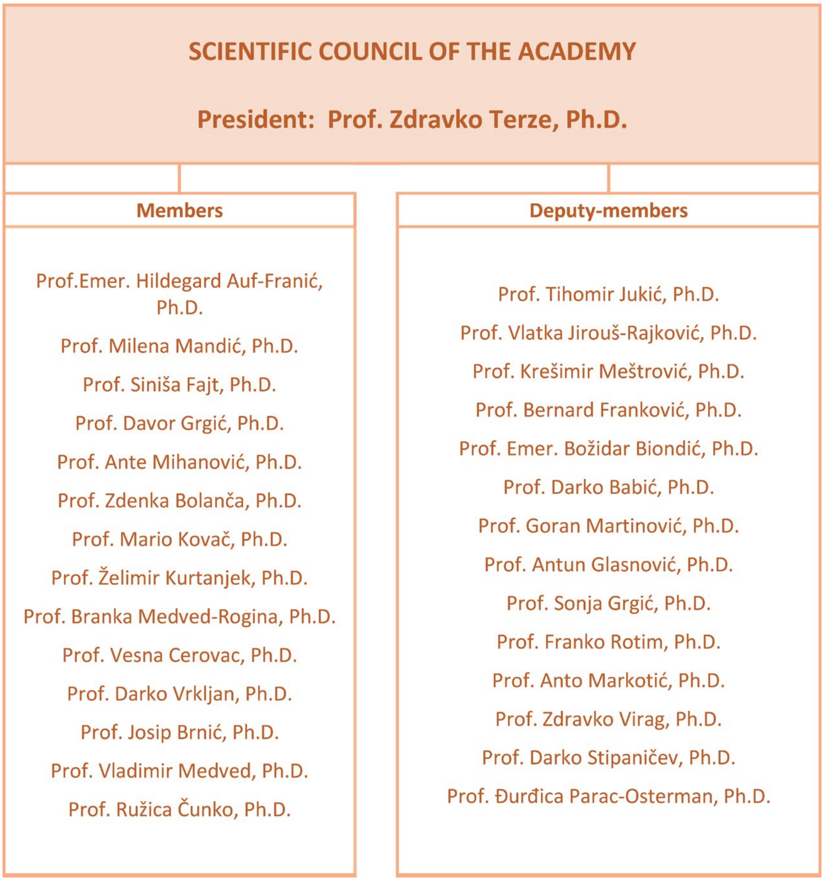


Fig. 5 – Scientific Council of the Croatian Academy of Engineering 2017-2021

President of the Academy is the function of a member and Chairperson of the Scientific Council, but it is stipulated that he may transfer his powers to the Vice-President. Each Department shall nominate one representative of the Department as a candidate for member of the Scientific Council. Secretary and Deputy Secretary of the Department cannot be candidates for membership of the Scientific Council. Decision on election of members of the Scientific Council (one per Department) is made by the Presidency on the proposal of each Department.

Organization of the Activities of the Academy

According to the provisions of the Statute the Academy organizes its activities in Departments, Centers, Committees and other organizational forms. The activities and organization of work of the Departments, Centers, Committees and other organizational forms are regulated by the Statute and bylaws and rules of procedure.

Task management of the Academy is carried out by the Departments, Centers and Committees that have no legal personality.

At the head of a Department there is Secretary of the Department of the Academy, Head of the Center of the Academy presides over each Center and at the head of a Committee there is Chairperson of the Committee of the Academy. In the bodies of the Academy a Department of the Academy is represented by Secretary of the Department, Heads of the Centers of the Academy are represented by the President of the Council of the Centers, and each Committee is represented by Chairperson of the Committee. Secretaries of Departments of the Academy and Chairpersons of Committees of the Academy and President of the Council of the Centers and their deputies shall be elected for a term of four years with the possibility of reelection for a successive mandate.

Departments of the Academy

Departments of the Academy are:

Department of Architecture and Urban Planning, Department of Bioprocess Engineering, Department of Electrical Engineering and Electronics, Department of Power Systems, Department of Civil Engineering and Geodesy, Department of Graphical Engineering, Department of Information Systems, Department of Chemical Engineering, Department of Communication Systems, Department of Transport, Department of Mining and Metallurgy, Department of Mechanical Engineering and Naval Architecture, Department of Systems and Cybernetics and Department of Textile Technology, Fig. 6.

Departments, Secretaries of the Departments and Deputies

Department of Architecture and Urban Planning Secretary: Zoran Veršić, Ph.D. Deputy: Prof. Bojan Baletić, Ph.D.	**Department of Bioprocess Engineering** Secretary: Prof. Jagoda Šuškovć, Ph.D. Deputy: Prof. Drago Šubarić, Ph.D.
Department of Electrical Engineering and Electronics, Secretary: Prof. Mario Vražić, Ph.D. Deputy: Prof. Ivica Pavić, Ph.D.	**Department of Power Systems** Secretary: Prof. Neven Duić, Ph.D. Deputy: Prof. Željko Tomšić, Ph.D.
Department of Civil Engineering and Geodesy Secretary: Prof. Meho Saša Kovačević, Ph.D. Deputy: Prof. Damir Medak, Ph.D.	**Department of Graphical Engineering** Secretary - Prof. Klaudio Pap, Ph.D. Deputy: Prof. Darko Agić, Ph.D.
Department of Information Systems Secretary: Prof. Sven Lončarić, Ph.D. Deputy: Prof. Dinko Begušić, Ph.D.	**Department of Chemical Engineering** Secretary: Prof. Vesna Tomašić, Ph.D. Deputy: Prof. Damir Kralj, Ph.D.
Department of Communication Systems Secretary: Prof. Davor Bonefačić, Ph.D. Deputy: Prof. Snježana Rimac-Drlje, Ph.D.	**Department of Transport** Secretary: Prof. Hrvoje Gold, Ph.D. Deputy: Prof. Mario Anžek, Ph.D
Department of Mining and Metallurgy Secretary: Prof. Biljana Kovačevi-Zelić, Ph.D. Deputy: Prof. Gordana Bedeković, Ph.D.	**Department of Mechanical Engineering and Naval Architecture** Secretary: Prof. Željko Domazet, Ph.D. Deputy: Prof. Antun Galović, Ph.D.
Department of Systems and Cybernetics Secretary: Prof.Mario Cifrek, Ph.D. Deputy: Prof. Bojan Jerbic, Ph.D.	**Department of Textile Technology** Secretary: Prof. Edita Vujasinović, Ph.D. Deputy: Prof. Tanja Pušić, Ph.D.

Fig. 6 – Departments of the Croatian Academy of Engineering 2017-2021

The above figure also lists the names of the Secretaries of the Departments and their Deputies elected for the 2017-2021 mandate. The Departments are founded, merged, divided, abolished and operate pursuant to the decision of the Assembly of the Academy.

Committees of the Academy

Committees are inter-departmental bodies of overall importance for the work of the Academy. Prominent experts from business and persons who are not members of the Academy may collaborate in the Committees. The number of such collaborators cannot be higher than 40% of the total number of the members of the Committee.

Committees of the Academy

Committee	Committee for Economic and Regional Co-operation	Committee for International Co-operation	Committee for Awards	Committee for Ethics	Committee of the Science Foundation
Chairperson	Prof. Nedjeljko Perić, Ph.D.	Prof. Nikola Čavlina, Ph.D.	Prof. Bojan Jerbić, Ph.D.	Prof. Edita Vujasinović, Ph.D.	Prof. Željko Tomšić, Ph.D.
Deputy-Chairperson	Prof. Damir Ježek, Ph.D.	Prof. Karolj Skala, Ph.D.	Prof. Drago Šubarić, Ph.D.	Prof. Gordan Bedeković, Ph.D.	Prof. Vesna Lelas, Ph.D.
Members	Prof. Niko Malbaša, Ph.D. Prof. Nevenka Ožanić, Ph.D. Prof. Marin Milković, Ph.D. Prof. Damir Kralj, Ph.D. Prof. Tanja Pušić, Ph.D. Prof. Slavko Krajcar, Ph.D.	Prof. Vladimir Mrša, Ph.D. Prof. Emer. Dubravka Bjegović, Ph.D. Prof. Bruno Zelić, Ph.D. Prof. Biljana Kovačević-Zelić, Ph.D. Prof. Emer. Ana Marija Grancarić, Ph.D.	Prof. Dražen Aničić, Ph.D. Prof. Stanislav Bolanča, Ph.D. Prof. Marko Rogošić, Ph.D. Prof. Sonja Grgić, Ph.D. Prof. Trpimir Kujundžić, Ph.D. Prof. Zvonko Dragčević, Ph.D. Prof. Dubravko Rogale, Ph.D. (by office) Prof. Krešimir Ćosić, Ph.D.	Prof. Srečko Pegan, Ph.D. Prof. Ivica Grbac, Ph.D. Prof. Miljenko Lapaine, Ph.D. Prof. Darko Babić, Ph.D. Prof. Ivan Petrović, Ph.D. Prof. Emil Hnatko, Ph.D.	Prof. Zvonko Dragčević, Ph.D. Prof. Bojan Jerbić, Ph.D. (by office) Prof. Siniša Srbljić, Ph.D.

Fig. 7 – Committees of the Croatian Academy of Engineering 2017-2021

Figure 7 shows the organizational structure of five committees of the Academy, their chairpersons and members elected for the 2017-2021 mandate.

Centers of the Academy

Center is a scientific research unit of the Academy established for a specific field of science with the aim of conducting scientific research intended for immediate application in the economy. Centers are established pursuant to the Bylaw of the Organization of Centers of the Croatian Academy of Engineering. The initiative to establish a Center is given by the Departments, the proposal is determined by the Governing Board, and the decision is made by the Presidency of the Academy. The Council of the Centers is a coordinative body of the Centers. The President and Heads of the Centers are members of the Council, Fig. 8.

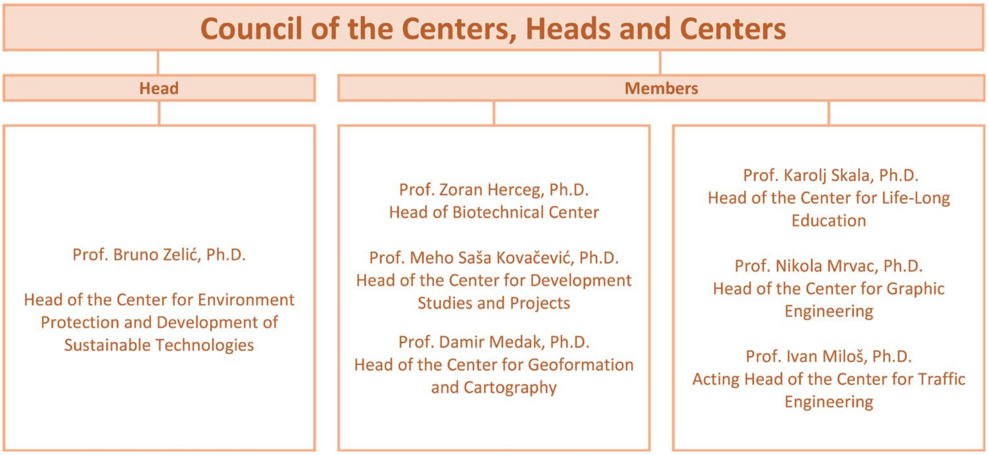


Fig. 8 – Councils of the Centers, Heads and Centers of the Croatian Academy of Engineering 2017-2021

The Members of the Council elect the President of the Council of the Centers who will represent them at the Presidency of the Academy and report on the activities of the Centers.

Entrepreneurial Council of the Academy

The Entrepreneurial Council of the Academy is a newly established advisory board of the Academy for the cooperation between the Academy and the economy. The Entrepreneur Members of the Academy constitute the Entrepreneurial Council of the Academy. A Ph.D. title is not required to acquire the status of an entrepreneur member of the Academy. The reputation of an entrepreneur member of the Academy is based on his/her exceptionally personal contributions in fields such as: development and production business in the industry; management business in industry and economy; technology transfer; patenting original industrial processes, technologies and entrepreneurship. An entrepreneur member of the Academy should be a person who, through his/her work in the economy, has made a significant contribution to his/her company and in the wider community, and preferably on the international scene. The Chairperson of the Committee of Economic Cooperation convenes sessions of the Entrepreneurial Council of the Academy and chairs them.

Other Forms of Organization

In addition to the current organization scheme of the Academy, the Academy may establish councils, committees and other organizational forms of temporary character. Decision to establish such bodies will be taken by the Presidency which may cause a change in the organization scheme to a smaller extent.

The Academy has a Professional Service to perform administrative, technical, financial, accounting and other duties necessary for the realization of the activities of the Academy. Secretary-General of the Academy is the head of the administration.

The Academy may entrust an authorized organization with a partial or complete performance of the duties, if it is so decided by the Presidency.

Normative Acts of the Academy

Gaurina-Međimurec, N.

Secretary-General of the Academy

The Croatian Academy of Engineering is a scientific organization that brings together distinguished domestic and foreign scientists in the field of technical and biotechnical sciences in order to support the effective scientific and economic development of Croatia without gaining any profit. Its activity is regulated by a series of normative acts, which are adopted by the Assembly of the Academy or the Presidency of the Academy. The Assembly of the Academy adopts the Statute of the Academy and the Bylaw on Membership, whereas the Presidency of the Academy adopts other normative acts pursuant to Article 13 of the Law on Associations (Official Gazette 17/14 and 70/17) the Croatian Academy of Engineering has the Statute which is its fundamental general act and nine other general acts (bylaws/rules of procedure) which comply with the Statute of the Academy.

Over the past 25 years the normative acts were amended according to the needs of the Academy, and each amendment contributed to a more efficient action of the Academy. The First Statute of the Academy was passed by the Assembly of the Academy at its session on 19 January 1993. Thus, in the mandate of the previous Board (2013-2017) some existing normative acts were amended and some new ones were adopted.

The Assembly of the Croatian Academy of Engineering at its thirty-second session held on May 13, 2015 adopted the **Statute** of the Croatian Academy of Engineering and at its 32nd session held on 15 May 2017 adopted **the Bylaw on Election to Membership** of the Academy.

The Presidency of the Croatian Academy of Engineering at its sessions in 2015 and 2016 adopted the following normative acts:

- Bylaw on the Organization and Activities of the Centers of the Croatian Academy of Engineering (March 9, 2015)
- Rules of Procedure of the Work of the Scientific Council (April 20, 2015)

- Bylaw on Awards and Recognitions of the Croatian Academy of Engineering (April 18, 2016)
- Regulation on Acquisition and Distribution of Income (October 17, 2016)
- Normative Acts Associated with Financial Operations of the Academy (October 17, 2016)
- Bylaw of the Scientific Fund of the Academy (December 19, 2016)
- Rules of Procedure of the Work of the Departments (December 19, 2016)
- Labor Bylaw of the Academy (December 19, 2016)

Below is a brief description of areas regulated by a particular normative act.

Statute of the Croatian Academy of Engineering

This Statute regulates the provisions on the name, seat, representation, seal and flag, objectives and scopes of activity as well as economic activities pursuant to the law and the way of ensuring the support of the public where the Croatian Academy of Engineering operates. Furthermore, regulated are the provisions on the conditions and procedure of joining and termination of membership, rights and obligations, and disciplinary liability of members and the procedure of keeping the list of the members, on the Academy bodies, their composition and the way of convening sessions, election, recall, powers, decision-making and terms of office and regular manner of convening the assembly as well as in the case of expiry of the mandate; election and recall of the liquidator of the Academy as an association, dissolution of the Academy; on the assets, the method of acquisition and disposition of assets; asset management in the event of the dissolution of the Academy, and on the manner of settling disputes and conflicts of interest within the Academy and other issues of importance for the Academy.

Bylaw on Membership in the Croatian Academy of Engineering

The Bylaw on Membership regulates the procedure for election of members and termination of membership and criteria for the election into the Croatian Academy of Engineering.

Bylaw on the Organization and Activities of the Centers of the Croatian Academy of Engineering

This bylaw, along with the underlying principles, regulates the organization and functioning of the Centers. The Centers are established for specific fields of science with the aim of promoting scientific and development research intended for immediate application in the economy, and thus make a contribution to the overall faster technological progress of the Republic of Croatia. The Bylaw applies to all existing Centers and those to be established in the next period.

Rules of Procedure of the Work of the Scientific Council

The Rules of Procedure of the Scientific Council of the Croatian Academy of Engineering regulate the work of the Scientific Council. The provisions of these Rules of Procedure are related to the work of the Scientific Council, the preparation and convening of sessions and the way of making decisions.

Bylaw on Awards and Recognitions of the Croatian Academy of Engineering

The process of nomination for the Academy awards and medals, and deciding on them is stipulated by the Bylaw on Awards and Acknowledgements of the Academy.

Regulation on Acquisition and Distribution of Income

This Regulation stipulates the way of income earning and distribution. The HATZ's income includes: membership contributions, personal membership fees, budget revenues, project revenue, donations, sponsorships, participation fees, income from sales of books and other HATZ publications, service incomes and other incomes.

Normative Acts Associated with Financial Operations of the Academy

These regulations stipulate: income and distribution of income; costs and expenses; the right to create liabilities; liquidation of documents; cash maximum and the management of long-term assets.

Bylaw on the Scientific Fund of the Academy

The Scientific Fund participates in co-financing scientific projects in which the Academy participates; providing funds for awards awarded by the Academy; helping young scientists of technical professions, winners of the Vera Johanides Award, in acquiring knowledge and skills, and encouraging their international affirmation through education, participation in scientific conferences and advances in scientific research.

Rules of Procedure of the Work of the Departments

The Rules of Procedure stipulate the functioning of the Departments, the way to make decisions, the method of election and the activities of the Secretary and his/her Deputy. The Department is one of the fundamental organizational and active forms of the Academy. The activities of the Department are presented at the sessions of the Department or during the work on various projects carried out within the Department or Academy, with economic entities or institutions approved by the Governing Board, the Presidency or the Assembly of the Academy.

Labor Bylaw of the Academy

This Bylaw regulates the organization of work and systematization of jobs, and the rights and obligations of employees who are employed at the Croatian Academy of Engineering.

Code of Ethics

Code of Ethics does not belong to the group of normative acts of the Academy in form of bylaws and rules of procedure, but it obliges the members of the Croatian Academy of Engineering to ethical behavior. The Code of Ethics stipulates that the members of the Academy realize the significance of the impact of their knowledge and teaching, their projects and achievements, technologies and processes, advice and services on economic development, competitiveness of Croatian products and quality of life by accepting their personal commitment to profession and committing themselves to the highest level of ethical and professional behavior.

New Statute and New Bylaw on Election to Membership

Already in the first year of the New Govering Board's mandate (2017-2021) it was noticed that the additional updating of the existing normative acts was necessary in accordance with new needs of the Academy and with the aim of further enhancing the efficiency and connections with economy.

For this purpose, amendments and corrections were made to the existing Statute and the Bylaw on Election to Membership. Following the proposal of the Presidency of the Academy, the Assembly of the Academy, at its 34th (electronic) session, on 29 April 2018 adopted a new Statute and a new Bylaw on Election to Membership. The adopted amendments, in relation to the previous Statute, include the following:

- The Entrepreneurial Council of the Academy was established as an advisory body of the Academy for business cooperation between the Academy and economy, and it is composed of the entrepreneur members of the Academy.
- A new membership category was created – "Entrepreneur Member of the Academy".
- The name of the membership category 'Member of the Academy" was changed into 'Full Member of the Academy'.
- The text of individual articles of the Statute was shortened so that the corresponding bylaws and rules of procedure are indicated.
- Some of the competences of the Assembly (Art. 25) and the Presidency (Art. 32) were redefined in such a way that the Assembly decides on the election of associate members of the Academy and confirms the elected full members, international members, members emeritus, entrepreneur members and honorary members, while the Presidency decides on the election of full members, international members, emeritus members, entrepreneur members, honorary members and supporting members.
- The Presidency decides on the amount of the membership fee.
- The term 'fifth member of the Governing Board' was introduced. The fifth member is elected on the proposal of the Nominating Committee for the Governing Board instead of the previous President of the Academy, in the event that the President of the Academy has been elected for the second consecutive mandate or he/she is unable to be a member of the Governing Board after the first mandate.
- The mandate of the members of the Governing Board is limited in such a way that after two consecutive mandates the members of the Governing Board of the Academy can no longer be elected to the next Governing Board of the Academy.
- The possibility was introduced that the President of the Academy, who is per function a member and President of the Scientific Council, transfers this function to one of the Vice-Presidents of the Academy.
- The text of the Statute related to the job of "Executive Secretary of the Academy" was deleted.
- Names of Academy Awards are general and no longer contain a specific name, and the acknowledgements of the Academy are Medals and Certificates of Appreciation.

The Bylaw on Membership was updated and brought into line with the new Statute.

Conclusion

The Croatian Academy of Engineering is a complex and organized system, which is apparent from a number of complex normative acts. The normative acts appropriately cover all aspects of the organization and activities, contributing to an organized and efficient work of the Academy as an important scientific institution of the Republic of Croatia.

History of the Academy through the Reports of the Presidents

Croatian Academy of Engineering[1]
The First Ten Years – January 19, 1993 – 2003

Past-Presidents of the Academy
Božičević Josip (1993 – 1997), Božičević† Juraj (1997 – 2003)

Let our Academy fly as Tin's flier (it flies as swirling leaves / you are born for flying, my darling / the flower without the root is neither for earth nor for rest), because, after a decade of flying, the Academy has fliers, its airfields and its flying hills for its flying offs. However, it should be borne in mind that mindfulness should be preserved despite many circumstances, because scattering always threatens; it should be careful not to hurt its roots, it is only ten years old, because underground roots also know how to find their sunshine. Stay the same; let's pray to fate that it helps you in intentions, in collecting crops, gathering of friends, hosting chance travelers, finding a home for victims, no matter it is about Croatian economy or Croatian people – stay a place of permanent residence, but also a place of permanent residences and also of permanent departures and arrivals. Those who come should feel awe toward the commitment made, because it will be awe-inspiring.

Stanko Sever
on the occasion of the 10th anniversary
of the Croatian Academy of Engineering
10(1) 2003

1. First steps in Establishing the Croatian Academy of Engineering

2013 marks the twentieth anniversary of the Croatian Academy of Engineering. In 1991 Hrvatsko društvo za sustave (Croatian Systems Society – CROSS) was founded which supported the beginning of activities. Professors Juraj Božičević, Franjo Jović and Marko Petrinović encouraged the establishment of the Society which will

[1]This is the reprint of the article published under the same title in 2014, in the Jubilee Monograph "Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013". The permission for reprint has been granted by the authors.

make use of science of systems and system thinking and contribute to a more successful collaboration among professionals so much needed in a newly created state. Already the beginning of activities, first conferences and discussions showed the importance of engineering and its connections. At that time engineering sciences exhibited disciplinary fragmentation which was a serious impediment to knowledge transfer and successful economic development.

On the basis of these findings Professors Juraj Božičević, President of the Croatians Systems Society, Josip Božičević and Osman Muftić agreed in the autumn of 1992 to overcome the problems by establishing the Croatian Academy of Engineering after the model of scientific societies in the world. They agreed on the contents of the letter written by Juraj Božičević that was sent to colleagues at technical colleges to inform them about the idea. By the end of the year numerous interviews were performed, different opinions on the possible organization of the Academy, the manner of its management and other issues were discussed. In December 1992 everything was ready for the convening of the Inaugural Meeting of the Academy.

The Inaugural Conference of the Academy took place January 19, 1993. Prof. Dražen Aničić, Ph.D., Prof. Branko Bonefačić, Ph.D., Prof. Josip Božičević, Ph.D., Prof. Juraj Božičević, Ph.D., Prof. Leo Budin, Ph.D., Prof. Husein Džanić, Ph.D., Prof. Zijad Haznadar, Ph.D., Prof. Marin Hraste, Ph.D., Prof. Mirko Krpan, Ph.D., Prof. Ivo Marković, Ph.D., Prof. Darko Maljković, Ph.D., Prof. Tomislav Mlinarić, Ph.D., Prof. Osman Muftić, Ph.D. and Prof. Ivo Soljačić, Ph.D. attended the Inaugural Conference. They decided to establish the Croatian Academy of Engineering

Fig. 1 – View of the participants of the Inaugural Conference of the Croatian Academy of Engineering

– HATZ. They adopted the Statute of the Academy and elected a “temporary presidency”, collective executive body made up of: Prof. Dražen Aničić, Ph.D., Prof. Josip Božičević, Ph.D. and Prof. Juraj Božičević, Ph.D. Finally, two reviewers’ boards were appointed in order to organize elections for the first members of the Academy. The criteria for evaluating, scoring and electing the first members of the Academy were defined.

The guiding principle of the members was to create economic identity, to preserve production, to strengthen the synergy of engineering sciences and mutual understanding of social and engineering sciences, to build the institutional infrastructure and innovation culture and to promote science and education.

It should be noted that the Croatian Civil Engineering Institute provided an initial financial support for the Academy and that its manager Prof. Petar Đukan, Ph.D. showed understanding for this important project. The Institute of Traffic Engineering provided organizational support and Prof. Vladimir Marić, Ph.D. was the administrative secretary.

2. Criteria for the Election of Members

Distinguished scientists, experts from the field of engineering and bioengineering sciences joined, establishing the Croatian Academy of Engineering. The main issue was how to determine the criterion for the election of the first members. At the conference the founders agreed on a temporal status until the determination of criteria and the announcement of the public competition for members of the Academy, inviting faculties and institutes to propose appropriate candidates. After the first announcement of the public competition for Academy members all the candidates and founders were elected to permanent members and classified according to the same criteria, which with minor corrections are still in force today for the election of members, because they guarantee a strict, wise and just judgment about scientific achievements, teaching activities, contribution to economy and innovation culture as well as activities in scientific and professional societies of candidates.

In the fifties of the 20th century engineering sciences were fragmented as a consequence of dividing into independent studies, and numerous disciplinary faculties were established. Thus, it was a particularly important task of the Academy to introduce synergies into the field. From this point of view it was necessary to ponder upon the criteria for the members from all areas of science, from universities, from scientific and industrial research institutes. Criteria were developed and prepared for discussion by Prof. Juraj Božičević, Ph.D. and Prof. Zijad Haznadar, Ph.D. covering the equivalent evaluation of the possible results of all the different activities.

Each result was rated with a certain number of points, and on this basis the minimum number of points that an individual must have to become a full, extraordinary or associate member of the Academy was determined. We were also aware that the effectiveness of an emerging organization was not a list of operational results of the members, but that these results are the only guarantee that only those joined the community who will try to make THE CROATIAN ACADEMY OF ENGINEERING a prestigious institution, which will be distinguished by quality. The leadership of the Academy, i.e. President, Vice-Presidents, Secretary General and Secretaries of the Departments were responsible for the success of the Academy.

Today, after two decades when we elect the third generation of members, it is interesting to discuss criteria. They would probably be only slightly altered, supplemented with questions that would present the members more as social beings, their characteristics, the attitude towards changes and their knowledge about changes, especially about how they had accepted knowledge brought to science and society by information technology.

After the election of the first permanent members on the basis of the above criteria, **the first leadership of the Croatian Academy of Engineering was elected**: President Prof. Josip Božičević, Ph.D., Vice-President Prof. Dražen Ančić, Ph.D. and Secretary General Prof. Juraj Božičević, Ph.D.

3. Code of Ethics

Initial activities of the Academy showed that the Code of Ethics created in order to match the values of the members and their activities in a social community will play an important role. We also accepted the working motto of the friendly Croatian Systems Society: *positive thinking and constructive action.*

Fig. 2 – The poster of working motto of the Academy during the first ten years, included in the Code of Ethics: positive thinking and constructive action

4. First Projects

In collaboration with the Croatian Systems Society the first joint projects were planned, and the development of the Academy was gradually boosted. Initial activities were interconnected with the experience of the Croatian Systems Society, and part of our first conferences was jointly organized. As the Secretary General and at the same time the President of the Croatian Systems Society I was entrusted with defining and proposing a program in which I found great pleasure. I suggested that multidisciplinary *conferences Engineering Sciences for the Croatian Economy* as a basic activity were organized and selected current topics were presented at shorter conferences. Six conferences dealt with the following themes:

- The first conference in 1994 – *Situational Judgment, Guidelines and Developmental Possibilities* was a support of creating a modern institutional infrastructure, and collaboration with natural, social and human sciences.
- The second conference in 1995 – *Creating a Stable and Capable Economy*, vision of intelligent Croatia, identity, Danubian and Mediterranean Croatia
- The third conference in 1997 – *Compatibility and Infrastructure*
- The fourth conference in 1999 – *Systematic Thinking of Sustainable Development*
- The fifth conference in 2001 – *The Progress of Economy and Science. Biosubstrates and Bio-fuels, Acting in Emergency Situations*

Fig. 3 – View of the hall with participants of the Opening Conference (Administration Building of Zagreb Fair)

Fig. 4 – View of the hall with participants of the Opening Conference (Administration Building of Zagreb Fair)

- The sixth conference in 2003 – *Vision of Intelligent Croatia* attracted numerous participants. It is worth mentioning the discussion topics because they covered all the important issues for the operation of the young Croatian state, important for its sustainable future. The participants were invited to discuss the following topics:

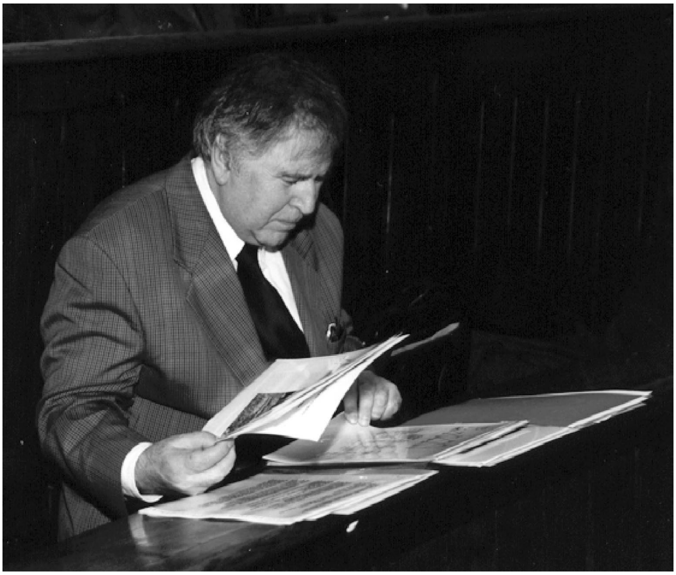


Fig. 5 – President of the Academy Prof. Juraj Božičević, Ph.D. in his working environment

- Croatian space, its construction and maintenance
  - Natural resources
    - Traffic roads and transport,
    - Geostrategic position, relationships to neighboring countries and the world,
    - People, intellectual capital and values
    - Knowledge and education,
    - Science, research and development,
    - System of government,
    - Institutional infrastructure,
    - Croatian cultural space,
    - Communication and information infrastructure,
    - Energy, environment and sustainable development
    - Impact of climatic changes,
    - Economy and finances,
    - Industry,
    - Service jobs,
    - Protection against natural disasters,
    - Relationship between global and national,
  - National innovation system.

Fig. 6 – Round tables and discussions were the gathering place of the members of the Academy (1998)

Fig. 7 – One of numerous discussions at the Faculty of Science (1999)

The comprehensive topics of the Conference had to serve as an excellent basis for human resources and knowledge necessary for the further consideration of the Croatian development policy for knowledge economy.

It is worth mentioning that the Conferences were announced by original invitations posted in the entrance halls of all Croatian universities and major institutions. The invitation to the Sixth Conference was particularly well accepted which is presented in this article. The author of this and most other announcements was Hrvoje Božičević.

Fig. 8 – “Vision of Intelligent Croatia” – Multidisciplinary Conference, Zagreb, June, 2003

5. Conferences, Symposia and Colloquia

In parallel with these conferences we organized a number of conferences and contributed to the synergy of technical disciplines and transfer of new knowledge and experiences. In the first place it is necessary to point out a series of conferences under the title of *Scientific Meeting HATA*, which were held in principle once a month.

Some meetings were organized in cooperation with selected societies, and let's mention only the selected ones:

16. Forum *Biotechnology, food technology, university, economy* in cooperation with the Croatian Society of Biotechnology″.

17. Forum *Vision, goals, strategies and activities of the Croatian Academy of Engineering* whose starting point is to find answers to the question: How to be a leading creative and innovative multidisciplinary community of scientists in engineering, how to contribute to the development of engineering sciences and to the transfer of technical knowledge important for the progress of the Croatian economy and welfare of the population?

18. Forum *Relationship of the government, university and industry and its impact on the global business* with guest engagement of Prof. Danko Gajski from the University of California, USA.

19. Forum *Canadian experience of the cooperation of universities and industries* with guest Prof. Zvonko Vranešić, Ph.D. from the University of Ontario, Canada.

In 1997 we launched the other series of conferences and colloquia *Education for the Information Society*, and included the following interdisciplinary topics and the books of proceedings of the same title were also published:
- The first colloquium – Are we ready to accept changes
- The second colloquium – Multimedia, remote learning and instruction
- The third colloquium – Insights, knowledge and judgment
- The fourth colloquium – Professions of the future, engineers of the future

The colloquia were held under the auspices of the Ministry of Education and Sports and the Ministry of Science and Technology in cooperation with the Croatian Systems Society, with the support of the Faculty of Chemical Engineering, University of Zagreb.

It is necessary to point out the cooperation of prominent professors of the Faculty of Teacher Education and the Faculty of Humanities and Social Sciences.

The last multidisciplinary conference of the decade was held under the auspices of the Ministry of Science and Technology *Using Forest Biomass.* Nearly 100 participants attended the Conference as well as the previous Conference *Materials and Technological Development.* The books of proceedings of the same title were published.

At each annual assembly one of the Academy members gave a plenary lecture, contributing to new knowledge and findings.

6. What Will Croatia Live on?

The discussions *Products and Production in Croatia* were held once a week during 1998 and 1999 and attracted special interest of the academic community. The discussions were held under the motto *What will Croatia live on?* Nearly all economic activities were covered, and numerous useful conclusions and recommendations were arrived at of which only the most important are pointed out. It is necessary to emphasize that the discussions were attended by Academy members and hundreds of experts from industry and universities. Support was also provided by several faculties and the National and University Library of Zagreb where the most part of discussions took place. The most important conclusions in which production is the most important topic are:

a) Production creates social energy, supports confidence and individuality of the people, and is the basis of economic prosperity. The country without production is poor, sentenced to a subordinate position, and its people to extinction.

b) The engineers are fully aware of the fact that production is fundamental to the autonomy and existence of the state that associated with economists and other professionals can contribute effectively to the development and advancement of the Croatian economy.

c) There are well-trained engineers in Croatia, who have knowledge and skills which can help them develop products and production, and make products competitive in the international market. With their innovation they can contribute to creating new jobs and increasing employment. If unused, they can lose this potential

d) Croatia must stop the decline in production, it is necessary to deliberately preserve, maintain or develop selected large industrial enterprises, because only with them small-sized and medium sized enterprises can be developed. The activities of small-sized and medium-sized enterprises should be facilitated; the establishment and the initial activities of small-sized enterprises should be supported by encouraging and supporting entrepreneurship and innovation.

e) The future prosperity of economy must, above all, rely on entrepreneurship, which must be politically supported as a long-term program with the development of advisory services, conditions and values that contribute to innovation.

f) It is necessary to carefully develop awareness of the market and customer, as users of our products, of the fact that no one can avoid competition and that national competitiveness is the responsibility of all, from the teacher to the Government.

g) In education it is important to teach about production, and it is necessary to develop the knowledge that production is a requirement of economic development and increase in the quality of life of entire population.

Furthermore, it is necessary to develop an awareness of the fact that the progress of economy is not inherited, but it is rather created with wise and thoughtfully organized business operations using all available resources.

h) Efforts are necessary to overcome the following as soon as possible:

- Lack of responsibility and care about the production and its stimulation;
- Expensive production, very high and responsible consumption in some parts of the non-production sphere;
- Lack of vision, goals and strategies of economic development, dominance of political over economic objectives, focusing attention on isolated parts of the current effects, which is particularly evident in privatization, in the management of national assets, in reconstruction, etc.
- Underdevelopment of economic, physical and institutional infrastructure and its adaptation to the European model;
- Limitations of the cognitive capabilities of the complex European, world and own economic circumstances to understand other people's strategies;
- Lack of trained, experienced and responsible leaders and managers in many areas; poor and irresponsible management of the company;
- Insufficient utilization of the available professional potential, creative and work capabilities of people, specifically engineers, experts in the field of exact sciences and technology;
- Mismatched funding and planning of the development of science and technology to the needs of the Croatian economy, and also the vague role of universities and scientific institutes in supporting economic development;
- Failure of education to adapt to market economy, especially the extremely poor and inappropriate management of higher education;

h) If production is advocated, the principles of sustainable development should be respected in the broadest sense, meaning to take care about the future generations and about long-term health and environmental integrity.

It includes care about:
Quality of life (not just about revenue growth)
Fair relationships among people, including poverty prevention
Harmonious relationships among generations because in the future people deserve at least the environment which we are enjoying today
Ethical dimensions of human welfare

7. The First Centers of the Croatian Academy of Engineering

In an effort to contribute to economy development and that members use their expertise, we decided to establish Centers and to preserve the Departments solely as the research units of the Academy. Interdisciplinary and multidisciplinary activities of the centers are advocated separately: advisory, organization of discussions and expert meetings, project development, and assessment and review of projects, preparation and publication of studies and similar activities.

The first center – Center for Development Studies and Projects – CEDEP had an additional purpose of preserving intergenerational cooperation and creating conditions for the work of retired members.

The second center – Center for Biotechnology was developed in cooperation with the Faculty of Food Technology and Biotechnology and Pliva Research Institute.

The third center was conceived as a gathering place of members who will devote themselves to contemporary issues of sustainable development. Therefore, Prof. Mladen Črnjar, Ph.D., was asked to propose an access to the organization and future activities in collaboration with Prof. Bombeles of the United States. The death of Prof. Bombeles broke up the establishment of the Centre.

8. Bulletins and Annuals of the Academy

In 1994 the bulletin TEHNIČKE ZNANOSTI (Engineering Power) was launched in which numerous members published their views. It also reports on the activities and conference conclusions, the activities of members, on the dissertation defended at engineering faculties and other important news.

The bulletin in English ENGINEERING POWER has been published since 1998. It was designed to present the activities of the Academy and to cover various important events in the field of engineering sciences in Croatia, and based on the history of engineering sciences and publishing to present the technical and manufacturing culture of Croatia.

The books of proceedings of the Conferences and other selected conferences, part of which were published in cooperation with the Croatian Systems Society, were well received by the public. In addition to the results of scientific and professional work, the papers published covered all the issues relevant to build the country, especially institutional structure.

The analysis of activities of the Academy showed that the meetings held at the national level proved successful, that their contribution to the synergy of technical disciplines and the initiative for interdisciplinarity were very useful, that it should be preserved, and that disciplinary meetings should be avoided and left to disciplinary scientific and professional societies. After establishing the publication Annual of the CROATIAN ACADEMY OF ENGINEERING it was concluded that the members would publish their papers in English.

The first annual was published in Croatian, and all the subsequent annuals were published in English. Prof. Dražen Aničić, Ph.D. made a significant contribution to their contents and editing.

9. Awards

The Croatian Systems Society takes special care of the young generation, and already at the beginning of its activities it launched a competition for the award *Power of Knowledge.* Young people from all over Croatia applied for the first competition, original ideas on the subject of City as a Complex System. As financial funding was limited, the idea had to be abandoned; the Secretary General of CROSS Alojzije Caharija, Ph.D. proposed the idea of joint awarding to the leadership of the Academy. At a working meeting of the leaderships of CROSS it was agreed that the Academy initiated the awarding of distinguished scientists in the field of engineering sciences and the award *Power of Knowledge* becomes the highest annual award of the Academy for the contribution to the development of the Academy and to the promotion of engineering sciences.

Then it was decided to introduce two more awards:

a) One of them is intended for successful engineers in industry and was named after Prof. Rikard Podhorsky, Ph.D., a distinguished university professor, the founder and first editor in chief of the Technical Encyclopedia.

b) The other one is intended for successful young scientists for their outstanding research results and is named after Prof. Emer. Vera Johanides, Ph.D., a distinguished professor in biotechnology, a Honorary Member of the Croatian Academy of Engineering who particularly supported young researchers.

Criteria and evaluation of candidates to be awarded were discussed. Many participants expressed their misgivings that the awards would be devalued if reduced only to a certain form of scoring success in the profession, and the rating of the candidate as a social being was ignored, including their ethnicity and relationship to the environment.

It was concluded that after giving awards characteristics were discussed and positive experiences were transferred to the next group of evaluators.

10. Cooperation with Media, with the Spheres of Government and Economy

Media reported very briefly on our meetings, and very rarely on certain conclusions, more on the presence of prominent persons from the sphere of government, as well as on their occasion speeches.

Conferences were usually attended by representatives in charge of science and technology. In 2000 the Minister of Science and Technology, Prof. Hrvoje Kraljević, Ph.D. accepted our proposal of cooperation on the development strategy of Croatia, and after the publication of our book Croatian Development Policy for Knowledge Economy (edited by Prof. Juraj Božičević, Ph.D., Croatian Academy of Engineering, Zagreb, 2000) we joined the realization of the project TEST important for the support of innovation projects.

It is important to mention the cooperation with the Croatian Chamber of Commerce in which we did not find interlocutors that would help us to inspire and initiate individual development projects, which we advocated, for example, to create an institutional infrastructure. However, holding conferences in the Great Council Hall was very beneficial to us.

In October 2001 we organized a round table discussion under the title of *The Perception of Engineering in Croatia* with the participation of members of the Croatian Academy, communicologists, sociologists and journalists. They discussed issues of the overall effects on media and ways to promote the knowledge about technology and its role in the development of Croatian society and economy. The question how to think about the media in a new way as an important means of strengthening Croatian existence, how to transfer as much knowledge as possible to citizens and how to stimulate innovation and the creation of entrepreneurial culture was especially emphasized. The book of proceedings of the same title was published. It was also concluded that another round table discussion of the same topic should be organized and discussions of the most important issues, especially on the effect of the most recent information technologies, should be deepened.

11. The Creation of Distributed Computing Infrastructure in CROATIA – CRO GRID

Guided by ever increasing demands for stronger distributed network computing in science we aimed to establish an advanced scientific research infrastructure. Professor Karolj Skala, Ph.D. from the Ruđer Bošković Institute launched the CRO GRID project initiative in 2002, which was approved and prosecuted into the further development phase by Prof. Juraj Božičević, Ph.D., President of HATZ .

Members of the Croatian Academy of Engineering gathered in solemn assembly in 2003 on the occasion of the 10th anniversary of the establishment the Academy and announced by proclamation, on February 5th 2003, that "*The creation of research infrastructure is becoming increasingly important for the progress of science and the application of a direct impact on technological innovation and social competitiveness, and contributes to the development of adaptive knowledge-based economy. In this regard, we particularly emphasize construction projects of modern distributed computing network CRO GRID for comparative use of the computer* ".

By the end of 2003, the Ministry of Science, Education and Sports approved the complex technological infrastructure project CRO GRID coordinated by prof. Leo Budin with three sub-projects coordinated by FER – Faculty of Electrical Engineering and Computing (Middleware) Prof. Srbljić, RBI – Ruđer Bošković Institute (Applications) Prof. Skala and SRCE – University Computing Center) (Infrastructure) Dobrinić, B.Sc. 11 institutions and 54 researchers from Croatian universities and RBI were involved in the CRO GRID project. This led ultimately to the creation of a national eInfrastructure in 2006, known as CRO NGI, which is additionally becoming to be part of the EU EGI e-Infrastructure with nodes at FSB-Split, RBI-Zagreb and SRCE-Zagreb which is technically supported by SRCE.

12. Cooperation with Universities, Croatian Academy of Sciences and Arts and Academy of Medical Sciences of Croatia

Since the members of the Academy are mostly members of the university community, it is natural that they are interested in education conferences which attracted a lot of interest and in the cooperation of members of all areas of science.

Three interdisciplinary conferences on the overall issues of higher education with particular support from Zagreb University took place. It should also be emphasized that the cooperation of university teachers of University of Split and University of Rijeka were at a high level. Discussions were substantial, and numerous helpful messages were sent to university institutions and spheres of political decision-making on science and education; so, the main conclusions were:

The academic community should
- guarantee the students an excellent education necessary for life
- well – thought – out scientific work
- increase socially necessary knowledge resources through research
- contribute to the preservation and strengthening of national culture and identity
- judge world developments and the impact of other people's strategies on economy and culture
- have a critical attitude towards socially negative phenomena which are crucial for survival and sustainable future
- strengthen the systematic care for education quality assurance.

The cooperation with the Croatian Academy of Sciences and Arts was not easy, because some of our colleagues doubted whether to join the Croatian Academy of Engineering or a new department of the Academy of Sciences and Arts (HAZU), which was in the process of foundation and in 1995 it had a rather small number of members. Its leadership did not support our proposal on cooperation between the academies which would be joined by the Academy of Medical Sciences of Croatia. Moreover, with the help of politics it influenced the decision of the Croatian Parliament to change the original names. We managed to keep the original name in English Croatian Academy of Engineering and the original acronym HATZ. The Croatian Parliament on the initiative of the Academy of Sciences and Arts changed our name. We have become Hrvatska akademija tehničkih znanosti – Croatian Academy of Engineering.

The Croatian Academy of Sciences and Arts founded the Department of Technical Sciences 4 years later after founding the Croatian Academy of Engineering in 1997. However, any effort of the Croatian Academy of Engineering and the Minister of

Science and Technology, Prof. Ivica Kostović, Ph.D. to develop the strong Croatian Academy of Engineering which could contribute in cooperation with the Croatian Academy of Sciences and Arts and the Academy of Medical Sciences of Croatia to developing and strengthening the Croatian scientific community failed. Only some of the older members of the Croatian Academy of Engineering, such as academician Dragutin Fleš, who advocated cooperation between the academies, were inclined to the idea. The final part of the text written by Academician Dragutin Fleš and published in the bulletin Tehničke znanosti (Engineering Power).

This brief review of the activities of members of the Department of Technical Sciences of the Croatian Academy of Sciences and Arts and members of the Croatian Academy of Engineering shows that both institutions have similar responsibilities towards profession and society. One of these responsibilities is associated with the rapid development of science and technology, so engineers must continually update their knowledge in order to be able to accept the "unpredictable reality." The other responsibility of both academies is not only to monitor technology development, but also to promote and to use the developed technology in our country. They should simultaneously direct their activities at trade development, environmental concern and economic development. Because of the overlapping of scientific fields and similar responsibilities towards profession and society it is understandable that since the first days of the establishment of the Croatian Academy of Engineering there has been a considerable cooperation between both academies. This cooperation is mostly done through scientific councils and committees of Croatian Academy of Sciences and Arts and includes all fields of science and art, and the Croatian Academy of Engineering can be organized more intensely and better. However, we developed an excellent cooperation with the Academy of Medical Sciences of Croatia. The cooperation started with frequent meetings and conversations of both Managements. We talked about possible topics from the fields of medicine and technology, information and biochemical technologies and nanotechnologies in medicine, in particular the development of a collaborative climate.

We initiated a series of joint conferences, the Forums on communications between doctors and engineers, and we call attention only to the initial conferences:
- The first forum *Biotechnology and Biomedicine* was held in February, 1999
- The second forum *Team Work of Doctors and Engineers* was held in October, 1999, etc.

We were particularly proud to have organized the Conference *Telemedicine in Croatia,* in the organization of which the Faculty of Electrical Engineering and Computing, University of Zagreb, and CARNet participated. Sixteen invited experts presented their own experiences in the application of telemedicine in different areas of medicine, and there was a roundtable discussion on the development of telemedicine and its applications in Croatia. It is important to point out the leading role of our honorary member Prof. Kurt Richter, Ph.D. in the organization of this meeting.

13. Becoming Members of CAETS

Once we gained the reputation in Croatia as a result of our activities, we started thinking about international cooperation in 1998. We wrote to academies in Great Britain, Sweden, USA and the Czech Republic, reporting on the establishment and activities of the Croatian Academy of Engineering. As I stayed in London, I visited the Royal Academy of Engineering which played a significant role in the activities of CAETS. I presented the activities of the Croatian Academy of Engineering and the vision of its development. I talked about the plans of the Croatian Academy of Engineering to join CAETS, a prestigious global community.

The communication with the Vice-President of CAETS Steven N. Anastasion was particularly encouraging and beneficial.

Mr. Michael Lavalou, CAETS President and member of the French National Academy of Engineering and Mr. William C. Salmon, CAETS Secretary General came to evaluate our work and to decide about our membership. They arrived in Zagreb at the end of March 2000 and during several days they appraised our work, visited the Faculty of Electrical Engineering and Computing and the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. They were satisfied with the acquired experience and announced to support the membership of the Croatian Academy of Engineering in CAETS.

14. Preparations for Becoming a Member of Euro-CASE

Several official letters were exchanged before becoming a member of Euro-CASE; even a working meeting was convened in May of 2001 in Zagreb in which we participated as “observer members” at the Conference ”Euro-CASE Workshop on Reduction of Energy Consumption and Greenhouse Gas Emissions in Europe“ with the aim to adopt an exemplary *Declaration on Reduction of Energy Consumption with GHG emissions in Europe* based on the experiences of member states and observer states and on the basis of an expert discussion.

Croatian experiences were presented on behalf of the Croatian Academy of Engineering by Prof. Vladimir Mikuličić, Ph.D. We were invited to cooperation, and a representative of the Croatian Academy of Engineering should join the working group for energy of Euro-CASE.

15. 10th Anniversary and the Transition into the 21st Century

We marked the tenth anniversary ceremonially, and a plan for development and activities in the further four-year period had been prepared. By courtesy of our member, the Dean of the Faculty of Food Technology and Biotechnology and the Rector of the University of Zagreb an abandoned one-story house was placed at our disposal. Thus, conditions for the new leadership of the Croatian Academy of Engineering were created to build the Academy House and much-needed working premises.

The anniversary address by the President should be pointed out because its content makes a contribution to the conclusion of the presentation on the establishment and the start of activities of the Croatian Academy of Engineering:

One of the basic human characteristic is the ability to maintain, develop and improve the system in which people live and the environment in which they work.

To be successful in these activities, people must have clear goals, positive values, knowledge and capability for organized and team work at their disposal.

In the early nineties, when we started thinking about the founding of the Academy, challenges with which Croatia and Croatian state leadership will be confronted after the achievement of national independence were clear to us, and also at the moment of creating global systems that rapidly changed overall relations in the world.

Moreover, one by one, every single thing in human life has been touched by science and then with the help of technology it has enveloped the spirit and life of people.

The application of new technologies, especially information ones, affected human expression, thought, communication and prompted the overall changes in human activities. We started to live in a highly turbulent, fragmented social environment with a wide range of values, goals, lifestyles and resources in an effort to realize them. We, engineers, scientists in the field of engineering and biotechnical sciences understood that we live in an unsteady world of rapid and dramatic changes, but also in a world of great opportunities.

We knew that we would not be able to fully comprehend and utilize them if we do not overcome their disciplinary fragmentation and do not encourage connections and cooperation of all engineering fields, and then improve the communications among professionals from engineering and natural-science, social and human areas. We have established the Croatian Academy of Engineering aware that knowledge and unity in knowledge can keep us and, then well organized we can preserve the available potential and the ability to work, and thus adequately contribute to the creation of the Croatian state.

And so, today we celebrate the tenth anniversary of existence and work, and we are pleased to point out the successful realization of our basic mission:

To contribute excellently and actively to the development of engineering and biotechnical sciences and knowledge transfer important for the progress of the Croatian economy and for the welfare of people.

We proudly inform: we held more than a hundred public meetings – forums, discussions, colloquia, symposia, congresses and conferences; we published 20 books with a total of 3160 pages containing 440 papers. Almost 3000 experts attended our conferences. In addition, the bulletin TEHNIČKE ZNANOSTI (Engineering Power) is published four times a year, and occasionally the bulletin ENGINEERING POWER in English. The Annual is published in English. Our programs are created mainly around the basic meeting, multidisciplinary conference ENGINEERING SCIENCES FOR CROATIAN ECONOMY. This year we will hold the sixth multidisciplinary conference, and in the next decade of our work, starting from the first week of February 2004, we will begin a new program under the title of TECHNICAL DAYS.

Members of the Academy did volunteer work for thousands of hours, but without the help of our supporting members: engineering and biotechnical faculties of the Universities of Zagreb, Osijek, Rijeka and Split, colleges, institutes and several companies, it would have been difficult to develop all these activities.

The results of our meetings are various useful conclusions and recommendations to the spheres of political and economic decision-making. We speak freely and in an organized manner, we propose and advocate numerous useful activities, but we cannot affect the realization of our best ideas.

However, not to mention our numerous initiatives and ideas, I will point out that in 2000 we were elected to a full member of the International Council of Academies of Engineering and Technological Sciences (CAETS) headquartered in Washington, which provides an excellent opportunity for promotion.

We strive to achieve a better cooperation with the Croatian Academy of Arts and Sciences and the Academy of Medical Sciences of Croatia because only by working together we can make advantage of our not inconsiderable potential for the welfare of Croatia. We have developed cooperation with a number of professional societies, particularly with the Croatian Systems Society, but also with the Croatian Engineering Association and with the Croatian Academy of Educational Sciences.

For the anniversary celebration, we decided to publish a convenient Proclamation of our basic point of view, on which we intend to rely in the future work.

At the Ceremonial assembly held on February 5, 2003 in Zagreb on the occasion of the tenth anniversary of the establishment and functioning of the Academy the Proclamation was published.

16. Conclusion and Future Outlook

In its initial activities the Croatian Academy of Engineering had certain difficulties, difficulties with of state institutions, as well as of the Ministry of Science and Technology, the Academy is was not seen as a respected community of scientists. For example, in 1996 a request for entry into the Register of scientific organizations according to the Law on Scientific Research Activity was submitted to the Ministry, but the request was not accepted. We sent the request over and over again despite notices of rejection. We were aware that we developed a very successful activity and made our contributions. That outwitting lasted until the beginning of 2000, when the Academy was finally entered into the Register. Thus, the conditions were created that one day in the future the Academy acquires the status of a scientific organization. Over the past decade numerous non-members were of great help in the work of the Academy in the organization of scientific conferences. In token of gratitude we tried to repay them naming them members amici. Their friendly activity was an important contribution to the consideration and realization of new contents in the program of work.

At the same time we decided to appoint older university professors, scientists who had contributed to the progress of engineering and biotechnical sciences, education of young scientists and contributed to the development of scientific infrastructure and strengthening of cooperation with scientific institutions as *honorary members.* We marked the 10th anniversary by publishing the publication *Who is Who in the Croatian Academy of Engineering* in English and thus we presented all the members of the Academy to the world.

We must also mention supporting members, primarily the faculties which enabled the activities and existence.

In our publications and articles as well as conference discussions we reflected upon actual issues of engineering sciences, economy and society as well as upon own sustainable development and sustainable future. We were especially aware of the importance of preserving the Academy as an open scientific society and the danger under the influence of social conditions at the beginning of the 21^{st} century. The Academy does not neglect their patriotic role and does not want to become a closed society, which has its own purpose. I emphasize the terms of sustainability:

– Science, research and development in the function of the Croatian economy, security and identity.

– Need to encourage and strengthen best possible communication between authorities and experts.

– Multidisciplinary teamwork as a prerequisite for the successful management of economic policy and decision-making.

Acknowledgement

When I was Secretary-General and then President of the Academy, I successfully cooperated with the first president Prof. Josip Božičević, Ph.D. to whom I am especially grateful for the knowledge transfer in organizational skills, but also to Prof. Dražen Aničić, Ph.D. first Vice-President and then Secretary-General, a skilled associate without whose wisdom and leadership skills we could not realize the described comprehensive program. With special gratitude I emphasize the cooperation of Vice-Presidents Prof. Ivo Alfirević, Ph.D. and Prof. Mirko Krpan, Ph.D.

Prof. Jasna Kniewald, Ph.D., selflessly took care of international cooperation together with the Secretary-General. Particularly useful were my talks on development issues with Prof. Zijad Haznadar, Ph.D., and Prof. Darko Maljković, Ph.D. I emphasize that the work of all associates on these projects was voluntary.

Conferences and many other events were preceded by short musical performances by choirs, classical ensembles and soloists, which created an additional positive atmosphere, being a particular feature of our activities.

Croatian Academy of Engineering 2003 – 2009[1]

Kniewald, Z.

Past-President of the Academy (2003 – 2009)

By becoming a full member of the Croatian Academy of Engineering elected at the Annual Assembly in 1998 in the Department of Bioprocess Engineering, I also accepted the Act of Constitution of the HATZ with all duties and obligations as a HATZ member. From the time when I became a HATZ member until the beginning of my presidential mandate I organized three conferences about biotechnology (1999, 2001 and 2003) with the Croatian Academy of Medical Sciences, Scientific Council for Agriculture and Forestry of the Croatian Academy of Sciences and Arts, Croatian Society of Biotechnology and PLIVA Inc. These Conferences were international with English speaking lecturers, and following the Conferences proceedings as internationally recognized publications were published.

My presidential mandate started on July 1, 2003 and ended in June 30, 2009.

Today, as we are celebrating 25 years since the establishment of the Academy we differently look at individual events than five years ago on the occasion of the jubilee edition to mark the 20th anniversary of the Academy's activities. Some activities relevant for the period from 2003 to 2009 became very significant and important. Unfortunately, as will happen with this issue and many before and after them, each new generation of social workers/politicians starts from the beginning of its mandate. The basic problem of all pre-election programs at all levels and all of political structures is the lack of awareness of the significance and importance of long-term technological developments in the subsequent period. Therefore, on the occasion of its establishment and further activities the Academy promoted the activities of knowledge transfer, its development and application for the benefit of the Croatian economy.

[1]This is an updated and ammended version of the original article by the same author, originally published under the same title in 2014, in the Jubilee Monograph "Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013".

In the first year (2003) the administrative consolidation and location of the HATZ were dominant activities. Due to a great help of the Faculty of Food Technology and Biotechnology and the University of Zagreb we rented an old and quite damaged building on the location of Kačićeva Street 28, which was restored with the financial support of the Ministry of Science, Education and Sports of the Republic of Croatia and activities of our members Prof. Jure Radić, Ph.D., Prof. Mladen Obad Šćitaroci, Ph.D., Prof. Nedjeljko Frančula, Ph.D. and Prof. Hildegard Auf-Franić, Ph.D. Furthermore, HEP donated funds for the adaptation and organization of HATZ Library. The total HATZ income for the mentioned period is shown in Table 1:

Table 1 – HATZ Income in period 2002-2009

Year	HATZ Income (Kunas)
2002	226,866.00
2003	667,509.00
2004	527,029.00
2005	851,667.00
2006	1,479,350.00
2007	835,372.00
2008	760,821.00
2009 (planned)	759,400.00

Fig. 1a) – Hired premises of the Academy on 10 March, 2003

Fig. 1b) – Premises renovation

Fig. 1c) – Opening session of the Presidency of the Academy in the new premises on 13 February 2004

Fig. 1d) –˝Renovated House of the Academy on 9 September, 2005

The activities of the Academy greatly increased after the inauguration of the Governing Board in 2003, which consists of the Academy President, two Vice-Presidents, Secretary General and Former President with the technical support of only one employed Business Secretary. This type of organization was also active in 2014.

On 1 July 2003 the HATZ websites were already opened, but remained inactive. After restoration and with new contents the websites were reopened thanks to our member Prof. Miljenko Lapaine, Ph.D. and his team, and by 2009 they had about 350,000 visitors.

In order to promote its activities the HATZ published 200 posters (in format A2 and A3), in Croatian and English, with the description of location, structure, activities, sponsors and broad spectrum of workshops that could be organized for industrial purposes.

In 2003 there were 14 HATZ Departments and 8 Standing Committees. This organization is still active, although in 2004 the Department of Chemical Engineering was divided into the Department of Chemical Engineering and the Department of Textile Technology. Now, since then there are 15 departments. In the period until 2005 the HATZ got its flag and in 2008 the HATZ gold plated medals were prepared for distinguished HATZ visitors or HATZ members who achieved extraordinary results within the HATZ in the past period. Until 2009 only one of the 100 produced medals was assigned, and it was to our honorary member prof. Kurt Richter (AUT) for his activities with the Austrian Academy of Sciences before signing a bilateral agreement with the HATZ. The bilateral agreement between HATZ and Austrian Academy of Sciences was signed on June 18, 2009.

In 2003 the HATZ started to organize centres as specialized places within the Academy for the promotion and development of specific projects for industrial purposes. At that time there were two Centres: Centre for the Development of Studies and Projects, whose head was Prof. Juraj Božičević, Ph.D. and the Biotechnical Centre with the Head Prof. Zlatko Kniewald, Ph.D. Later on four other Centres were organized: Centre for Life-Long Education, Head Prof. Tomislav Filetin, Ph.D., Centre for Geoinformatics and Cartography, Head Prof. Nedjeljko Frančula, Ph.D., Centre for Graphical Engineering, Head Prof. Vilko Žiljak, Ph.D. and Centre for Environment Protection and Development of Sustainable Technologies, Head Prof. Đurđa Vasić Rački, Ph.D. During the period from 2003 to 2009 Centres were active with different dynamics which is seen in the Annual HATZ reports.

Due to lack of money the regular competition and distribution of Annual Awards: Power of Knowledge, "Rikard Podhorsky" and "Vera Johanides" were not possible in 2003. The foundation of the Academy was established by donation of our Honorary Member from Canada and Croatian scientist Prof. Emer. Branko Ladany, Ph.D. After signing the Donation Agreements with Institute Končar Inc., PLIVA

Inc. and Zagrebačka pivovara Inc. and later until 2009 agreements for HATZ Foundation and fund awards were also signed with the "Centar za vozila Hrvatske" and Belupo Inc. The Foundation was active and successful until the end of 2009. These activities provided funds from 2004 to 2009 for up to five "Vera Johanides" awards for young scientists (not HATZ members) and up to three "Rikard Podhorshy" awards and one Power of Knowledge award annually (for HATZ members).

The previous HATZ president, Prof. Juraj Božičević, Ph.D., made great efforts for international HATZ recognition. In 2000 we were elected as a regular member of CAETS on the 13th of October Council Meeting, Beijing, China. He also made first activities for the HATZ membership in Euro-CASE. The Committee for International Cooperation (head Prof. Jasna Kniewald) organized great activities until 2003 as well as from 2003 to 2009. The regular HATZ participation in annual CAETS meetings and participation in international projects such as "Engineering

Fig. 2a) – Signing the Agreement with the Vehicle Center of Croatia, Ltd.

Fig. 2b) – Signing the Agreement with Belupo, Inc.

Fig. 2c) – Signing the Agreement with the Hungarian Academy of Engineering

Education", "Oceans and the World's Future" (2005 Cairns, Australia) and "Environment and Sustainable Growth" (2007 Tokyo, Japan) were among other HATZ activities to promote our knowledge, tradition, possibilities and willingness for cooperation among engineers and technologists worldwide. In 2021 the CAETS presidency will be in the HATZ – Croatia, which is a great honour for each of CAETS member countries and we must prepare for this responsible duty.

In 2005 our full openness was achieved through our admission to full membership of the Croatian Academic and Research Network (CARNet) and transfers all our activities to our server and the subsequent organization of the entire service network through the University.

In 2005 the HATZ President (Prof. Emer. Zlatko Kniewald, Ph.D.) and the HAZU President (Academician Milan Moguš) were invited and delegated by the Croatian Government to Beijing, China to the 10th Anniversary of the Chinese Academy of Engineering and on June 2 signed two separate Agreements for cooperation with the Chinese Academy of Engineering. They were also received by the Prime Minister of China.

We succeeded in the communication with Euro-CASE and in 2005 the HATZ was accepted as an observing Euro-CASE member, because only countries that are full EU members can become the Euro-CASE member. Intensive and permanent cooperation between the HATZ and Euro-CASE finally gave results and the HATZ became a regular Euro-CASE member in 2009 when Croatia received an invitation to become an EU member. The Euro-CASE and CAETS were supporting all of our international activities, particularly the celebration marking 150th anniversary of Nikola Tesla's birth was accompanied with several activities listed at the the end of this report.

Croatian scientists, HATZ members, traditionally have good cooperation with Hungarian scientists. This was the reason to sign (June 28, 2006) a bilateral cooperation agreement with the Hungarian Academy of Engineering.

HATZ members participated in CAETS meetings 2003 – 2008 in Los Angeles, USA; Stavanger, Norway; Cairns, Australia; Brussels, Belgium; Tokyo, Japan; The Hague, Netherlands. Several CAETS Statements were adopted by the HATZ, and corresponding Croatian governmental authorities were also informed about its contents.

HATZ activities were recognized within and outside Croatia with several specialized meetings where several HATZ members participated very often together with foreign participants:

1. February 27, 2004, “Current Approaches to the Education of Engineers” Zagreb
2. November 13-17, 2004, “The First Congress of the Croatian Scientists from Homeland and Abroad” Zagreb – Vukovar, in Cooperation with the Ministry of Science, Education and Sports Republic of Croatia
3. February 26, 2005. “Development of New Technologies and Products in Croatia”, Zagreb
4. June 3, 2005, “Ethics in Application and Development of the Engineering Sciences”, Zagreb
5. July 10, 2005, CAETS Meeting “Oceans and the World’s Future” invited lecture “The Ocean and its Environment as a Source of Food Production”, Cairns, Australia
6. February 27, 2006, “National Security and Transport Perspectives in Croatia” organized by Croatian Parliament, Zagreb
7. September 7, 2006, “Human Resources in the Fighting of Terrorism” organized by Republic of Croatia Ministry of the Interior – Police Academy, Zagreb
8. February 28, 2006, Knowledge-Based Croatia – A Possible Contribution of the Croatian Scientists”, Zagreb
9. June 27 – 28, 2006, Central Celebration, in Cooperation with the Croatian Parliament – On the Occasions of “2006 – The Year of Nikola Tesla” and 150th Anniversary of his Birth NIKOLA TESLA (1856 – 1943) and International Scientific and Professional Meeting “The Life and Work of Nikola Tesla”, Zagreb
10. June 28-29, 2006, “The Visions and Work of Nikola Tesla: Today and Tomorrow, Zagreb
11. September 13, 2006, Symposium “Tesla in Croatia”, UNESCO House, Paris, France
12. October 7 – 11 2006, “Marie Curie Workshop”, Celebrating Nikola Tesla, Zagreb & Belgrade
13. November 24, 2006, “With Tesla in the Development of Croatia”, Zagreb, May 7-10, 2007
14. “The Second Congress of Croatian Scientists from Homeland and Abroad”, Split, in Cooperation with the Ministry of Science, Education and Sport of the Republic of Croatia
15. October 23-26, 2007, “Environment and Sustainable Growth” – invited lecture “Participation of Croatia as a West Balkan Country in European Scenarios about Energy and Greenhouse Gas Emissions”, Tokyo, Japan
16. Marking the 150th Anniversary of Andrija Mohorovičić’s birth during 2007 (detailed description in attachment to this report),
17. November 8-10, 2007, “Engineering Education and the Bologna Process 3 years later “, Zagreb,
18. December 12, 2008, “Nikola Tesla – from Childhood to New Yorker Hotel” Polytechnic University, Madrid, Spain invited plenary lecture delegated by the Ministry of Science, Education and Sports Republic of Croatia.

Fig. 3a) – Opening speech of President Stjepan Mesić at the celebration of "The 150th Anniversary of the Birth of Nikola Tesla"

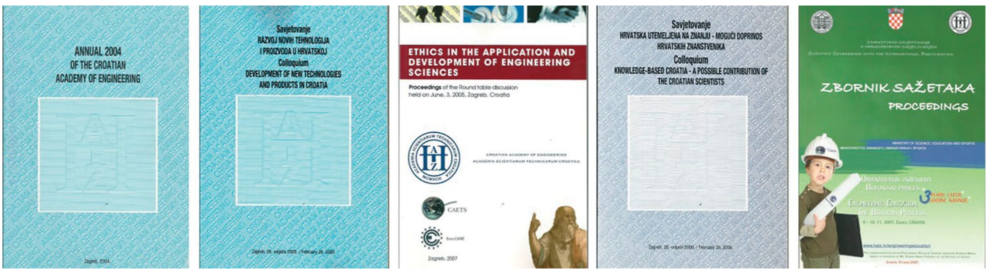
Fig. 3b) – "The Life and Work of Nikola Tesla", Vatroslav Lisinski Concert Hall, Zagreb, June 27, 2006

Fig. 3c) – “The Life and Work of Nikola Tesla”, Vatroslav Lisinski Concert Hall, Zagreb, June 27, 2006

Today, during the preparation of the jubilee edition after 25 years of the Croatian Academy of Engineering activities I will take a look at three groups of Academy activities that we organized in the period from 2003 - 2009 and which are now in the spotlight of the Government of Croatia:

Engineering Education and the application of its knowledge for the needs of the Croatian economy:

1. February 27, 2004, “Current Approaches to the Education of Engineers” Zagreb
2. February 26, 2005, “Development of New Technologies and Products in Croatia”, Zagreb
3. June 3, 2005, „Ethics in the Application and Development of Engineering Sciences“
4. February 28, 2006. „Knowledge-based Croatia – A Possible Contribution of Croatian Scientists“, Zagreb
5. November 8-10, 2007, “Engineering Education and the Bologna Process “ 3 years later “, Zagreb

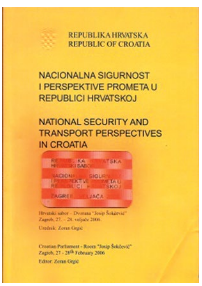


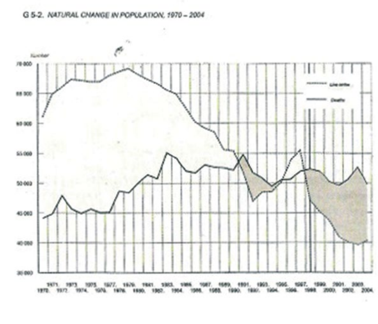
The Proceedings of the "Current Approaches to the Education of Engineers" were published in the „Annual 2004 of the Croatian Academy of Engineering". The plenary lecture "Problems Enforcing the Bologna Declaration" was presented by prof. Kurt R. Richter, Honorary HATZ Member and Corresponding Member of the Austrian Academy of Sciences.

These activities should form the basis for the adoption of the strategy of a long-term development of engineering education at universities in Croatia in order to raise the worrying low grade recognition of the quality of Croatian universities in the world.

Active contribution to the analysis of long-term problems about geopolitical position of the Croatia with a special emphasis on the long-term staffing problems faced by the Republic of Croatia

1. February 27, 2006, "National Security and Transport Perspectives in Croatia" organized by the Croatian Parliament, Zagreb
2. September 7, 2006, "Human Resources in the Fighting of Terrorism" organized by the Republic of Croatia, Ministry of the Interior – Police Academy, Zagreb
3. Zlatko Kniewald: „Human Resources as a Pre-condition of Traffic Safety in the Republic of Croatia", in "Human Resources in the Fighting of Terrorism" pp. 101 – 110 (2006) (Editor: Zoran Grgić, Publ. Croatian Parliament), ISBN 953-96644-3-8
4. Vilko Žiljak: „Security Systems based on Graphic Technologies" in "Human Resources in the Fighting of Terrorism" pp. 111 - 116 (Editor: Zoran Grgić, Publ. Croatian Parliament), ISBN 953-96644-3-8





The available natural population resources

In Figure 1 the natural population yield in the period 1970-2004 is shown. In the same Figure also the annual number of the deaths is shown.

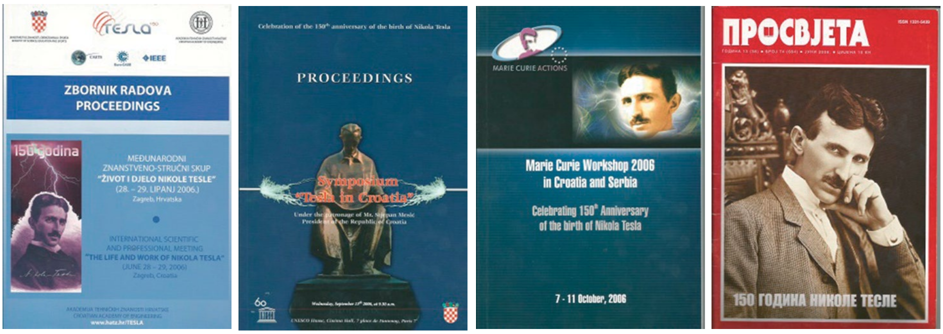
Figure 1. Natural change in population 1970-2004
Statistical Yearbook 2005, p. 111, National Bureau of Statistics RC

The number of the live births in 1970 was around 61.000, in 1979 around 68.000, while the number of the newborn in 2001 was 40.993, and in 2004 40.307, which means that in comparison with 1979 there has been a decrease of 40%. This is not only a fact to be concerned about, but an alarming issue.

In 2006 we pointed the problem of birth rate (reduced from 1979th to 2004th by 40%) and compared to the number of deaths (annual average from 40,000 to 50,000). At that time the number of deaths was already significantly higher than live births. It was suggested that in the long run it would result in lack of labour force in Croatia, jeopardizing the pension system and the excess capacity of universities in Croatia Neighbouring countries from which students previously came have developed their own high education system. What did we do in the past 12 years to solve the problem? Today our annual birth-rate is about 38,000, students make an average of 18-20% of the population, and the capacities of universities in Croatia are almost on the level of the annual birth rate.

Celebration of the 150th anniversary of the birth of Nikola Tesla in Zagreb, Smiljan, Paris, Belgrade and Madrid

1. June 27 – 29, 2006, Central Celebration in Cooperation with the Croatian Parliament – On the occasions of "2006 – the Year of Nikola Tesla" and 150th Anniversary of his Birth NIKOLA TESLA (1856 – 1943) and International Scientific and Professional Meeting "The Life and Work of Nikola Tesla", Zagreb
2. September 13, 2006, Symposium "Tesla in Croatia", UNESCO House, Paris, France
3. Zlatko Kniewald: Nikola Tesla kao poticaj mladima, Prosvjeta **74,** 50-51, 2006. ISSN 1331-5439
4. October 7 – 11, 2006, "Marie Curie Workshop", Celebrating Nikola Tesla, Zagreb & Belgrade
5. November 24, 2006, "With Tesla in the Development of Croatia", Zagreb, May 7-10, 2007
6. December 12, 2008, "Nikola Tesla – from Childhood to New Yorker hotel" Polytechnic University, Madrid, Spain. Invited plenary lecturer Prof. Emeritus Zlatko Kniewald was delegated by the Ministry of Science, Education and Sports of the Republic of Croatia. (Lecture and discussion available at: https://www.youtube.com/watch?v=jeK6lf3sAmQ*)*
7.



On 10th July of 1856 Nikola Tesla was born, the man who invented the 20th Century. Tesla was a marvellous inventor and he was indisputably one of the greatest minds of technology and science of all times. Tesla`s rich technological and scientific contribution resulted in 112 US patents. The timelessness of his inventions became evident in the course of time. But instead of celebrating and remembering his genius efforts, we have to continue to finish a lot of his initiated projects or ideas in the field of physics and electricity.

Croatian Academy of Engineering organized these Annual Assembly Meetings:

1. 17th Annual HATZ Assembly, February 2003, 10th Anniversary of HATZ 1993 – 2003, and election of candidates for the new Governing Board of the Academy,
2. 18th Annual HATZ Assembly, May, 28, election of the new Governing Board of the Academy, starting July 1, 2003

In the period 2003 – 2009

1. 19th Annual HATZ Assembly, February 27, 2004,
2. 20th Annual HATZ Assembly, February 26, 2005,
3. 21st Annual HATZ Assembly , February 28, 2006,
4. 22nd Annual HATZ Assembly, March 9, 2007,
5. 23rd Annual HATZ Assembly, March 14, 2008,
6. 24th Annual HATZ Assembly, March 14, 2009, election of the new Governing Board of the Academy, starting July 1, 2009.

Publications of the Croatian Academy of Engineering:

1. ANNUAL OF THE CROATIAN ACADEMY OF ENGINEERING, 2003,
2. ANNUAL OF THE CROATIAN ACADEMY OF ENGINEERING, 2004,
3. ANNUAL 2005 OF THE CROATIAN ACADEMY OF ENGINEERING,
4. ANNUAL 2006 OF THE CROATIAN ACADEMY OF ENGINEERING,
5. ANNUAL 2007 OF THE CROATIAN ACADEMY OF ENGINEERING,
6. ANNUAL 2008 OF THE CROATIAN ACADEMY OF ENGINEERING.

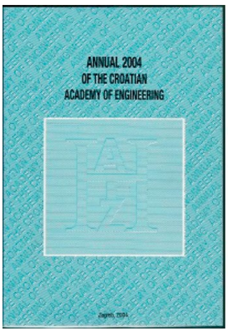


Fig. 4a) – Annual 2004 of the Croatian Academy of Engineering

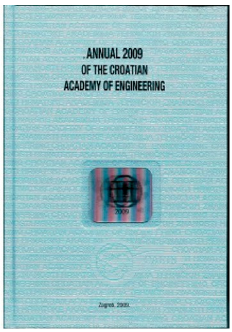


Fig. 4b) – Annual 2009 of the Croatian Academy of Engineering

Tehničke znanosti (Technical Sciences), Bulletin of the Croatian Academy of Sciences in Croatian

1. Vol. 10 (3) and (4) 2003,
2. Vol. 11 (1) and (2) 2003,
3. Vol. 12 2005,
4. Vol. 13 2006,
5. Vol. 14 2007,
6. Vol. 15 2008,
7. Vol. 16 2009.

Engineering Power, Bulletin of the Croatian Academy of Sciences, in English

1. Vol. 3, 2004,
2. Vol. 4 (1) and (2), 2005,
3. Vol. 5, 2006,
4. Vol. 6, 2007,
5. Vol. 7, 2008,
6. Vol. 8, 2009.

Fig. 5 – Award Appreciation from Stavanger, Norway

In this report no particular activities of the Departments, Centres and Standing Committees are presented, while most of them are described in the above mentioned HATZ publications. Besides, in the period from 2003 – 2009 great administrative archives were collected and are now available for every interested HATZ member or any other. Through TV, radio, newspapers and by invitations to newspaper reporters the HATZ was present in all current news.

During this period the HATZ administration had one permanently employed person, even during the absence of Mrs. Melanija Strika, due to illness; unemployed persons were selected from the Zagreb Employment Bureau. From 2003 – 2009 accounting was kept by an approved private office.

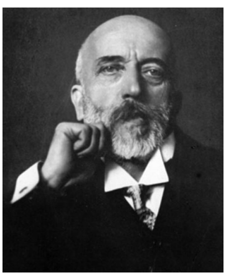
Finally, I would like to thank all the members of the Governing Body, Presidency, Department Secretaries and Standing Committees members, as well all HATZ members for their efforts to make the HATZ better and more recognizable in Croatia and abroad.

To me it has been an honour and pleasure to be the President of the Academy from 2003-2009.

Programme of the Croatian Academy of Engineering on the occasion of marking the 150th birth anniversary of Andrija Mohorovičić

Prof. Emeritus Zlatko Kniewald, Ph.D., emeritus member of the Croatian Academy of Engineering, member of the Scientific Council for Agriculture and Forestry of the Croatian Academy of Sciences and Arts

In 2017 the Croatian Academy of Sciences and Arts celebrated 160 years since the birth of Andrija Mohorovičić. When we celebrate anniversaries, we are all focused on exploring unknown facts about people who have earned eternal glory not only in their homeland, but also in the whole world or better said in humanity. Marking the 160th anniversary in 2017, the Croatian Academy of Sciences and Arts again initiated the 60-year old issue of installing a permanent memorial to the academician Andrija Mohorovičić in Zagreb.



However, we have to wonder why some worthy scientists are more famous and recognized in the world than in their homeland Croatia. This is nothing new, but this issue should be discussed in more detail or in other words to be investigated. Sometimes, a person is not spoken about for these or those reasons, but when we mention a Faraday, Dante Alighieri, Copernicus or any other famous person who has found his place in history, we stop only on his real contribution, and do not ask whom he was closer to in his social, political or world-view issues. It is time for us to finally grow up in Croatia, no matter how harsh it sounds.

Since its founding the Croatian Academy of Engineering (HATZ) has devoted one part of its programme to reviving the memories of Croatian scientists who marked the age, in which they lived, with their work. Their merits and discoveries have not been forgotten, but in the new technological revolution starting in the 20th century and continuing in the 21st century, they experience their application and true value. It is sufficient to mention Nikola Tesla, Ruđer Bošković, Marin Getaldić and Andrija Mohorovičić, even though we have devoted our attention to Vera Johanides and Vatroslav Lopašić, whose busts were installed in the Academy Park. Yes, it happened in 2007, when in the world, but also in Croatia, the 150th birth anniversary of Andrija Mohorovičić was marked. Although memory gradually fades, the records bring us back to that time.

The 22th Annual HATZ Assembly was held on 9th March, 2007. On this occasion Prof. Marijan Herak, Ph.D. (today an associate member of the Croatian Academy of Sciences and Arts) gave a lecture "Andrija Mohorovičić – a Great Man of Croatian Science" to HATZ members and guests" on the occasion of his 150th birth anniversary.

It was a period of lively HATZ activities on the domestic and international level. In 2006 the 150th birth anniversary of Nikola Tesla was marked by a series of conferences and symposia, and under the auspices of the Marie Curie Foundation a joint symposium of Croatian and Serbian scientists was held both in Zagreb and Belgrade.

The HATZ bulletin (Engineering Power, 6 (2007) was published in English and reported about the invited lecture of Prof. Marijan Herak presented during the 22nd Annual HATZ Assembly.


Engineering Power

BULLETIN OF THE CROATIAN ACADEMY OF ENGINEERING

Andrija Mohorovičić – the great Croatian Scientist

Invited lecture on the occasion of the 150th anniversary of his birth presented during the Assembly of the Croatian Academy of Engineering (HATZ) at its 22nd meeting held on March 09, 2007.

Professor Marijan Herak, Ph. D.

University of Zagreb, Faculty of Sciences and Mathematics
Department of Geophysics, A. Mohorovičić Geophysical Institute

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The Croatian Academy of Engineering continued to support the promotion of Academician Andrija Mohorovičić. 2010 was dedicated to the 100th anniversary of the discovery of Moho-Layer which was named after our famous A. Mohorovičić. In that year of marking the 100th anniversary of the epoch-making discovery of Andrija Mohorovičić the HATZ, upon the proposal of its active member and HATZ vice-president, Prof. Vilko Žiljak, Ph.D. and member of the Brethren of the Croatian Dragon, accepted the proposal to install a bust in Zagreb in memory of the academician Andrija Mohorovičić. It was verified that there is no memorial installed either in the area of the Technical Museum or in the area of the Croatian Meteorological and Hydrological Service of which A. Mohorovičić was one of the founders. In accordance with the HATZ programme and in cooperation with the Brethren of Croatian Dragon a working group was formed in whose work, besides several members of the Society of Natural Sciences, I was included as a HATZ representative. Several meetings were held in the premises of the Society conducted by Mr. Alojz Getliher, Dragon Bartenthalski of St. Mary Zvonimiruličke.

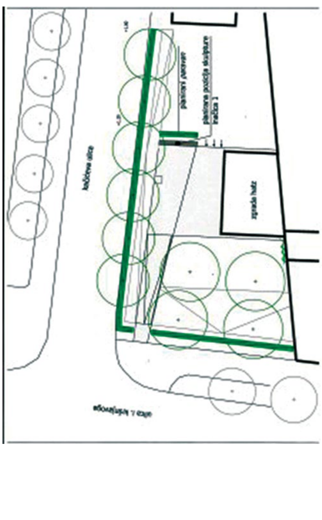
A bust to Andrija Mohorovičić installed in 1996 in front of his birth house in Volosko near Opatija was made by the academic sculptor **Josip Poljan,** author of numerous artistic achievements of sacred themes. He died on the Feast of Corpus Christi, on 4th June, 2015 at the age of 90 years without being able to see that his work decorates one of the locations in Zagreb. I met Prof. Josip Poljan two or three times, and we discussed whether this bust should be made or, with his consent, a replica of the existing one should be made. I must mention that Prof. Josip Poljan was ready to accept any solution and was incredibly mentally alert for his advanced age and maximally cooperative. Personally, I am sorry that we could not accomplish this task.

With the help of its governing bodies the HATZ could encourage activities to install a permanent memorial to A. Mohorovičić in Zagreb.

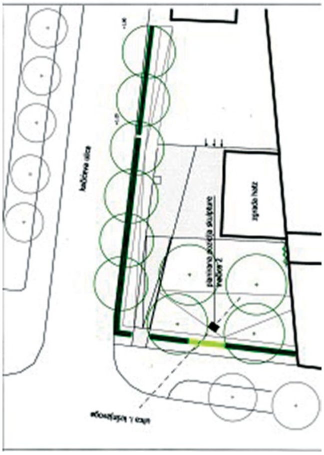
The second session of the Scientific Council of the HATZ was held on 31st March 2011.

Item Ad 5.3) – quote:

"The report was presented by Prof. Emeritus Z. Kniewald, and all HATZ members received the proposed conclusions of the 2nd session of the Scientific Council.



In 2007 the 150th anniversary of the birth of the great Croatian scientist A. Mohorovičić was celebrated. The year 2009 marked the 100th anniversary of discovering the Moho-layer named after A. Mohorovičić who is particularly responsible for this discovery. During 2010 the HATZ cooperated with the Brethren of Croatian Dragon and the University of Zagreb install a sculpture of A. Mohorovičić in the HATZ environment. The draft was prepared by Prof. M. Ščitaroci-Obad, Ph.D., a member of the Academy in the Department of Architecture and Urbanism (two possible variants attached). In this regard a meeting with the Rector of the University of Zagreb, Prof. A. Bjeliš, Ph.D. and the Vice-Rector, Prof. B. Baletić, Ph.D., an Academy member, was held. The City Assembly of the City of Zagreb proposed that by December 2, 2011, a statue of A. Mohorovičić should be installed according to an architectural solution on one of four possible locations in Zagreb:



Meteorological and Hydrological Service, Vranyczanyjeva poljana or in front of the HATZ office. The Brethren of Croatian Dragon would provide funding sources for making a statue, its installation and the sculptor's fee. The HATZ would be a convenient location due to the proximity of the faculties that scientifically apply the discovery of the Moho-Layer: Faculty of Civil Engineering, Faculty of Geodesy and Faculty of Mining, Geology and Petroleum Engineering" – end of quote.**

**Conceptual design created by Prof. Mladen Obad-Ščitaroci, today a regular HAZU member, and technically drawn by Damir Krajnik, Ph.D., Associate professor at Faculty of Architecture, University of Zagreb.

The relevant City Council of the City of Zagreb later decided that there was no agreement yet on the location of the memorial to A.Mohorovičić in Zagreb, and unfortunately we are witnesses that this issue has not been solved until today.

At the 5th session of the HATZ Presidency on April 19, 2011, the conclusions of the 2nd session of the HATZ Scientific Council were adopted under item Ad 4.2.1) – quote:

"The installation of the monument to Andrija Mohorovičić and the option to be installed at the HATZ location were discussed, respectively. In addition, the Academy is already planning to install busts of the late Academy members: V. Johanides and R. Podhorsky after whom two Academy awards were named" – end of quote.

Later on the HATZ installed busts of Prof. Emeritus Vera Johanides and Prof. Vatroslav Lopašić who were honorary HATZ members in front of its office in Kačićeva Street 28. It is interesting to mention that the bust of Prof. Emeritus Vera Johanides is the only bust dedicated to a university woman professor in Zagreb and probably in Croatia too.

What can be said as a conclusion, except that many Croatian scientists are more famous and recognized in the world than in their homeland. We will probably not wait the next decade to finally find a place in Zagreb where to install a worthy memorial to Andrija Mohorovičić.

Croatian Academy of Engineering 2009 – 2013[1]

Tonković, S.

Past-President of the Academy (2009 – 2013)

In the electoral process of the Electoral Commission for elections of the new Governing Board in the spring of 2009 at the Assembly held on March 14, 2009 the new leadership, the new Governing Board and the composition of the new Presidency of the Croatian Academy of Engineering for a mandate period from July 01, 2009 to June 30, 2013 was confirmed. The leadership of the Croatian Academy of Engineering was elected: Prof. Stanko Tonković, Ph.D., President, Prof. Miljenko Lapaine, Ph.D., and Prof. Vilko Žiljak, Ph.D., Vice-Presidents and Goran Granić, Ph.D., Secretary-General, and according to the Statute of the Croatian Academy of Engineering the former President, Prof. Emer. Zlatko Kniewald, Ph.D. was associated to the Governing Board. The joint session of the new and former Presidency the Croatian Academy of Engineering was held on June 30, 2009.

The opening (constituting) session of the new Governing Board of the Croatian Academy of Engineering was organized on Tuesday, July 7, 2009, in the Academy House, Kačićeva 28, Zagreb. During the four-year mandate the Governing Board held 27 sessions, and the Presidency held 13 sessions, dealing with activities according to the Statute of the Croatian Academy of Engineering and the activities of the regular work of the Croatian Academy of Engineering. The Scientific Council of the Croatian Academy of Engineering held 3 sessions (3rd Session – Joint Session of Scientific Council and Governing Board on February 2, 2012). Four Assemblies of the Academy were held (March 27, 2010; May 05, 2011; December 20, 2012 and May 21, 2013).

In the beginning of the mandate, as President, I participated at the CAETS conference (CAETS Convocation 2009 – Global Natural Resources – Management and

[1]This is the reprint of the article published under the same title in 2014, in the Jubilee Monograph "Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013". The permission for reprint has been granted by the author.

Sustainability) in Calgary, Canada, from 13 to 17 July, 2009. From 2009 to 2011 I was a member of the Board of Directors of CAETS. Successful cooperation with CAETS continued throughout all the mandate period.

On September 11, 2009 the Ministry of Science, Education and Sports issued **License for Scientific Activity** in the scientific field of Engineering Science. Accordingly, the Croatian Academy of Engineering was entered into the Register of scientific organizations under number 0338.

In the meantime effort was being performed on the text of the Statute of the Croatian Academy of Engineering. Special recognition for this activity goes to Goran Granić, Ph.D.

The 25th Annual Assembly of the Academy was held on Saturday, March 27, 2010. At the Assembly the new Statute of the Croatian Academy of Engineering and Ordinance on the Election of members of the Croatian Academy of Engineering (amended in the fall of 2012). Basic features of the new Statute are the simplification and harmonization with the statutes of most similar academies in the world, the ending of the status of extraordinary members, and the introduction of the electronic voting as equal to other models of voting.

Fig. 1 – Assembly of the Academy, March 27, 2010

According to the new Statute the Croatian Academy of Engineering has members, associates, emeriti, honorary members, international members, members amici and supporting members. During the entire mandate, and thereafter, the process of transition of extraordinary and full members in the unique status member of the Academy, and the recruitment of new associate members continued. The procedures were very complex and time consuming.

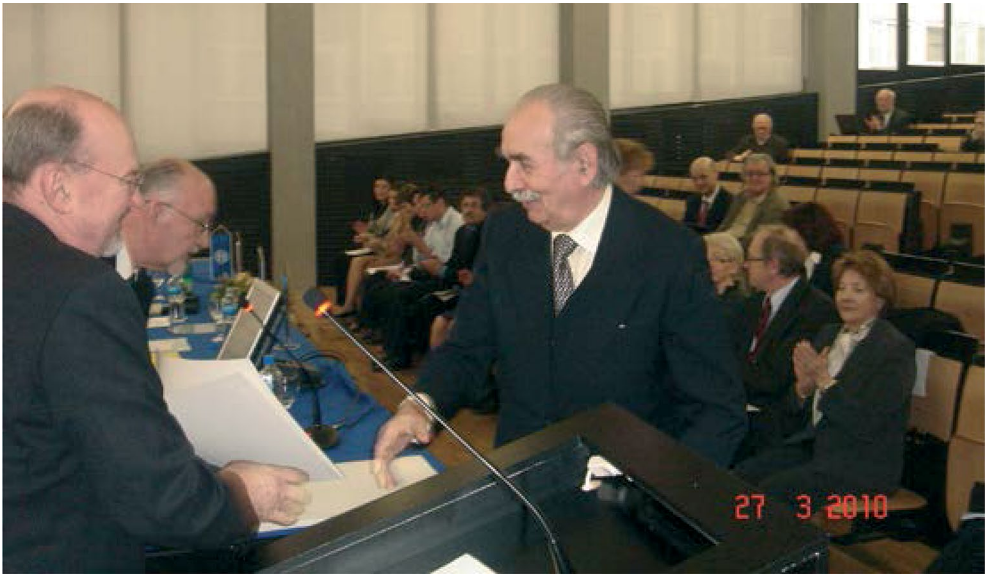


Fig. 2 – Prof. Marijan Bošnjak, Ph.D. receiving the Academy Award for his life – long activities in the Academy at the Assembly of the Academy, March 27, 2010

In September 2010, the Academy was visited by President of the Republic of Croatia, Prof. Ivo Josipović, Ph.D. We discussed the role of the Academy and Engineering Sciences in the development of the Croatian economy and industry. Acknowledgement and Medal of the Academy were given to the President.

Fig. 3 – Presentation of Acknowledgement and Medal of the Academy to the President of the Republic of Croatia Prof. Ivo Josipović, Ph.D. while visiting the House of the Academy in September, 2010

Fig. 4 – Rector of the University of Zagreb, Prof. Aleksa Bjeliš, Ph.D. visited the House of the Academy in April, 2011

In April 2011 the Rector of the University of Zagreb, accompanied by the Vice-Rector, member of the Academy Prof. Bojan Baletić, Ph. D. visited the Academy.

On January, 2014 the Symposium “Engineering Ethics and Croatian Economy” at the Faculty of Electrical Engineering and Computing organized by the Ethics Committee of the Croatian Academy of Engineering and the Faculty of Electrical Engineering and Computing was held.

The publishing activity of the Academy continued. During my mandate period two Annuals of the Croatian Academy of Engineering (2009 and 2010/11) were published as well as three issues of the Bulletin “Tehničke znanosti / Engineering Power”.

Special mention should be made of Annual 2009 of the Croatian Academy of Engineering, in which, along with conceptual novelties, a new “Who is Who” was published, which required great efforts by of the Governing Board and Presidency of the Croatian Academy of Engineering.

The central celebration on the occasion of the 300th anniversary of the birth of Rugjer Bošković was held at Vatroslav Lisinski Concert Hall on May 17, 2011 organized by the Croatian Academy of Engineering and the Ministry of Science, Education and Sports. In front of a large audience, as President of the Academy, I opened celebration and expressed my admiration and praise of the character and work of Rugjer Bošković. The Minister of Science, Education and Sports Radovan Fuchs, Croatian Parliament Speaker Luka Bebić and Croatian President Ivo Josipović gave their occasion speeches too. In the opinion of those present and the press much credit for the success of this celebration goes to Krešimir Dolenčić (director), Aljoša Paro (scenic design), Willem Miličević (video and photo processing) and executive producer Goran Granić, Ph.D. As President I especially expressed gratitude to Secretary-General Goran Granić, Ph.D., who was one of the main organizers of the celebration.

Fig. 5 – President of the Academy, Prof. Stanko Tonković, Ph.D., opening speech on the occasion of the celebration of the 300th anniversary of the birth of Ruđer Bošković, Vatroslav Lisinski Concert Hall, May 17, 2011

Fig. 6 – President of the Republic of Croatia, Prof. Ivo Josipović, Ph.D., opening speech on the occasion of the celebration of the 300th anniversary of the birth of Ruđer Bošković, Vatroslav Lisinski Concert Hall, May 17, 2011

Fig. 7 – Assembly of the Academy, May 17, 2011

The 26th Annual Assembly of the Croatian Academy of Engineering was held on Tuesday, May 17, 2011, after the celebration of the 300th anniversary of the birth of Rugjer Bošković at Vatroslav Lisinski Concert Hall.

Pursuant to articles 16 and 46 of the Statute a new categorization of membership was implemented, and full members became Academy members, most of extraordinary members were converted to the status of Academy members, associate members became Academy associates, corresponding members became international members of the Academy, members emeriti became Academy emeriti, honorary members became honorary members of the Academy, member friends became friends of the Academy, and supporting members became supporting members of the Academy. Decisions were given to all members of the Academy. As President, I particularly thanked Prof. Juraj Božičević, Ph.D. (who performed the duties of Secretary-General and President of the Academy) and Prof. Dražen Aničić, Ph.D. (former Secretary General of the Academy), who are also among the founder members of the Academy, for their great contribution to the development and work of the Academy.

On 28 September, 2011, the Croatian Academy of Engineering marked the life and work of its honorary member Prof. Emeritus Vera Johanides who died in 2000, with an appropriate scientific symposium. Prof. Vera Johanides was the founder of biotechnology, in particular biochemical engineering in Croatia. Marking the work of Prof. Emeritus Vera Johanides was performed jointly by Croatian Academy of Engineering and Faculty of Food Technology and Biotechnology, University of

Fig. 8 – Prof. Jasna Franekić, Ph.D. receiving the Academy Award "Power of Knowledge" at the Assembly of the Academy, May 17, 2011

Zagreb in cooperation with the Biotechnology Foundation of the Faculty of Food Technology and Biotechnology of the University of Zagreb, Croatian Society for Biotechnology and donors from the industry.

On this occasion the memorial bust of Vera Johanides was unveiled in the park of the Academy House. The bust was made by sculptor Prof. Slavomir Drinković, Ph.D. In this way the Academy honored one of its first members, a renowned and acknowledged scientist from the field of biotechnology.

In the winter of 2012 problems with my health unfortunately began. They lasted, with brief interruptions, until the end of my mandate, of course affecting my activity and work in the Croatian Academy of Engineering.

For health reasons, I could not perform my duties in the period **from January 23, 2012 to June 11, 2012 and from November 20, 2012 to June 20, 2013**. Pursuant to Article 35, paragraphs 2 and 3 of the Statute of the Croatian Academy of Engineering Secretary-General Goran Granić Ph.D. and Prof. Vilko Žiljak, Ph.D., Vice-President of the Academy deputized for me during my absence.

In the first period Goran Granić, Ph.D., led a series of sessions of bodies of the Croatian Academy of Engineering, especially of the Awards Committee and the procedure for the election of new members, for which I am sincerely grateful.

In July 2012, members of the Governing Board Prof. Miljenko Lapaine, Ph.D. (July 10, 2012) and Goran Granić, Ph.D. (July 04, 2012) resigned from all their positions in the Croatian Academy of Engineering.

In March 2012 the Croatian Academy of Engineering signed the Agreement on Scientific and Technical Cooperation with the Academy of Medical Sciences of Croatia, the Croatian Academy of Legal Sciences and the Academy of Forestry Sciences.

Unfortunately, because of illness I was not present at a very successful meeting held on September 3, 2012, in Zagreb (Sheraton Hotel) between senior representatives of the Chinese Academy of Engineering and the Croatian Academy of Engineering. The meeting was led by Prof Vilko Žiljak, Ph.D., Vice-President of the Croatian Academy of Engineering and by Prof. Pan Yunhe, Vice-President of CAE. As a result of the meeting the Agreement on Cooperation between the Croatian Academy of Engineering and the Chinese Academy of Engineering was signed on January 23, 2013

After long discussions and consultations, at the initiative of Prof. Juraj Božičević, Ph.D., Head of the Center for Development Studies and Projects of the Academy and Prof. Franjo Jović, Ph.D., Secretary of the Department of Systems and Cybernetics "The Talks about the Present and Future of Engineering in Croatia" were initiated which encourage socializing, thinking and exchange of views on major development issues.

The 27th Annual Assembly of the Croatian Academy of Engineering was held on December 20, 2012. Besides the regular items on the Agenda of the Assembly, I particularly emphasize the election of new members and associates of the Academy, the announcement of the public competition for the appointment to the remaining places in the Departments of the Academy and the election of the Commission for starting the official announcement of the competition and the election of the new leadership of the Croatian Academy of Engineering for the mandate period from July 1, 2013 to July 1, 2017.

Along with the co-organizers the University of Zagreb, Faculty of Food Technology and Biotechnology, Croatian Society of Biotechnology and Biotechnology Foundation, the Academy was the organizer of the second international symposium "Vera Johanides – Biotechnology in Croatia by 2020". This exceptionally successful symposium was held 10 – 11 May 2013 in the Great Hall of the University of Zagreb. A detailed report with peer-reviewed papers in the Annual 2013 of the Croatian Academy of Engineering was foreseen.

During the spring of 2013, pursuant to the Statute of the Academy the elections of the new leadership of the Academy were held. At the session held on May 14, 2013 the Presidency of the Academy accepted the Report of the Commission for the election of new leaders of the Croatian Academy of Engineering chaired by Prof. Karolj Skala, Ph.D. It was decided to conduct electronic voting.

The new leadership of the Croatian Academy of Engineering was elected by voting for a mandate period from July 01, 2013 to June 30, 2017 in the following composition:

- Prof. Vladimir Andročec, Ph.D., President
- Prof. Vladimir Medved, Ph.D., Vice-President
- Prof. Zdravko Terze, Ph.D., Vice-President
- Prof. Dubravko Rogale, Ph.D., Secretary-General

On 21 May, 2013 the 20th anniversary of founding the Croatian Academy of Engineering was held at the Mimara Museum. In a festive environment, along with other guests and occasion speeches, the celebration was led by my deputy, Prof. Vilko Žiljak, Ph.D. The course of the celebration is also available on video recording.

The 28th Annual Assembly of the Croatian Academy of Engineering was held after the anniversary celebrations, on the same day, May 21, 2013. I did not attend the Assembly, but all data can be found in the Minutes and the video recording of the Assembly. The most important fact is that the Assembly accepted the new leadership of the Academy in the abovementioned composition. New leadership began operating on July 1, 2013.

In the second mentioned period Prof. Vilko Žiljak, Ph.D. was, among other things, especially active and involved in the preparations of organizing and holding the 27th and 28th Annual Assembly of the Academy and the celebration of the 20th anniversary of founding the Croatian Academy of Engineering for which I am very thankful to him.

More detailed information about everything that happened in this period can be obtained at the Secretariat of the Academy, or from me personally or from the members of Governing Board, particularly for the periods when Goran Granić, Ph.D. (February 23, 2012 to June 11, 2012) and Prof. Vilko Žiljak, Ph.D. (November 20, 2012 to June 20, 2013) deputized for me.

I would like to express my sincere gratitude to the whole Governing Board for their efforts, conscientiousness, and time taken to execute ungrateful and burdensome obligations and enable the successful work of the Academy in the mentioned period.

Croatian Academy of Engineering 2013-2018

Andročec[1], V.

President of the Academy

Introduction

Croatian Academy of Engineering (HATZ) was founded on 19 January 1993 is a scientific organization which brings together distinguished scientists from Croatia and abroad in the fields of technological and biotechnological sciences with the objective of promoting technical sciences, gathering and encouraging co-operation of the scientists of different technical, biotechnical and other professions in order to support efficient scientific and economic development of Croatia without gaining any profit. In 2009, the status of the Academy as a scientific organization within the Ministry of Science, Education and Sports of the Republic of Croatia was recognized.

Election of the Governing Board of the Academy in 2013 and Program Guidelines

The Governing Board of the Academy composed of:

1. Prof. Vladimir Andročec, Ph.D., President
2. Prof. Zdravko Terze, Ph.D., Vice-President
3. Prof. Vladimir Medved, Ph.D., Vice-President
4. Prof. Dubravko Rogale, Ph.D., Secretary-General

was elected in 2013 whose mandate started on 1 July 2013 and lasted to June 30 2017 adopted a strategy program with the plan of activities and their implementation. Prof. Emer. Stanko Tonković, Ph.D. joined the Governing Board in compliance with the Statute as the 5th member.

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[1] Prof. Vladimir Andročec, Ph.D., has been elected President of the Academy in 2013, then re-elected in 2017, and is currently serving his second term of office (2017-2021).

Thinking about the future of the Academy as a scientific community and with the intention of acting in order to support its existence, the new Governing Board studied the experiences of other academies and scientific societies in the world and it was concluded that in the new period the Academy should become a work unit that will help individuals and organizations and the society as a whole in:

- systematic preparation for the future;
- acquiring skills of prediction and discussion;
- support and development of innovation culture;
- acquisition and application of knowledge;
- communication with the authorities and with economy;
- connecting science with industry.

It was necessary to take into account the fact that the world of work gradually transforms which affects the orientation of individuals in new circumstances and requires the prevention of the consequences of obsolescence of knowledge with regard to the effect of globalization and rapid development of technologies and information society with the results on which the world and our economy are based.

The Croatian economy weakened by war and transitional problems has so far been weak and there is still no clear vision of development, although it is the main component of achieving the prosperity of Croatia and its citizens.

Cognitive, social, and economic changes, which happened, particularly emphasized the importance of the Academy and the role in overcoming problems and challenges in the consideration of projects and ideas that will contribute to the development of the economy and consequently the wider community. Based on these premises, in 2013 the Governing Board proposed the program of work of the Academy which includes the following:

a) Strengthening cooperation with economic entities, faculties, institutes and ministries. More intensive connections of the Academy with the economy and government institutions and the implementation of a larger number of projects and contracts increase the benefits of the members and considerably;

b) Organizing specialized meetings of each of the Departments of the Academy with current topics arising from the work area of the Department. This resulted in a significant number of events each year and enabled the members to participate in the activities of the Academy in an optimal way;

c) Holding Central Conferences of the Academy 'Technical Sciences for the Croatian Economy' as scientific and professional conferences that proved to be a useful meeting place for scientists and businessmen during the first decade of the activities of the Academy. The last conference of this kind was held in 2003 and was attended by a large number of participants, especially members of the Academy, which is one of the most important reasons for membership in the Academy. In the past mandate this activity was realized mostly through round-tables and workshops with a topic of interest of technical sciences for the industry and economy;

d) Strengthening marketing actions to promote the Academy as the top scientific institution of the Croatian economy. This applies in particular to the adoption of declarations considering contemporary problems of the Croatian economy and proposals for Croatia's strategic development. Scientific and technological themes and projects that are of interest for the development of the Croatian economy in the field of technical and biotechnical sciences were proposed to competent authorities. They would be realized by the Academy and its affiliated members;

e) Continuing support of publishing books and other publications of the Academy and the introduction of patronage in publishing books and papers of Academy members, and thus they become the editions of the Academy. On the occasion of the twentieth anniversary of the foundation of the Academy in 2014, the Jubilee Monograph 'Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013' was published;

f) Encouraging all members to recognize their interest through the work of the bodies of the Academy and to contribute to the work of the Academy, in particular to the implementation of the program of the Academy, which would position it as a useful, respected and committed institution of the Republic of Croatia recognized in the world.

Membership and activities of the bodies of the Academy, update of normative acts and modernization of the web pages of the Academy and other important activities

Number of members after the 20th anniversary celebration and the HATZ Annual Assembly in May 2013 was as follows:

Members of the Academy	104
Emeriti members of the Academy	65
International members of the Academy	9
Associates of the Academy	78
Honorary members of the Academy	8
Amici members of the Academy	15
Supporting members of the Academy	49
IN TOTAL	328

Number of members after the 5th (electronic) session of the Presidency (outside of the session) in April 2018 was:

Members of the Academy	102
Emeriti members of the Academy	85
International members of the Academy	13
Associates of the Academy	66
Honorary members of the Academy	10
Supporting members of the Academy	62
IN TOTAL	338

In the period 2013-2017 the Academy held 5 internal calls to elect new emeriti and members of the Academy, 3 public calls to elect new associates, international and honorary members, 1 internal call to elect new leaderships and members of Departments, Committees, Centers and the Scientific Council and 2 internal calls to elect the new Governing Board of the Academy.

For a smaller number of members of the Academy and supporting members of the Academy the membership in the Academy terminates for non-fulfillment of membership obligations, by virtue of the Statute (individual members who have reached the age of 70 and have not been promoted into higher membership categories) or on a personal request.

The Governing Board of the Academy 2013-2017 held 90 sessions, the Presidency held 17 sessions, and 4 plenary sessions of the Assembly, and 5 electronic sessions of the Assembly were held.

The Governing Board of the Academy 2017-2021 has so far held 22 sessions, the Presidency has held six sessions (5 regular sessions and 1 electronic session), and 2 electronic sessions of the Assembly outside the session were held, and on 21st May 2018 the ceremonial session (35th annual session) of the Assembly of the Academy will be held on the occasion of the 25th anniversary of the foundation and operation of the Academy.

The activities of the Academy (auspices, organization of conferences, and participation in conferences of public interest) have been steadily increasing over the last 5 years and in that period 75 auspices for conferences were given, 46 conferences were held in the organization of the Academy or in co-operation and the leaders of the Academy participated in over 150 conferences of public interest.

The Scientific Council of the Academy in both mandates held a total of 9 sessions, and numerous sessions were held by Departments, Committees and Centers of the Academy.

Fig. 1 – Round Table ‘Experiences and Guidelines in Implementing Major Energy Projects’
Co-organizers: Croatian Academy of Engineering – Committee for Economic Cooperation and Regional Cooperation (chairman Prof. Nedjeljko Perić, Ph.D.), Croatian Chamber of Economy and Innovation Center Nikola Tesla (HGK, November 2017)

The vision and mission of the HATZ include the connection and synergy of high-quality human scientific and professional potentials in the field of technical and biotechnical sciences while respecting the high ethical principles and norms. From this perspective, the Academy analyzes, evaluates and is ready to offer solutions within its *meritoriousness* and competences regarding the overall social, economic and political situation in the Republic of Croatia.

With our rational and impartial, scientific and professional approach, we want and can be a partner and collaborative organization for all social actors who in the first place want improvement and development of the Croatian scientific and educational system, improvement of the innovation and entrepreneurial climate in society, economic development with the highest European and international standards about environmental protection, employment increase, increase in living standards and general well-being of all Croatian citizens.

Due to amendments in the laws regulating the areas of action of the Academy as well as due to the expansion of the activities of the Academy and the need to adapt the organizational and member structure of the Academy to new scientific, professional and economic challenges, in the past 5 years we have undertaken a comprehensive and very demanding task of thoroughly amending and updating the Statute and other normative acts of the Academy.

In compliance with its program, we hereby mention as important the information that in 2014 the Academy with the City of Zagreb signed the Agreement on the project ‘Earthquake Risk of the City of Zagreb.

On behalf of the City of Zagreb the City Office of Emergency Management is in charge of implementing projects, and on behalf of the Academy this is the Department of Civil Engineering and Geodesy, which brings together the best Croatian scientists and experts from the field of civil engineering, earthquake engineering and geodesy.

The project was applied for funding from EU funds and we hope for the best.

The Governing Board of the Academy in the mandate and the current 2017-2021 mandate carried out the financial consolidation of the Academy and attracted numerous successful and distinguished economic entities as well as scientific institutions to become supporting members and we will continue to do so.

In 2016 the offices of the Academy were renovated and repainted. Also, during 2017 and 2018 complete new IT equipment was acquired and the old and defective equipment was removed and disposed of. In 2018, a dumpster was purchased and placed in the yard of the Academy. The old part of the Archive of the Academy and other items that are not in everyday or frequent use were put into it.

International Activities (CAETS, Euro-CASE, SAPEA Project and Signing the Agreement with the IAS)

Since 2000 the Academy has been a member of International Council of Academies of Engineering and Technological Science headquartered in Williamsburg, Virginia, USA (CAETS) : www.caets.org), and since 2005 a member of the European Council of Academies of Applied Sciences, Technologies and Engineering headquartered in Paris, France, EU (Euro-CASE).

Over the past 5 years, the Academy has also been active in the field of international cooperation, in particular with CAETS and Euro-CASE. Vice-President of the Academy Prof. Zdravko Terze, Ph.D. and I, as the President of the Academy, are members of the Euro-CASE Board and every year we regularly attend two annual Board meetings.

With its membership in Euro-CASE and CAETS the Croatian Academy of Croatia aims to contribute to stronger European and international positioning of technical and biotechnical sciences in Croatia, as well as Croatia in general. In this sense we would like to make available our scientific and professional potentials and international contacts also to the government bodies of the Republic of Croatia, in particular in designing and launching projects and withdrawing more funds from EU funds available to Croatia.

As President of the Academy I participated in Brussels in September 2013 on a serious and wide-scale meeting between the European Commission and the JRC and representatives of all Academy-members of the Euro-CASE, which was dedicated to the future of the development of innovation and technologies in the EU – Seminar "Independent science-and technology-based policy advice from Euro-CASE (innovation and technology policy of the EU). Falling behind on innovation and technology was underlined, the development of which should be supported.

In 2013 and 2014 the Academy achieved a very intensive collaboration on the International (European) Project SETA ('South East Transport Axis') through its

Traffic Engineering Center, which was initiated by the late Prof. Nenad Dujmović, Ph.D., as the first Head of the Center, and continued by Prof. Ivan Miloš, Ph.D., as Head of the Center, in cooperation with Academy members from the Traffic Department. Our Academy participates on this valuable project, along with 11 international partners from 6 countries, as associate partner together with the City of Rijeka with a share of 10%.

The Cooperation Agreement for this project was signed in 2013 in the second phase of the implementation and this phase was successfully finalized.

In 2014 we participated in the Euro-CASE Annual Conference (December 2-3) in Brussels, under the title of EU-Academia Euro-CASE Annual Conference 'Evidence-based Policy Advice and Innovation Policy beyond Horizon 2020' .

In 2015 we participated in the Euro-CASE Annual Conference (2-3 November) in Delft and Den Haag organized by the Netherlands Academy of Technology and Innovation (AcTI Netherlands). The theme of the conference was 'Engineering Smart Cities of the Future'.

Fig. 2 – Euro-CASE Board Meeting and Euro-CASE Annual Conference (Den Haag i Delft, Netherlands, November 2 – 3, 2015)

Fig. 3 – Euro-CASE Conference and Board Meeting (Kopenhagen and Lyngby, Denmark, 13-15 November 2016)

In 2016 representatives of the Academy participated on the Annual Conference of Euro-CASE organized by the Danish Academy of Technical Sciences (ATV Denmark), which was held from 13 to 15 November 2016 under the theme of ‘Big Data – Smarter Products, Better Societies.

Representatives of the Academy – Prof. Vladimir Andročec, Ph.D., President of the Academy and Prof. Zdravko Terze, Ph.D., Vice-President of the Academy, participated in two sessions of the Euro-CASE Board in 2016, as members of the Governing Board in Paris, France, 21-26 May 2016 and in Lyngby, Denmark, 13-15 November 2016. In May 2016, representatives of the Academy also attended the meetings related to the SAPEA project (Science Advice for Policy by European Academies).

The SAPEA project, in which the Academy participates through its membership in Euro-CASE, is very interesting for the academic community as well as for the economic and political life of the member states of the European Union. The idea comes from the European Commission and represents an interacademic cooperation at the EU level, and within it five associations of European Academies are networked (The 5 European Academy Networks): (AE – Academia Europaea), ALLEA – All European Academies (whose member is the Croatian Academy of Sciences and Arts), EASAC – European Academies Science Advisory Council, Euro-CASE and FEAM – Federation of European Academies of Medicine. Apart from the European Academies, this project also brings together academies from Israel, Armenia, Georgia and Turkey. The goal of this inter-academic cooperation at EU level is to provide the European Commission with an independent and interdisciplinary policy based on scientific facts, combining the resources of 100 individual academies across Europe, each having hundreds of members and covering all scientific disciplines: social, humanistic, natural, technical and medical sciences. The SAPEA project was officially launched in Brussels on December 13, 2016, funded under the Obzor 2020 program, and our prominent members of the Academy participate in the work of the established scientific bodies of the Project.

Fig. 4 – Official launch of the SAPEA project (Brussels, Belgium, 13 December 2016)

In 2017 the leaders of the Academy participated in two regular sessions of the Board of the Euro-CASE in Paris and Madrid, and at the Annual Meeting and Conference of CAETS in Madrid.

Fig. 5 – Official Signing of the Agreement on Cooperation with the Slovenian Academy of Engineering (Ljubljana, Slovenia, 28 September 2017)

In September 2017 the Academy signed an Agreement on Cooperation with the friendly Slovenian Academy of Engineering (IAS) in Ljubljana on the basis of the previous long-standing excellent cooperation and a series of reciprocal visits and bilateral meetings of the two academies.

Cooperation with the Economy

With regard to the engineering background of the Academy, one of our goals is to cooperate with the economy, and within the framework of the Academy a special Committee for Cooperation with the Economy was established that has lately encouraged and implemented various forms of cooperation. We are particularly pleased with the fact that the number of supporting members of the Academy from business, and especially the reputable and technologically advanced companies that cooperate with us in the development of new technologies, increases significantly.

Realizing that a completely new technological revolution called Industry 4.0 is taking place that will significantly change the world in the near future, especially in the area of IT technology and robotization, we have decided to even stronger connect the actualities of the Academy with the economy and work together in its development. Therefore, the new Statute introduces a special institution of membership – entrepreneur members and Entrepreneurial Council. Entrepreneur members are elected on the basis of the criterion of a significant contribution to our economy and its development, and the Entrepreneurial Council made up of members of entrepreneurs is an advisory body of the Academy that will encourage the members of the Academy to cooperate with the economy through joint development projects.

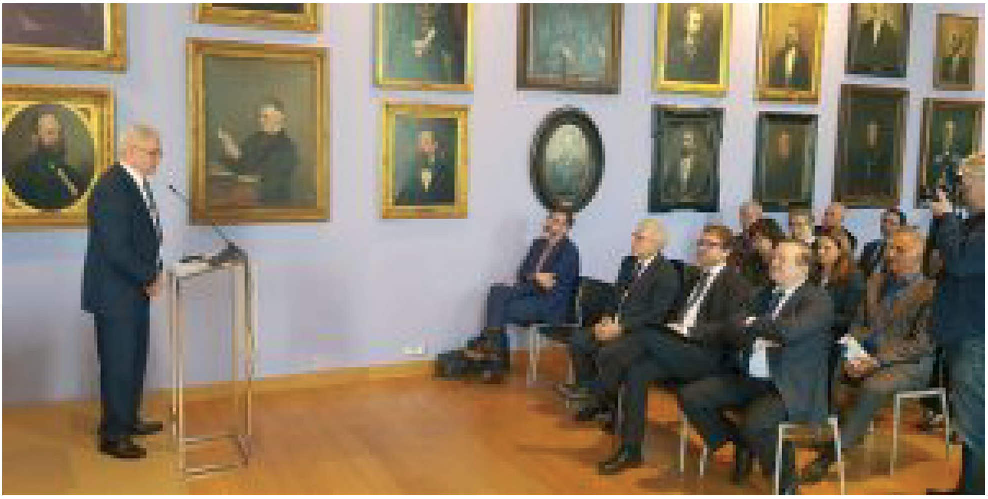

Fig. 6 – Public discussion "Cooperation between University and Economy" – example of good practice: Company Tehnix d.o.o. held on 11 April 2018 in the Great Hall of the University of Zagreb in the organization of University of Zagreb, Croatian Academy of Engineering and Scientific Council for Technological Development of the Croatian Academy of Sciences and Arts

Fig. 7 – Meeting of Đuro Horvat, B.Sc. oec., President of the Company, with Prof.. Vladimir Andročec, President of the Croatian Academy of Engineering, related to an agreement on joint projects which was held on 3 October 2017 at Tehnix d.o.o.

Fig. 8 – Meeting of the members of the Governing Board of the Croatian Academy of Engineering with Mr. Đuro Horvat, President of the Company, held on June 5, 2017 at Tehnix d.o.o

Fig. 9 – Roundtable titled ‘Cybernetic-Physical Systems and Internet Things’, held on April 11, 2018 at the Croatian Chamber of Commerce, Zagreb

Fig. 10 – The Governing Board of the Croatian Academy of Engineering, in cooperation with the Association of Innovators of Zagreb, organized an educational workshop 'Innovations and Patents' on November 29, 2017 at the Academy House

Cooperation with the Ministry of Science and Education of the Republic of Croatia and solving of the legal status of the Academy

The Academy wishes to make available its scientific and professional potentials and international contacts also to the government authorities of the Republic of Croatia, especially in terms of creating and launching projects and withdrawing more funds from EU funds available to Croatia. Since the Academy can thus contribute far more not only to stronger positioning and financial stability, but also to the Budget of the Republic of Croatia – from which it is minimally financed through the Ministry of Science, Education and Sports, exclusively for a specified purpose using public calls for co-financing the work of associations, publication of scientific books, organization of conferences and applying for membership fees in international scientific organizations. Over the past period, we have undertaken very intensive activities with the aim of further legal regulation of the academic status of the Academy and of the problem of re-accreditation conducted by the Agency for Science and Higher Education.

The result of these joint efforts is promising, and we expect the announced legal regulation of the scientific status of our Academy and other vocational academies: Croatian Academy of Legal Sciences, Croatian Academy of Medical Sciences and Academy of Forestry Sciences.

Installing a bust in the memory of the deceased Prof. Vatroslav Lopašić, Ph.D.

On 17 October 2016 the Academy solemnly unveiled a bust of the deceased honorary member of the Academy Prof. Vatroslav Lopašić, Ph.D. in the yard of the HATZ House in Zagreb, Kačićeva 28. Prof. Vatroslav Lopašić, Ph.D., a deceased honorary member of the Croatian Academy of Engineering, was a prominent Croatian physicist – a classic of Croatian physics, scientist, expert and university teacher who formed and educated many generations of young engineers and gave an immense contribution to the establishment of scientific institutions and studies, the improvement and development of studies of natural and technical sciences in Croatia. The bust is a creation of academic sculptor Boris Leiner.

Fig. 11 – Solemn unveiling of the bust of Prof. Vatroslav Lopašić, Ph.D., a honorary member of the Croatian Academy of Engineering and a distinguished Croatian physicist (HATZ, October 17, 2016)

Cooperation with Croatian Academy of Sciences and Arts, Lexicographic Institute Miroslav Krleža, Croatian Engineering Association and sister vocational academies (Croatian Academy of Medical Sciences, Croatian Academy of Legal Sciences and Academy of Forestry Sciences)

The Academy has a particularly successful cooperation with the Croatian Academy of Arts and Sciences, with which it signed a Cooperation Agreement and with the Miroslav Krleža Lexicographic Institute in 2014, with which, together with HAZU, it signed the Tripartite Cooperation Protocol on an extremely important project ' Croatian Technical Encyclopedia '. The Intensive work on this project during the previous years, especially during 2016 and 2017, will result this year in the publication of the first volume of the Encyclopaedia. A number of members of the Academy have specifically been involved in this project.

The Academy also achieves excellent cooperation with related vocational academies of the Republic of Croatia: Croatian Academy of Medical Sciences, Croatian Academy of Legal Sciences and the Academy of Forestry Sciences.

A quadrilateral cooperation agreement was signed by these four sister academies in 2012, and in 2016, as well as in previous years, they achieved a number of successful joint activities and projects, meetings and forums, and the joint research symposium of four Academies 'Modern Technologies: Ethics of Use and Legal Regulation 'should be particularly mentioned. It was initiated by the Croatian Academy of Medical Sciences and held on March 17, 2017 at the Croatian Medical Association in Zagreb. Four academies cooperate through the Council and Coordination of the Academies as their joint coordination bodies.

One of the most important meetings of the Academy, organized in cooperation with the Croatian Engineering Association (HIS), is the Engineer's Day of the Republic of Croatia, which these two organizations have jointly organized since 2015. HATZ and HIS signed the Agreement on Scientific and Professional Cooperation in 2014. So far four Engineer's Days have been held:

- On 2nd March 2015 at the Ministry of the Economy, Entrepreneurship and Crafts of the Republic of Croatia under the auspices of the Croatian Academy of Sciences and Arts

- On 2nd March 2016 at the Faculty of Electrical Engineering and Computing in Zagreb, under the auspices of the Prime Minister of the Republic of Croatia and in co-organization with the Faculty of Electrical Engineering and Computing

- On 2nd March 2017 at the Faculty of Forestry in Zagreb, in co-organization with the Faculty of Forestry

- On 2nd March 2018 at the Faculty of Civil Engineering in Zagreb in co-operation with the Faculty of Civil Engineering.

In the period 2013-2018 the Academy published 3 Annuals in English (of which 1 jubilee annual on the occasion of the 25th anniversary of the Academy, with the latest section ‘Who is Who in the Croatian Academy of Engineering (2018), 1 Annual in Croatian, Jubilee Monograph on the occasion of the 20th Anniversary of the HATZ in English, including ‘Who is Who in the Croatian Academy of Engineering (2013)’, 1st and 2nd (extended) and 3rd (extended and supplemented) edition of the monograph on Faust Vrancic by Prof. Gojko Nikolic, Ph.D., (in co-operation with the Public Open University Zagreb), 6 Independent Bulletins in English ‘Engineering Power’, 2 independent Bulletins in Croatian ‘Tehničke znanosti’, 3 double issues of the Bulletin in Croatian and English ‘Technical Sciences / Engineering Power’ and 1 Book of Abstracts of the Round Table Discussion of the Academy “Status and Future of Technological and Biotechnological Sciences in Croatia in the 21st Century’ held on May 8, 2017.

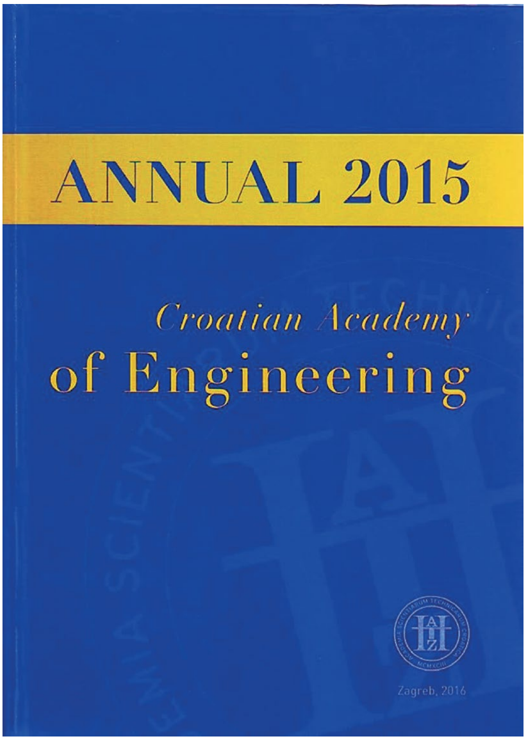

Fig. 12 – “Annual of the Croatian Academy of Engineering 2015” (Zagreb, 2016)

Fig. 13 – “Godišnjak Akademije tehničkih znanosti Hrvatske 2016” (Zagreb, 2017.)
“Annual of the Croatian Academy of Engineering 2016” (Zagreb, 2017)

ISSN 1330-7207

Tehničke znanosti

GLASNIK AKADEMIJE TEHNIČKIH ZNANOSTI HRVATSKE Vol. 21(1) 2017

RIJEČ GLAVNOG I ODGOVORNOG UREDNIKA

Poštovani čitatelji,

Izuzetno smo ponosni i radosni što vam, ubrzo nakon prvog ovogodišnjeg broja ***„Engineering Powera“***, možemo predstaviti dvobroj našega Glasnika na hrvatskom i engleskom jeziku ***„Tehničke znanosti“*** Vol. 21(1) 2017 / ***„Engineering Power“*** Vol. 12(2) 2017.

Ovo izdanje nastalo je u suradnji suradnika Akademije i gostujućeg urednika Marija Cifreka s njegovim kolegama i suradnicima s Fakulteta elektrotehnike i računarstva u Zagrebu i iz Kliničkog bolničkog centra Zagreb. Izdanje je posvećeno odabranim istraživačkim projektima iz područja neurofiziologije, koji se bave električkim signalima mozga, odnosno njihovim mjerenjem, procesiranjem, analizom i primjenom.

Naša Akademija, kao znanstvena organizacija posvećena promociji i popularizaciji tehničkih i biotehničkih znanosti, stalnom poticanju suradnje naših najistaknutijih znanstvenika te jačanju javne svijesti o važnosti tehničkih i biotehničkih znanosti, dosljedno i odlučno poduzima napore kako bi čitateljima naših publikacija iz svih područja i profesija pružila najvažnije i najvrjednije uvide u aktivnosti naših članova, a time i u stanje pojedinih područja u tehničkim i biotehničkim znanostima.

Glavni i odgovorni urednik
Vladimir Andročec, Predsjednik Akademije tehničkih znanosti Hrvatske

RIJEČ UREDNIKA

Prožimanje inženjerskih znanosti i suvremene medicinske prakse jedan je od najboljih primjera nužnosti multidisciplinarnog pristupa u današnjoj znanosti. Od računalnog modeliranja i numeričkih simulacija fizikalnih i kemijskih procesa unutar bioloških sustava te upotrebe instrumentarija temeljenog na sve sofisticiranijim tehnološkim rješenjima za dijagnostičke svrhe, do inteligentnih ortopedskih pomagala i pametne protetike (*„wearable robotics“*), primjena naprednih inženjerskih rješenja nezaobilazna je u gotovo svim granama suvremene medicine.

Svijest o nužnosti takve povezanosti preslikava se i u svakodnevnim aktivnostima Akademije tehničkih znanosti Hrvatske koja usko surađuje s Akademijom medicinskih znanosti Hrvatske i kliničko-istraživačkim institucijama u okviru rada na zajedničkim projektima, organizaciji znanstvenih skupova te drugim djelatnostima od društvenog značaja.

Imajući u vidu gore rečeno, posebno me raduje predstaviti ovo izdanje ***„Tehničkih znanosti“*** s temom koja domene inženjerskog djelovanja i medicinske prakse povezuje na posebno aktualan način. Gostujući urednik je Mario Cifrek, član suradnik Akademije tehničkih znanosti Hrvatske, Odjel za sustave i kibernetiku i redoviti profesor Fakulteta elektrotehnike i računarstva Sveučilišta u Zagrebu.

Urednik
Zdravko Terze, Dopredsjednik Akademije tehničkih znanosti Hrvatske

RIJEČ GOSTUJUĆEG UREDNIKA

Električki signali mozga – mjerenje, obrada, analiza i primjene

Biomedicinsko inženjerstvo je interdisciplinarno područje koje ujedinjuje znanja iz inženjerstva (elektrotehnika, računarstvo, informacijsko-komunikacijske tehnologije, fizika, kemija…), biologije i medicine. Razvoj medicinskih znanosti, organizacije zdravstvene zaštite i zdravstvene skrbi krajem prošlog i početkom ovog stoljeća usko je i nedjeljivo povezan s razvojem elektroničkih, računarskih, informacijskih i komunikacijskih tehnologija. Elektromedicinski uređaji i oprema sastavni su dio skoro svakog pregleda/zahvata, a računala i informacijsko-komunikacijski sustavi su danas nedjeljivi dio svakodnevnice.

Elektroencefalografija (EEG) je jedna od osnovnih neurofizioloških metoda registracije bioelektričke aktivnosti mozga. Prvi put se spominje u radovima neuropsihijatra Hansa Bergera koji je tridesetih godina prošlog stoljeća korištenjem osjetljivih galvanometara snimio prve signale koji prema današnjoj klasifikaciji spadaju u alfa frekvencijsko područje. EEG se kao dijagnostička metoda počinje rutinski provoditi pojavom prvih komercijalno dostupnih elektroencefalografa pedesetih godina prošlog stoljeća. Tu svakako treba istaknuti da je prof. dr. sc. Ante Šantić već 1957. godine, kao zaposlenik Instituta za elektroprivredu u Zagrebu, konstruirao i komercijalizirao 12-kanalni elektroencefalograf, prvi u srednjoj i istočnoj Europi. Po dolasku na Elektrotehnički fakultet Sveučilišta u Zagrebu, 1972. godine osniva Laboratorij za biomedicinsku elektroniku i pokreće predavanja iz predmeta Biomedicinska elektronika, za koji je napisao i istoimeni udžbenik, te time postavlja temelje biomedicinskog inženjerstva u Hrvatskoj. Tehnološki napredak omogućio je da već sedamdesetih godina prošlog stoljeća dr. sc. Stanko Tonković, dipl. ing., zaposlenik Elektrotehničkog fakulteta u Zagrebu i dr. sc. Velimir Išgum, dipl. ing, zaposlenik Kliničkog bolničkog centra Zagreb obrađuju EEG signale na računalu PDP-8. Dr. sc. Išgum nastavlja svoju karijeru na Klinici za neurologiju KBC Zagreb gdje je tijekom svojeg radnog vijeka sudjelovao u osnivanju Laboratorija za evocirane potencijale te kasnije osnovao i Laboratorij za kognitivnu i eksperimentalnu neurofiziologiju. Nekoliko radova u ovom tematskom prilogu predstavljaju nastavak istraživanja koja su započeta u tim laboratorijima.

Pokretanje i razvoj ovakvog inter- i multi-disciplinarnog područja bilo bi neizvedivo bez podrške i aktivnog sudjelovanja liječnika. Ta izuzetno kvalitetna i plodna suradnja održala se i do današnjih dana, što je izravno vidljivo iz priloga koji slijede.

U ovom tematskom prilogu prikazana su neka od aktualnih istraživanja iz područja neurofiziologije u kojima se koristi mjerenje, obrada i analiza elektroencefalografskih signala. U prvom prilogu prikazano je nekoliko projekata sučelja mozga i računala, područja koje se vrlo aktivno istražuje. Slijedi prilog o invazivnom EEG monitoriranju s primjenom u kirurškom liječenju pacijenata s farmakorezistentnom epilepsijom. U trećem prilogu opisano je korištenje metode evociranih potencijala u dijagnostici multiple skleroze. U četvrtom članku opisana je primjena i dijagnostička vrijednost vibracijskih evociranih potencijala, dok se peti članak bavi slušnim evociranim potencijalima s naglaskom na korištene podražaje i paradigme.

Gostujući urednik
Mario Cifrek, Sveučilište u Zagrebu, Fakultet elektrotehnike i računarstva, Zagreb

Fig. 14 – Bulletin of the Croatian Academy of Engineering in Croatian “Tehničke znanosti” Vol. 21(1) 2017

ISSN 1331-7210

1993 – 2018

Engineering Power

BULLETIN OF THE CROATIAN ACADEMY OF ENGINEERING Vol. 13(1) 2018

Euro-CASE CAETS

EDITOR-IN-CHIEF'S WORD

Dear Readers,

Being true to our promise, we proudly present you another new issue of our Academy's Bulletin in English – ***„Engineering Power"*** Vol. 13(1) 2018. Guest-Editor of this issue is Igor Karšaj, a successful young scientist and expert, Associate of the Academy in the Department of Mechanical Engineering and Naval Architecture.

The Croatian Academy of Engineering especially encourages its younger members, immediately after their admission to membership of the Academy, to participate in all Academy's activities in which they may excel themselves and present their scientific and expert knowledge and skills. In this way, the Academy further stimulates their domestic and international renown through the presentation of their projects and achievements and grants them access to new opportunities for co-operation with distinguished international associations of engineering academies.

Editor-in-Chief
Vladimir Andročec, President of the Croatian Academy of Engineering

EDITOR'S WORD

In the second subsequent issue of "Engineering Power", presenting a part of multidisciplinary research activities at the University of Zagreb, based on synthesizing of technological and biotechnological sciences, the Academy continues with its introduction of the research teams at the Faculty of Mechanical Engineering and Naval Architecture of Zagreb. The Guest-Editor of this issue is Igor Karšaj, PhD, Associate Professor at the Faculty of Mechanical Engineering and Naval Architecture and Associate Member of the Croatian Academy of Engineering in the Department of Mechanical Engineering and Naval Architecture.

Editor
Zdravko Terze, Vice-President of the Croatian Academy of Engineering

FOREWORD

This issue is dedicated to the scientific work in the field of biomechanical engineering in the Laboratory for Numerical Mechanics at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. Our work concerns modeling of soft tissue behavior, particularly abdominal aortic aneurysms (AAAs) development.

We addressed the problem of intraluminal thrombus enlargement within abdominal aortic aneurysm. Our main goal was to develop a theoretical and computational biochemomechanical model of evolving properties of ILT incorporated into an initially healthy artery. We showed that thrombus-laden lesions can either arrest or rupture depending on the biochemical (e.g., concentration of elastases) and biomechanical (stiffness of fibrin) properties of the ILT. These computational results suggest that ILT should be accounted for when predicting a potential enlargement or rupture risk of AAAs and highlight some specific needs for further experimental and computational research. The scientific work within our group concerned the very first growth and remodeling model that addresses together the mechanobiology, biochemistry, and biomechanics of thrombus-laden AAAs.

The herein presented results are the result of fruitful cooperation with Jay D Humphrey's group from Yale University, USA, Gerhard Holzapfel's group from TU Graz, Austria, Seungik Baek from Michigan State University, USA and Ivo Lovričević, Medical School, University of Zagreb. The scientific work in our group was supported by grants from the Croatian Science Foundation project IP-2014-09-7382 and Installation Grant to I. Karšaj.

Guest-Editor
Igor Karšaj, University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture

Fig. 15 – Bulletin of the Croatian Academy of Engineering in English "Engineering Power" Vol. 13 (1) 2018

Fig. 16 – Monograph of Prof. Gojko Nikolić, Ph.D. titled "Life and Inventions of Faust Vrančić" (1st edition, Zagreb, 2015)

Fig. 17 – Monograph of Prof. Gojko Nikolić, Ph.D. titled "Life and Inventions of Faust Vrančić" (Second extended edition, Zagreb, 2016)

Fig. 18 – Monograph of Prof. Gojko Nikolić, Ph.D. titled "Life and Inventions of Faust Vrančić" (Third extended and supplemented edition, Zagreb, 2018)

Fig. 19 – Signing of the Contract for the publication of the 3rd extended and supplemented edition of the Monograph of Prof. Gojko Nikolic, Ph.D. 'Life and Inventions of Faust Vrančić ' (HATZ, February 2018) Sitting from left to right Ivan Šutalo, B.Sc. , Director of the Public Open University of Zagreb, Prof. Gojko Nikolić, Ph.D., monograph author, Prof. Nediljka Gaurina-Međimurec, Secretary-General of the Croatian Academy of Engineering and Prof. Vladimir Andročec, Ph.D., President of the Croatian Academy of Engineering

Awards and Recognitions of the Academy 2013-2018

At annual assemblies of the Academy in the period from 2013 to 2018, a total of 5 Lifetime Achievement Awards 'The Power of Knowledge', 8 Rikard Podhorsky Annual Awards, 5 Vera Johanides awards for young scientists from the economy and 23 Vera Johanides awards for prominent young scientists from the science system were granted.

Programme Guidelines of the New Governing Board of the Croatian Academy of Engineering 2017-2021

Based on the results achieved so far, the new, partially renewed Governing Board of the Academy (consisting of Prof. **Vladimir Andročec**, Ph.D., President of the

Fig. 20 – 31st Annual Assembly of the Croatian Academy of Engineering (11 May 2016)

Fig. 21 – Prof. Emer. Zlakto Kniewald, Ph.D., receives Lifetime Achievement Award "The Power of Knowledge" for 2015 at the 31st Annual Assembly of the Croatian Academy of Engineering (11 May 2016)

Fig. 22 – Prof. Emer. Đurđa Vasić-Rački, Ph.D., receives Lifetime Achievement Award "The Power of Knowledge" for 2016 at the 32nd Annual Assembly of the Croatian Academy of Engineering (15 May 2017)

Academy, Prof. **Zdravko Terze**, Ph.D., Vice-President, Prof. **Dubravko Rogale**, Ph.D., Vice-President, Prof. **Nediljka Gaurina-Međimurec**, Ph.D., Secretary-General, Prof. **Slavko Krajcar**, Ph.D., 5th member) wishes to go on with its work continuing the good results achieved and the activities that have been initiated, and in this regard it has prepared an ambitious program for the new mandate period.

At the present moment of a long-term general crisis in Croatia, the previous and future tasks are extremely challenging and difficult to achieve without recognizing the importance of the Croatian Academy of Engineering by Government Institutions and economy, and which will be possible to achieve only based on the actual achievements of all members of the Academy and their engagement in the Management Bodies of the Academy and the Croatian public and the synchronizing activities of Governing Board, Presidency, Departments, Centers, Committees and Scientific Council of the Academy.

The previous Governing Board undertook a series of activities making it possible to significantly raise the level of membership activities and by applying several new elements of membership mobilization it plans to increase the overall membership mobilization. The advantages are evident in the following:

- An increased amount of useful information that is sent by email to the membership of the Academy, and this practice will be continued in view of the positive feedback of the membership
- By means of the renewed web pages of the Academy more information is transmitted to members to which they can usefully react, and this will only be expanded by constantly improving the content on web pages,
- Regular publications of Annuals and HATZ Bulletins Engineering Power / Tehničke znanosti makes it possible that the members get their papers published. The Governing Board intends to publish a series of thematic issues which will be edited by members of individual Departments. This will additionally encourage the members to publicist activities.
- In order to increase the financial discipline of the payment of personal membership fees in this mandate, we deleted from the membership list twenty members who did not pay the membership fee for three or more years. It was proposed that members who did not pay membership fees for more than one year are deleted from the membership list and make room for active members who express their responsibility of belonging to the Academy.
- Using the normative limitation of the number of functions and the number of mandates in the Academy will provide wider opportunities for members in all Academy bodies so that a larger number of members interested in working in the Academy could achieve such opportunities.

In the next mandate the Governing Board shall:

- with utmost care monitor the work of individual departments and their obligation to organize conferences, and this activity will increase the mobilization of membership for work in the Academy, the Department and individual professions
- organize the Open Door Day of the Department when the Department will be able to present its professional and scientific activities and achievements. This way the members of the other Departments, who are interested in multidisciplinary activities, can familiarized themselves with the potentials of others,
- pay special attention to activities of our members during the status advancement and on occasions of granting Academy awards, which was prompted by this Governing Board by amending normative acts and by evaluating the contributions of the membership,
- organize the presentation of distinguished scientists of individual Departments where they will present their science work , laboratory and instrumentation potential and achievements by discussing possible forms of cooperation with other members of the Academy,
- motivate the members that the establishment and the work of the Centers can help them in achieving their professional and scientific activities, organization of symposia and the like using the infrastructure of the Academy,
- encourage calls for proposals and implementation of domestic and European projects through the Academy for interested members of the Academy.

In addition to engaging in the SAPEA project, in the next mandate the Governing Board of the Academy will directly encourage members to apply for projects funded by the EU Research Funds. In this context – in cooperation with other relevant institutions such as Agency for Mobility, Croatian Academy of Sciences and Arts, Croatian Chamber of Economy and the like institutions – and it will support the organization of information workshops of individual EU programs and inform members about the details of their performance. By networking all the participants in the process the absorption of EU funds will be improved, and accompanying activities within the work of the Academy – such as timely finding suitable partners for a particular project idea – will provide additional support for project teams, especially in multidisciplinary research. Also, with contacts within relevant international organizations attempts will be made to influence the formation of future research lines that will be funded by EU programs in the coming period, which could be in line with the priorities of the Croatian research community. Likewise, linking local research institutions to local authorities in order to successfully implement new technologies in everyday social practice (e.g. development of earthquake protection programmes and other disaster protection programmes, use of satellite images for civilian purposes, development of related software support, improvement of traffic connections, security and signaling, etc.) will be stimulated.

International Cooperation of the Croatian Academy of Engineering in the Period 1997-2018

Terze[1], Z., Kniewald[2†], J., Medved[3], V.

[1]Vice-President of the Academy
[2]Past-Chair of the Committee for International Cooperation (1997-2009)
[3]Past-Chair of the Committee for International Cooperation (2009-2013)

Croatian Academy of Engineering was established in 1993, immediately after the constitution of the Republic of Croatia. The main objective of the establishment was promotion of the engineering (including biotechnical) sciences through the organized activity of their members by advancing engineering 'best-practice' for the benefit of economy and technological development of the Republic of Croatia. To this end, the Academy was not established in order to develop a competitive spirit with the existing academies (Croatian Academy of Sciences and Arts, Academy of Medical Sciences of Croatia), but in order to collaborate with them (as well as with the industrial subjects) to support a scientific and technological advancement immediately after the defensive war. In this context, one of the first activities of the Croatian Academy of Engineering was to establish a strong international cooperation which could serve as a platform for promotion of the excellence of the Croatian academic and industrial institutions, allowing for the exchange of the ideas and 'know-how' engineering procedures.

Although Croatian Academy of Engineering celebrates today its twenty five year anniversary, and political circumstances and sociological framework in Republic of Croatia have changed a lot since 1993, an advancement of the international cooperation in science and engineering is still one of the main activities of the Academy. In this context, Croatian Academy of Engineering organized a number of scientific events and conferences, often in collaboration with other Croatian academies, universities and industrial subjects. For example, four international conferences on biotechnology were held in Zagreb from 2000 to 2005 (follow-up publications "Current Studies in Biotechnology" Vol. I-IV were published accordingly, Editor Prof. Zlatko Kniewald, Ph.D., member of the Croatian Academy of Engineering),

Fig. 1 – ‘ECCOMAS - Multibody Dynamics 2013’. Welcome Reception at the National University Library in Zagreb. Croatian Academy of Engineering was supporting institution of the Conference, together with the renowned international scientific associations such as IUTAM, ASME and ECCOMAS. The conference was held under auspicies of Croatian Academy of Sciences and Arts.

and those conferences were organized in collaboration with Academy of Medical Sciences of Croatia, Scientific Council for Agriculture and Forestry of the Croatian Academy of Sciences and Arts, Croatian Society for Biotechnology, Faculty of Food Technology and Biotechnology, and Pliva Inc.

Also, Croatian Academy of Engineering was a supporting institution of the number of distinguished scientific conferences, such as “ECCOMAS - Multibody Dynamics 2013”, (ECCOMAS - European Community on Computational Methods in Applied Sciences) which was held in Zagreb in 2013 (two years after Brussels in 2011, and two years before Barcelona 2015). It was organized under the auspices of the Croatian Academy of Sciences and Arts and sponsored by two Croatian companies (e.g. Končar and AVL), but also by the most prominent world organizations in the field of mechanical engineering, and computational and applied mechanics (ASME, IUTAM, ECCOMAS, IFToMM etc). Selected expanded papers of the Conference “ECCOMAS - Multibody Dynamics 2013” were published in a book by the international publisher Springer in the year 2014. The editor of the book is a member of the Croatian Academy of Engineering Prof. Zdravko Terze, Ph.D., and - according to the publisher’s sales statistics - the book ranked among the top 25% most succesful scientific editions in the pertinent category in the years to follow.

Fig. 2 – 'ECCOMAS - Multibody Dynamics 2013'. Working part of the Conference at the Faculty of Mechanical Engineering and Naval Architecture, Zagreb (session chairman Prof. Dr. Ing. Friedrich Pfeiffer, Emeritus of Excellence TU Munich).

Before we proceed with a report of the activities of the Academy, we would like to mention that, in order to fulfill their social mission, the Academies of engineering sciences (or similar associations of engineers/scientists) are established all over the world. The Royal Swedish Academy of Engineering Sciences (IVA) was established in 1919, being the first academy in the field of engineering sciences. Many other countries followed the example of Sweden. Considering the globalization of markets, intense international exchange of scientists and fast development, but also even faster obsolescence of technologies and specific technological solutions, the first joint meeting of the established academies (1st Convocation) - which in various forms was finally established as CAETS (International Council of Academies of Engineering and Technological Sciences. Inc.) - was held in 1985. The founders of CAETS were the Academies of USA, UK, Sweden, Australia and Mexico. CAETS was founded as a non-profit organization with the permanent seat in the National Academy of Engineering (NAE) in Washington, DC. Until 1999 CAETS received another 17 member states.

In the context of Croatian Academy of Engineering, becoming a member of CAETS was a long process which is preceded by preparation of the official documents, and invitation to a CAETS delegation to visit the Croatian Academy of Engineering. Furthermore, it was necessary to address all related issues, then a report was sent to all CAETS members who finally made a decision by voting. In late March of

2000 President of CAETS Prof. Michel Lavalou and Secretary-General William Salmon visited the Croatian Academy of Engineering in order to get acquainted with the activities of the Academy. In October 2000, Croatian Academy of Engineering was admitted to full membership of CAETS together with Korea, Slovenia, and Uruguay at the October meeting of CAETS in Beijing. Afterwards, in 2005 Germany was admitted, and South Africa was admitted in 2009. The membership of the Croatian Academy of Engineering in CAETS was one of the most important obligations because CAETS was either sponsor or co-organizer of a number of activities in Croatia since the establishment of the Croatian Academy of Engineering. This contributed to international recognition not only of the Academy, but also of the Republic of Croatia worldwide.

It should be noted that the President of the Croatian Academy of Engineering, Prof. Juraj Božičević, Ph.D., initiated and contributed significantly to the beginning of international affirmation of the Academy. Thus, after constituting individual Departments of the Academy, the individual Committees with the specific fields of activities were established. It must be remembered that the establishment of the Academy and its first international appearance on the international scene happened at a time when Croatia fought its own battle for the integrity of the territory and the gradual approach to European integrations (EU) and the achievement of international security by joining NATO. Although the first official request of the Academy for accession to the Euro-CASE (The European Council of Applied Sciences and Engineering) was rejected because the members of the Euro-CASE were restricted to the EU member states only, in the year 2003 new contacts were established with the Euro-CASE association. As a result, the associate membership of Croatian Academy of Engineering was established in 2005 whereby the Academy participated in the activities, but without voting rights in enforcing decisions. However, the delegation of the Academy took active part in the sessions of CAETS and Euro-CASE which significantly contributed to the decision of Euro-CASE to propose its members to admit the Croatian Academy of Engineering to full membership by way of exception. This means that the Academy was one of the first institutions of Croatia that was admitted to full membership of an association in which there are only EU members, namely before the full EU membership.

In addition to the execution of programs within the assumed obligations of CAETS and Euro-CASE, the Croatian Academy of Engineering contributed to the affirmation of Croatia at home and abroad by disseminating information on its activities at the international conferences and by using different media (such as www and Academy annuals, the bilingual bulletin Engineering Power/Tehničke znanosti). Also, the activities of all members of the Academy should be specially emphasized in this context since these activities within the framework of their professional contacts were very important in this kind of affirmation (especially considering high scientific and professional standards that are required to achieve status ‘member of Croatian Academy of Engineering’).

It is clear that all the above activities and objectives were possible only in organized form and with above-average engagement of individual members exclusively on a voluntary basis. Therefore, we should start from the very beginning and establishment of the first Committee for International Cooperation (later renamed to Committee for Academic International Cooperation) which was established at the session of the Presidency of the Academy on 2 July, 1997, composed of Chair Prof. Jasna Kniewald, Ph.D., and the members Prof. Ivan Ilić, Ph.D., and Prof Mate Sršen, Ph.D. Despite the fact that the organization scheme of the Committee was correctly developed and conceived, non-optimal conditions and lack of the fixed premises of the Academy made the work of the majority of the Committee members very difficult. The President of the Academy Prof. Juraj Božičević, Ph.D., proposed, and the Presidency adopted and elected the Chairs of the Committees on 10 July, 2001. In addition to the Committee for International Academic Cooperation, the Committee for Cooperation with Scientists in the World was established and chaired by Prof. Ivan Ilić, Ph.D., and consisting of the members: Prof. Tomislav Mlinarić, Ph.D., Prof. Juraj Bartolić, Ph.D., Prof. Damir Kalpić, Ph.D., and Assistant Prof. Nenad Debrecin, Ph.D. These committees were acting according to their programs to the next election meeting of the Academy in 2003 when new leadership of the Academy was elected (President Prof. Zlatko Kniewald, Ph.D.). In the mandate period from 2003-2005 the Committee for International Cooperation consisted of Chair Prof. Jasna Kniewald, Ph.D, and members: Prof. Božidar Biondić, Ph.D., Prof. Juraj Božičević, Ph.D., Prof. Ivan Ilić, Ph.D., Prof. Stanko Tonković, Ph.D., and Prof. Vilko Žiljak, Ph.D., and the constituting session was held on 25 September, 2003.

The second session of the Committee for International Academic Cooperation was held on 21 October 2003, together with the Committee for Cooperation with Scientists in the World, and it was agreed on joint activities in the next period. At this session proposals of involving our scientists in some current projects of CAETS were accepted: Prof. S. Tonković, Ph.D., and Prof. V. Medved, Ph.D.: “Bioengineering in Sports Medicine” and “Intelligent Rehabilitation Systems” - platform “Biomedical” holder RAEng (Great Britain); Prof. S. Pegan, Ph.D., proposed the project under the title of “Transnational and Intra-National Changes in Regional Planning” - platform “Sustainable Development” holder ATV (Denmark); Prof. I. Ilić, Ph.D., proposed the project under the title “Ecomobil - Vehicle for the Future” platform “Energy/Environment”, holders IVA (Sweden), NTVA (Norway) and FACTE (Finland). At this meeting it was also approved that the Croatian Academy of Engineering takes part in the implementation of the platform “Education” whose holder was NAE (USA), and the Academy accepted it and created the platform “Agriculture and its Environment” (manager of the working group Prof. Z.

Kniewald, Ph.D.) for the CAETS project “Future Engineering Challenges”. The mandate of the members of the Committee was the same as the mandate of the members of the Presidency and lasted two years. At the Assembly held in 2005 it was adopted that the mandate lasts four years; this was the reason that the mandate of the chairpersons of the Committees and that of the secretaries of the Departments was also changed to a four year period. In the mandate period 2005-2009 the Committee for International Cooperation consisted of Chair Prof. Jasna Kniewald, Ph.D, and members Prof. Zvonimir Janović, Ph.D., Prof. Srećko Pegan, Ph.D., Prof. Stanko Tonkovć, Ph.D., and Prof. Vilko Žiljak, Ph.D.

In 2009 Prof. Vladimir Medved, Ph.D., was elected to serve as a Chair of the Committee for International Cooperation, and the members of the Committee were Prof. Stanko Tonković, Ph.D., Prof. Vladimir Koroman, Ph.D., Prof. Bernard Frankovć, Ph.D., Prof. Jasna Franekić, Ph.D. and Prof. Mislav Grgić, Ph.D., who occupied their posts until 2013. Prof. Zdravko Terze, Ph.D., was elected to serve as a Chair of the Committee for International Cooperation in period 2013-2017. The members of the Committee in that mandate were: Prof. Ana Marija Grancarić, Ph.D., Prof. Biljana Kovačević Zelić, Ph.D., Prof. Bojan Jerbić, Ph.D., Prof. Karolj Skala, Ph.D., Prof. Mario Kovač, Ph.D., and Prof. Neven Duić, Ph.D. The most recent mandate started in 2017, with Prof. Nikola Čavlina, Ph.D., being elected as a Chair of the Committee, while the members of the Committee are Prof. Karolj Skala, Ph.D., Prof. Vladimir Mrša, Ph.D., Prof. emer. Dubravka Bjegović, Ph.D., Prof. Bruno Zelić, Ph.D., Prof. Biljana Kovačević-Zelić, Ph.D. and Prof. emer. Ana Marija Grancarić, Ph.D.

Although parts of international activities are also presented in other chapters of this book, there are several activities that have to be emphasized. First, it should be mentioned that cooperation with the Austrian Academy of Sciences was established due to the special efforts of our honorary member Prof. Kurt Richter, Ph.D.

Prof. Richter made his great contribution in 2006 when the Academy was entrusted to mark the 150th anniversary of the birth of Nikola Tesla according to the decision of the Croatian Parliament. Furthermore, thanks to Prof. K. Richter a meeting was organized in Vienna with the President of the Austrian Academy of Sciences Prof. Herbert Mang, Ph.D., who was then invited by the Croatian Academy of Engineering to pay a visit to Zagreb where he held a lecture at the University of Zagreb, and in 2009 a cooperation agreement was signed with the Austrian Academy of Sciences.

As a participant in the implementation of the project on the education of engineers, Croatian Academy of Engineering organized a roundtable in Cairns, Australia, at CAETS Convocation. We also participated with a thematic lecture at the World

Fig. 3 – Prof. K. Richter, Ph.D. receives acknowledgement as honorary member of Croatian Academy of Engineering, Zagreb, 2008. Professor Kurt Richter made his great contribution in supporting cooperation between Croatian Academy of Engineering and Austrian Academy of Sciences.

Congress “World Education of Engineers” in Budapest when, based on our notification of the abolition of the title engineer in Croatia, an official support was given to start the recovery of the title engineer in the higher education system of the Republic of Croatia, which was successful. This text should also mention the contribution of more than 20 members of the Academy who in cooperation with the State Intellectual Property Office worked on the translation of the sixth edition of the International Patent Classification from English to Croatian from 1996-1998.

This way Croatia ranks among only a few countries that have their own classification in their own language. This was also the moment when a new Croatian terminology in the field of engineering and biotechnical sciences was created in order to encourage innovations and to protect intellectual property which is one of the missions of the Croatian Academy of Engineering.

Fig. 4 – Participants of the CAETS meeting in Tokyo in 2007, during the visit to JAMSTEC technology centre.

Fig. 5 – Signing Memorandum of Agreement on Cooperation with the Chinese Academy of Engineering, Beijing, 2004.

The international cooperation of the Academy resulted in the first funds for the Fund for Awards donated at 2005 by Prof. Emeritus Branko Ladany, honorary member of Croatian Academy of Engineering, member of the Canadian Academy of Engineering (CAE) and the Croatian Academy of America, New York, USA. The Croatian Academy of Engineering took also on its social task by starting capital infrastructure projects for the Republic of Croatia. For example, a member of the Academy, Prof. Karolj Skala, Ph.D., from Institute Ruđer Bošković initiated the establishment of CRO GRID project on which 11 institutions and 54 researchers took part and which formed the basis for building the national e-Infrastucture in 2002. These activities integrated Croatia into European Grid Infrastructure. Prof. Juraj Božičević, Ph.D., President of the Croatian Academy of Engineering, played an important role during implementation of this project.

In the period of this report, four international cooperation agreements were signed: Memorandum of Agreement on Cooperation with the Chinese Academy of Engineering (2004) (with the Chinese Academy of Engineering an additional document "CAE-HATZ Memorandum of Understanding" was signed in 2013 after the visit of the CAE delegation to the Croatian Academy of Engineering in December 2012), Memorandum of Agreement on Cooperation with the Hungarian Academy of Engineering (2006), Memorandum of Agreement on Cooperation with the Austrian Academy of Sciences (2009), and Memorandum of Agreement on Cooperation with the Slovenian Academy of Engineering (2017).

Fig. 6 – Signing Memorandum of Agreement on Cooperation with the Hungarian Academy of Engineering, Zagreb, 2006.

Fig. 7 – Signing Memorandum of Agreement on Cooperation with the Slovenian Academy of Engineering (2017), Ljubljana, 2017.

Bilateral cooperation with these and other academies has been continuing to the present day and Croatian Academy of Engineering permanently supports scientific collaboration with international academic institutions. Along this line, Prof. Xilun Ding, Ph.D. (currently Dean of the School of Mechanical Engineering and Automation) and his collaborators from renown Beijing University for Aeronautics and Aerospace (BEIHANG University), China - during his visit to University of Zagreb, Faculty of Mech. Eng. & Naval Arch, Chair of Flight Vehicle Dynamics – visited Croatian Academy of Engineering as well as Croatian Academy for Sciences and Arts (2017).

Such international collaboration is furtherly promoted by active participation of the Academy members in the events organised by CAETS and Euro-CASE. For example, Academy members Prof. Karolj Skala, Ph.D., and Prof. Bernard Franković, Ph.D., participated in the CAETS annual meeting and symposium “Innovative Approaches to Engineering Education”, held in Budapest in 2013. Prof. Bernard Franković, Ph.D., was present as a representative of the Croatian Academy of Engineering in CAETS Board of Directors, while at the symposium ‘Innovative Approaches to Engineering Education’ Prof. Karol Skala, Ph.D., presented FP7 project “Embedded Computer Engineering Learning Platform-E2LP”, which was developed by Institute Ruđer Bošković and Faculty of Electrical Engineering and Computing from Zagreb, in cooperation with seven other EU institutions.

In more recent times Prof. Vladimir Andročec, Ph.D., President of the Academy, and Prof. Zdravko Terze, Ph.D., Vice-President of the Academy, participated in Euro-CASE Board Meetings in Den Haag/Delft, Netherlands (2015) and in Lyngby, Denmark (2016). Also, in 2017 Prof. Vladimir Andročec, Ph.D., and Prof. Zdravko Terze, Ph.D. attended CAETS 2017 Convocation at Real Academia de Ingeniería (RAI), Madrid, Spain, and visited University of Seville, where they had official meeting on the collaboration issues with Dean of the Faculty of Engineering Prof. Jaime Domínguez, Ph.D. (Member of RAI), and Prof. Zdravko Terze, Ph.D., delivered invited lecture 'Geometric Integration of Rotational Quaternions' for scientists and doctoral students of the Faculty.

In order to assist an effective exchange of information between different subjects and engineering/research sectors, as well as domestic and foreign entities, the Academy continuously supports conferences and scientific events, promoting excellence and engineering 'best-practice' orientation. To this end, US National Academy of Engineering and Euro-CASE have together, for the first time, organized a workshop entitled: "EU-US Frontiers of Engineering Workshop 2010", in Cambridge, UK (August 31. - September 03.2010). Purpose of the workshop was to assemble at one place leading engineers of younger generation by both partners in order to discuss, intensively and in multidisciplinary manner, key modern engineering problems. Workshop had four sub-themes: Bio-inspired Engineering, Materials Ecology, Augmented Reality and Signal Processing. The organizing commitee consisted of four pairs (EU and US) of co-chairs, one for each of the sub-themes, with

Fig. 8 - Prof. Xilun Ding, Ph.D., Beijing University for Aeronautics and Aerospace (BEIHANG University, China), and his collaborators, during their visit to University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, and Prof. Zdravko Terze, Ph.D., Head of the Faculty Chair of Vehicle Dynamics and Vice-President of the Croatian Academy of Engineering (2017).

Fig. 9 – Professor Mislav Grgić giving a presentation at the „EU-US Frontiers of Engineering Workshop 2010“ in Cambridge, UK. Prof. Mislav Grgić, Ph.D. in that time associate member of the Croatian Academy of Engineering in the Department for Communication Systems, served as a member of organizing committee of the workshop.

common leading chairs Professor Sergio Verdu, Princeton University, and Professor Richard Williams, University of Leeds.

Academy was invited to propose candidates which could serve as co-chairs for particular sections, and we have among our members selected and nominated Professor Mislav Grgić, at that time Associate of the Academy in the Department of Communication Systems, and member of the Commitee for International Cooperation. Among other conditions, such as excellence in research and significant track record, etc., Professor Grgić also fulfilled the „under the fourty“-age condition. Professor Grgić was elected on behalf of the organizer as european co-chair for the section „Signal Processing“. His American partner was Richard Baraniuk, Victor E. Cameron Professor, Department of Electrical and Computer Engineering, Rice University. Remaining co-chairs selected included experts from premier world engineering academic institutions such as M.I.T., Johns Hopkins University, University of Califirnia-Berkeley, Stanford, Delft University, Royal Institute of Technology, Sweden, ETH, Zürich, to name just the most prominent ones. The established network of young engineering experts and leaders bears a great potential value for development of both academic and industrial colaboration worldwide.

In the present days, the Academy also continuously informs its members on the activities related to the application of scientific and development projects within the framework of EU research programs, such as Horizon 2020 and other pro-

Fig. 10 – Lecture 'Discovery and Measurement of Characteristics of Higgs boson', Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb (2018) (organised by Croatian Academy of Engineering, Scientific Council of the Academy).

grams. Furthermore, members and representatives of the Academy organize and participate regularly in the workshops, national conferences and information days in the promotion of the international activities. This practice encourages the cooperation of individual institutions in Croatia and abroad and creates a network framework for the flow of information and research ideas, especially when lecturers and participants are renown international scientists such as Prof. Aleksandar V. Efremov, Ph.D. (Moscow Aviation Institute), who delivered a lecture „Progress in Pilot Vehicle System Approach to Solution of Flight Safety and Manual Control Problems“ (2014)), Tin Komljenović, Ph.D. (University of California, Santa Barbara, US), who delivered a lecture "Integrated Photonics for LIDAR and Communications' (2017), organised by the Croatian Academy of Engineering, Department for Communication Systems, and Prof. Ivica Puljak, Ph.D. (The European Organization for Nuclear Research (CERN), University of Split) who delivered a lecture 'Discovery and Measurement of Characteristics of Higgs boson' (2018), organised by the Croatian Academy of Engineering, Scientific Council of the Academy.

In this context, the Academy also organizes workshops and symposia in order to support further development of the traditional engineering fields within newly established international collaborations, but also with the aim of promoting new technologies and industrial challenges of the future. These activities should allow for better incorporation of Croatian engineers and scientists into competitive EU research ambient of the highly-advanced engineering fields, such as nanotechnology, artificial inteligence, and space technologies. Speaking of space, Croatian Academy

Fig. 11 – Roundtable 'Cyber Physical Systems and Internet of Things', organised by the Committee for Economic and Regional Cooperation, Croatian Academy of Engineering, in collaboration with Croatian Chamber of Economy and Innovation Centre Nikola Tesla, 2018.

of Engineering organized successful international event "Horizon 2020 Space Workshop" in Zagreb (2014), where - for the first time in Croatia - space technologies and field potential for Croatian companies have been discussed, anticipating thus signing of the agreement of cooperation between Republic of Croatia and European Space Agency in February 2018. Recently, successful roundtable 'Cyber Physical Systems and Internet of Things' has been organised by the Committee for Economic and Regional Cooperation, Croatian Academy of Engineering, in collaboration with Croatian Chamber of Economy and Innovation Centre Nikola Tesla, 2018.

As it was in the past, representatives of the Academy participate in number of activities organized by our international partners. For example, Prof. Vladimir Andročec, Ph.D., President of the Academy, participated in the meeting of representatives of the Academies members of Euro-CASE with representative of the European Commission in Brussels within the seminar "Independent Science-and Technology-Based Policy Advice from Euro-CASE" (2013). Also, reports on the activities of the Croatian Academy of Engineering are being published regularly in Euro-CASE Annual Reports over the recent years, our publications 'Engineering Power' and 'Annual Report' are being distributed to our collaborators on the permanent basis, and Academy participates in other international activities, such as

Fig. 12 – 'Horizon 2020 - Space Workshop'. Opening of the workshop at the Faculty of Mechanical Engineering and Naval Architecture, Zagreb, June 2014. The event was organized by the Croatian Academy of Engineering in collaboration with Institute Ruđer Bošković and the Agency for Mobility and EU Programmes, Croatia.

voting a member of the CAETS Board of Directors for the period 2014-2016. As a member of Euro-CASE, Croatian Academy of Engineering actively participates in the EU Horizon 2020 project SAPEA ("Science Advice for Policy by European Academies") that has been officialy launched in Brussels on December 13 2016. The overall objective of the project is to pull together timely, independent and evidence-based scientific expertise from more than 100 European academies from over 40 countries for the highest policy level in Europe and for the wider public. To this end, Croatian Academy of Engineering has nominated it's experts for different posts within the framework of the SAPEA project activities.

2018 – Celebrating 25 Years of Progress of the Croatian Academy of Engineering

Krajcar, S.

Member of the Governing Board of the Croatian Academy of Engineering

Croatian Academy of Engineering was founded 25 years ago. Twenty-five years have passed since the idea of a group of scientists in engineering with the idea of a strong promotion, but also a better evaluation of engineering at all levels in our society. Today when thinking of it, we conclude that our predecessors were, we acknowledge them, clairvoyant and in some way 'ahead of time'. At that time it was necessary to explain why the Academy was necessary and what purpose it would serve, and it was not easy. Today, too, we believe and thanks to the Academy, the acronym STEM has become, in a way, the Croatian word and a part of Croatian everyday life. We will dedicate this anniversary to this acronym in an appropriate manner.

I believe that most of you know what HATZ means and what its mission is, but it may be worth repeating it in a few words. The Academy is a central engineering institution in the Republic of Croatia with the task of being a creative and innovative multidisciplinary community of scientists of engineering professions; that it excellently and actively contributes to the development of technical sciences and the transfer of technical knowledge important for the prosperity and progress of the Croatian economy and the welfare of the people; that it endorses safe and beneficial use of technology, protection of the environment and the people from their inappropriate application; that it promotes professionalism and responsible behaviour with respect to high ethical standards; and that it promotes engineering in the society. This has been its commitment for a quarter of the century.

The Academy has been operating for 25 years in engineering, but also in the society as a whole. The Academy does not only recognize STEM, but lives in it. The Academy has competitiveness, but it is not competition. On the contrary, the Academy is a partner to all participants in the society. The Academy is a part of the European (Euro-CASE) and World (CAETS) family of academies and is proud of it. It is up to all of us, not just to the members of the Academy, to use the leverage for the development of our beloved homeland. We look forward to marking this year in a special way. We will use this year to mark the anniversary of the Academy with the general public to highlight the importance of engineering in our society. We live in a world of rhei pante, we live in a world where failure to act is an act that has the effect of falling behind. We live in a world of change with exponential characteristics. We live in a world where the saying of Jack Welsh: 'If the degree of changes in the environment is higher than your degree of changes, your end is near" plays an important role and should be handled with particular attention. We live in a world where changes, and even with the risk of error, are conditio sine qua non of our behaviour. Today, it is no longer up for discussion whether we should change or whether we should change it, but it is our duty to discuss how fast and in what way. The Latin proverb Periculum in mora (danger is in the delay) describes it well. Engineering changes. Engineering education must give answers to this challenge. The future of engineering is multidisciplinarity, two dimensions transform into three, the future of engineering ... 'it is a form of performing art.' And more.

In a way, the Academy recognizes it all and does it every day. In our society a characteristic feature for the academy is engineering, but also wider. True, it is worthy to admit that we have a good and high quality heritage and it is up to us all to continue it.

In a little while we will celebrate one hundred years of engineering studies in these regions (1919-2019). These are large numbers which please us greatly, but also put us under obligation. We want to emphasize this with various events in the celebration of this year.

So how are we going to mark the twenty-five years of existence? It is a simple answer. Working and somewhat self-sacrificing, as the engineers usually do. We will try to leave traces for the generations to come.

Within the frame of celebrating the 25th anniversary of the Academy the following activities are planned: Publication of the Annual of the Croatian Academy of Engineering (Academy today and tomorrow; selected scientific original papers of members of the Academy and 'who is who' in the Academy); Holding lectures and round tables aimed at the popularization of the Academy and its activities (according to the announcements it is planned to hold over 50 different professional events (workshops, round tables, meetings, conferences, etc.), either independent or together with other professional organizations; Publication of several issues of the Bulletin of the Academy Engineering Power; Raising the monument to Josip Božićević, President of our Academy, who through his engagement significantly contributed to its functioning; we will mark it also with more interviews and media talks on particular issues of public interest; we will also hold the regular annual conference in a ceremonial atmosphere in which, besides the admission to membership and promotion of individual members, academy awards will be awarded to members and non-members for the successes in their profession.

The Academy has a desire to strengthen cooperation with all participants in our society (based on the so-called Triple Helix model, i.e. government, economy and education cooperation) in order to critically exchange the latest findings from the world of engineering. Therefore, in this year of marking the 25th anniversary the Academy changes a part of its core documents because of the opening to others. The Academy introduces a new membership, the so-called entrepreneur member, meant for those experts in Croatia who have left a significant trace by transposing their knowledge, skills and innovativeness into industrial practice. In this way, we add another link to the chain of tasks of the Academy in its successful activities.

This year the Academy is also going to change its internet appearance (www.hatz.hr) with the desire for a better dissemination of information to the professional and other public. We want our portal to become a source of information with the idea of becoming an unavoidable Internet station for the professional and wider community.

The Academy has been and will remain a non-governmental, independent, non-party and non-profit association of competent, experienced and proven scientists of technical and biotechnical professions, but members who recognize their task more broadly than just professional activity.

Recognizing the achievements of the Academy to date, and we believe the power that the Academy has for the future, the Academy has received the high patronage of the President of the Republic of Croatia, Kolinda Grabar Kitarovic, for all the events within the framework of our anniversary, but also the patronage of the Mayor of the City of Zagreb, Milan Bandić, for the Festive Assembly of the Academy. Thank them.

Finally, we also need to have funds available for all of our activities. On this occasion, we would like to say “Thank you very much” to all the supporting members of the Academy without whom the Academy could not be what it is and could not achieve its goals. It is an impressive number of over seventy members, of whom the Academy is exceptionally proud, and we believe that the opposites is also true.

National Awards and Decorations of the Members of the Croatian Academy of Engineering from 1993 to 2017[1]

Strika, M.

With regard to the scientific, professional and innovative importance of their achievements, members of the Croatian Academy of Engineering received a number of prizes, awards and decorations, some of which are listed in this Annual and previously evaluated by the Editorial Board as the most important:

- National Awards for Scientific and Research Work “Nikola Tesla”,
- National Science Awards,
- Order of the Croatian Danica with the Effigy of Ruđer Bošković,
- Order of the Croatian Danica with the Effigy of Nikola Tesla,
- Award Fran Bošnjaković – University of Zagreb.

Members of the Croatian Academy of Engineering received a number of other major awards at home and abroad, but they are not listed in this Annual because of restrictions to the content. The list of these awards is available on the Academy’s website (www.hatz.hr) and in the section of members.

National Awards for Scientific and Research Work “Nikola Tesla” (1993)

- Solarić, Nikola, Prof. Emer. Ph.D. (1993)

National Science Awards (1996 – 2017)

- Jeren, Branko, Prof. Ph.D. (1996)
- Brnić, Josip, Prof. Ph.D. (1997)

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[1] This article is an updated and ammended version of the article of the same title, which was published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013“, on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

- Sućeska, Muhamed, Prof. Ph.D. (1997)
- Božičević, Josip, Academician Prof. Ph.D. (1998)
- Granić, Goran, Assist. Prof. Ph.D. (1998)
- Virag, Zdravko, Prof. Ph.D. (1998)
- Obad Šćitaroci, Mladen, Academician Prof. Ph.D. (1998)
- Muftić, Osman, Prof. Ph.D. (1999)
- Mrša, Zoran, Prof. Ph.D. (1999)
- Sorić, Jurica, Prof. Ph.D. (1999)
- Šantić, Ante, Prof. Ph.D. (2000)
- Franković, Bernard, Prof. Ph.D. (2000)
- Krakar, Zdravko, Prof. Ph.D. (2000)
- Božičević, Juraj, Prof. Ph.D. (2001)
- Sopta, Luka, Prof. Ph.D. (2001)
- Bašić, Tomislav, Prof. Ph.D. (2002)
- Sladoljev, Želimir, Prof. Ph.D. (2003)
- Lelas, Vesna, Prof. Ph.D. (2003)
- Zentner, Radovan, Prof. Ph.D. (2003)
- Haznadar, Zijad, Prof. Emer. Ph.D. (2004)
- Radić, Jure, Prof. Ph.D. (2004)
- Šantek, Božidar, Prof. Ph.D. (2004)
- Čorić, Većeslav, Prof. Ph.D. (2005)
- Katović, Drago, Prof. Emer. Ph.D. (2005)
- Vasić-Rački, Đurđa, Prof. Emer. Ph.D. (2005)
- Karšaj, Igor, Prof. Ph.D. (2005)
- Lovrić, Tomislav, Prof. Emer. Ph.D. (2006)
- Feretić, Danilo, Prof. Emer. Ph.D. (2007)
- Perić, Nedjeljko, Prof. Ph.D. (2007)
- Marić, Vladimir, Prof. Ph.D. (2007)
- Alfirević, Ivo, Prof. Emer. Ph.D. (2008)
- Tonković, Zdenko, Prof. Ph.D. (2008)
- Mandić, Milena, Prof. Ph.D. (2008), (2014)
- Marušić, Josip, Prof. Ph.D. (2009)
- Senjanović, Ivo, Academician Prof. Ph.D. (2009)
- Šušković, Jagoda, Prof. Ph.D. (2009)
- Kralik, Gordana, Prof. Emer. Ph.D., Dr.h.c. (2009), (2010), (2012)
- Pap, Klaudio, Prof. Ph.D. (2010)
- Šubarić, Drago, Prof. Ph.D. (2010), (2011), (2014)
- Žiljak, Vilko, Prof. Emer. Ph.D. (2010)
- Dragović Uzelac Verica, Prof. Ph.D. (2011), (2015)
- Hranueli, Daslav, Prof. Ph.D. (2011)
- Petrović, Ivan, Prof. Ph.D. (2011)
- Barbir, Frano, Prof. Ph.D. (2012)
- Ježek, Damir, Prof. Ph.D. (2012)

- Kelemen, Tomislav, Prof. Ph.D. (2013)
- Ožanić, Nevenka, Prof. Ph.D. (2013)
- Ćurković, Lidija, Prof. Ph.D. (2013)
- Lipovac, Nenad, Prof. Ph.D. (2014)
- Frece, Jadranka, Prof. Ph.D. (2014)
- Budin, Leo, Academician Prof. Emer. Ph.D. (2016)
- Duić, Neven, Prof. Ph.D. (2016)
- Skala, Karolj, Prof. Ph.D. (2016)
- Herceg, Zoran, Prof. Ph.D. (2016)

Award Fran Bošnjaković – University of Zagreb (1995-2017)

- Senjanović, Ivo, Academician Prof. Ph.D. (1995)
- Androić, Boris, Prof. Ph.D. (1996)
- Feretić, Danilo, Prof. Emer. Ph.D. (1996)
- Galović, Antun, Prof. Ph.D. (1999)
- Bogdan, Željko, Prof. Ph.D. (2001)
- Hraste, Marin, Academician Prof. Emer. Ph.D. (2001)
- Filetin, Tomislav, Prof. Emer. Ph.D. (2003)
- Haznadar, Zijad, Prof. Emer. Ph.D. (2003)
- Soljačić, Ivo, Prof. Emer. Ph.D. (2005)
- Gomzi, Zoran, Prof. Emer. Ph.D. (2006)
- Radić, Jure, Prof. Ph.D. (2006)
- Glasnović, Antun, Prof. Ph.D. (2007)
- Katović, Drago, Prof. Emer. Ph.D. (2007)
- Perić, Nedjeljko, Prof. Ph.D. (2009)
- Terze, Zdravko, Prof. Ph.D. (2010)
- Grancarić, Ana Marija, Prof. Emer. Ph.D. (2012)
- Pegan, Srečko, Prof. Ph.D. (2014)
- Kurajica, Stanislav, Prof. Ph.D. (2014)
- Ćurković, Lidija, Prof. Ph.D. (2015)
- Bogdan, Stjepan, Prof. Ph.D. (2015)
- Lončarić, Sven, Prof. Ph.D. (2016)
- Grgić, Mislav, Prof. Ph.D. (2017)
- Obad Šćitaroci, Mladen, Academician Prof. Ph.D. (2017)

Order of the Croatian Danica with the Effigy of Ruđer Bošković – for Science (1995-2017)

- Božičević, Josip, Academician Prof. Ph.D. (1995)
- Brnić, Josip, Prof. Ph.D. (1995)

- Ćosić, Krešimir, Prof. Ph.D. (1995)
- Lovrić, Tomislav, Prof. Emer. Ph.D. (1995)
- Radić, Jure, Prof. Ph.D. (1995)
- Andročec, Vladimir, Prof. Ph.D. (1996)
- Majdandžić, Niko, Prof. Ph.D. (1996)
- Tonković, Stanko, Prof. Emer. Ph.D. (1996)
- Katavić, Ivan, Prof. Ph.D. (1996)
- Mlinarić, Tomislav, Prof. Emer. Ph.D. (1996)
- Mrša, Zoran, Prof. Ph.D. (1996)
- Ružinski, Nikola, Prof. Ph.D. (1996)
- Sladoljev, Želimir, Prof. Ph.D. (1996)
- Soljačić, Ivo, Prof. Emer. Ph.D. (1996)
- Šantić, Ante, Prof. Ph.D. (1997)
- Hraste, Marin, Academician Prof. Emer. Ph.D. (1997)
- Rogale, Dubravko, Prof. Ph.D. (1997)
- Marović, Pavao, Prof. Ph.D. (1997)
- Đukan, Petar, Ph.D. (1997)
- Rožić, Nikola, Prof. Ph.D. (1997)
- Alfirević, Ivo, Prof. Emer. Ph.D. (1998)
- Auf-Franić, Hildegard, Prof. Ph.D. (1998)
- Feretić, Danilo, Prof. Emer. Ph.D. (1998)
- Krumes, Dragomir, Prof. Ph.D. (1998)
- Lelas (maiden name Hegedušić), Vesna, Prof. Ph.D. (1998)
- Ugrinović, Kosta, Prof. Ph.D. (1998)
- Kralik, Gordana, Prof. Emer. Ph.D., Dr.h.c. (2007)
- Milković, Mateo, Prof. Ph.D. (2007)
- Butković, Mirko, Prof. Ph.D. (2008)
- Kovač, Mario, Prof. Ph.D. (2008)
- Primorac, Dragan, Prof. Ph.D., MD (2015)
- Soljačić, Marin, Prof. Ph.D. (2017)

Order of the Croatian Danica with the Effigy of Nikola Tesla – for Invention and Innovation (1995 – 2017)

- Szavits-Nossan, Antun, Prof. Ph.D. (1997)
- Golubović, Adrijano, Prof. Emer. Ph.D. (1997)
- Radić, Jure, Prof. Ph.D. (1998)
- Kniewald, Zlatko, Prof. Emer. Ph.D. (2006)
- Markotić, Anto, Prof. Ph.D. (2011)
- Horvat, Đuro, BA Econ. (2011)
- Car, Stjepan, Prof. Ph.D. (2012)

Recipients of the Awards of the Croatian Academy of Engineering (2002-2017)[1]

Strika, M.

On the occasion of the 25th Anniversary of the Croatian Academy of Engineering we wish to present the winners of the Awards of the Croatian Academy of Engineering, which have been awarded annually since 2002 to the most distinguished scientist, scholars and to the young scientists and researchers for contributions to science and profession and the achievement of the objectives and programs of the Academy, as well as for the dedicated work that has contributed to the social recognition of the Academy.

The Awards of the Academy are:

- The Lifetime Achievement Award ***The Power of Knowledge*** (awarded since 2002),
- The Annual Award ***Rikard Podhorsky*** (awarded since 2004),
- The Award for Young Scientists ***Vera Johanides*** (awarded since 2002),
- The Award for Successful Young Scientists from the Economy ***Vera Johanides*** (awarded since 2012).

The Lifetime Achievement Award "The Power of Knowledge"

- Haznadar, Zijad, Prof. Emer. Ph.D. (2002)
- Frančula, Nedjeljko, Prof. Emer. Ph.D. (2003)
- Bošnjak, Marijan, Prof. Ph.D. (2004)
- Alfirević, Ivo, Prof. Ph.D. (2005)
- Janović, Zvonimir, Prof. Ph.D. (2006)
- Zovko-Cihlar, Branka, Prof. Ph.D. (2007)
- Božičević, Juraj, Prof. Ph.D. (2008)
- Ugarčić-Hardi, Žaneta, Prof. Ph.D. (2009)
- Franekić, Jasna, Prof. Ph.D. (2010)

[1] This article is an updated and ammended version of the article of the same title, which was published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013", on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

- Aničić, Dražen, Prof. Ph.D. (2011)
- Auf-Franić, Hildegard, Prof. Ph.D. (2012)
- *The 2013 Award was not granted because there had been no applicants*
- Soljačić, Ivo, Prof. Emer. Ph.D. (2014)
- Kniewald, Zlatko, Prof. Emer. Ph.D. (2015)
- Vasić-Rački, Đurđa, Prof. Emer. Ph.D. (2016)
- Perić, Nediljko, Prof. Ph.D. (2017)

The Annual Award "Rikard Podhorsky"

- Franekić-Čolić, Jasna, Prof. Ph.D. (2004)
- Nikolić, Gojko, Prof. Ph.D. (2004)
- Perić, Nedjeljko, Prof. Ph.D. (2004)
- Sever, Stanislav, Prof. Ph.D. (2004)
- Auf-Franić, Hildegard, Prof. Ph.D. (2005)
- Majdandžić, Niko, Prof. Ph.D. (2005)
- Radošević, Jagoda, Prof. Ph.D. (2005)
- Sorić, Zorislav, Prof. Ph.D. (2005)
- Grgić, Sonja, Prof. Ph.D. (2006)
- Šušković, Jagoda, Prof. Ph.D. (2006)
- Tomas, Srećko, Prof. Ph.D. (2006)
- Višković, Alfredo, Assist. Prof. Ph.D. (2006)
- Wolf, Hinko, Ph.D. (2006)
- Franković, Bernard, Prof. Ph.D. . (2007)
- Petrović, Ivan, Prof. Ph.D. (2007)
- Ujević, Darko, Prof. Ph.D. (2007)
- Zrnčević, Stanka, Prof. Ph.D. (2007)
- Bonefačić, Davor, Prof. Ph.D. (2008)
- Dragčević, Zvonko, Prof. Ph.D. (2008)
- Filetin, Tomislav, Prof. Ph.D. (2008)
- Medved-Rogina, Branka, Assoc. Prof. Ph.D. (2008)
- Mikulić, Dinko, Assist. Prof. Ph.D. (2008)
- Galović, Antun, Prof. Ph.D. (2009)
- Jurković, Sonja, Prof. Ph.D. (2009)
- Marušić, Josip, Prof. Ph.D. (2010)
- Pap, Klaudio, Assist. Prof. Ph.D. (2010)
- Salopek, Branko, Prof. Ph.D. (2010)
- Kurtanjek, Želimir, Prof. Ph.D. . (2011)
- Lelas, Vesna, Prof. Ph.D. (2011)
- Medved, Vladimir, Prof. Ph.D. (2011)
- Šubarić, Drago, Prof. Ph.D. (2012)
- Cifrek, Mario, Prof. Ph.D. (2013)
- Tonković, Zdenko, Assoc. Prof. Ph.D. (2013)

- Lončarić, Sven, Prof. Ph.D. (2014)
- Herceg, Zoran, Prof. Ph.D. (2014)
- Šantek, Božidar, Prof. Ph.D. (2014)
- Jerbić, Bojan, Prof. Ph.D. (2015)
- Ježek, Damir, Prof. Ph.D. (2015)
- Babić, Jurislav, Prof. Ph.D. (2016)

The Award for Young Scientists "Vera Johanides"

- Perl, Antonija, Ph.D. (2002)
- Gaurina Srček, Višnja, Ph.D. (2003)
- Velić, Darko, BSc (2003)
- Durgo, Ksenija, MSc (2004)
- Garašić, Ivica, BSc (2004)
- Grgić, Mislav, Ph.D. (2004)
- Jukić, Ante, Ph.D. (2004)
- Slačanac, Vedran, Ph.D. (2004)
- Budžaki, Sandra, MSc (2005)
- Halassy-Špoljar, Beata, Ph.D. (2005)
- Lacković, Igor, Ph.D. (2005)
- Pavlović, Hrvoje, MSc (2005)
- Trgo, Marina, Ph.D. (2005)
- Ambruš, Davorin, MSc (2006)
- Komes, Draženka, Assist. Prof. Ph.D. (2006)
- Pribanić, Tomislav, Assist. Prof. Ph.D. (2006)
- Suligoj, Tomislav, Assist. Prof. Ph.D. (2006)
- Zelić, Bruno, Prof. Ph.D. (2006)
- Babić, Jurislav, Assist. Prof. Ph.D. (2007)
- Baotić, Mato, Ph.D. (2007)
- Rezić, Iva, Ph.D. (2007)
- Tarbuk, Anita, MSc (2007)
- Vasić, Darko, MSc (2007)
- Čačić-Kenjerić, Daniela, Ph.D. (2008)
- Hursa, Anica, Ph.D. (2008)
- Krešić, Greta, Ph.D. (2008)
- Vašak, Mario, Ph.D. (2008)
- Vrsalović-Presečki, Ana, Ph.D. (2008)
- Bucić-Kojić, Ana, Ph.D. (2009)
- Findrik, Zvjezdana, Ph.D. (2009)
- Kopjar, Mirela, Ph.D. (2009)
- Otmačić Ćurković, Helena, Ph.D. (2009)
- Petošić, Antonio, Ph.D. (2009)
- Karšaj, Igor, Ph.D. (2010)

- Mužic, Marko, Ph.D. (2010)
- Molnar, Goran, Ph.D. (2010)
- Režek Jambrak, Anet, Ph.D. (2010)
- Jelavić, Mate, Ph.D. (2011)
- Dejanović, Igor, Ph.D. (2011)
- Đakulović, Marija, Ph.D. (2011)
- Skorin-Kapov, Nina, Assist. Prof., Ph.D. (2011)
- Beganović, Jasna, Ph.D. (2011)
- Jokić, Stela, Assist. Prof., Ph.D. (2012)
- Lerga, Jonatan, Ph.D. (2012)
- Lörincz, Josip, Assist. Prof., Ph.D. (2012)
- Žagar, Martin, Ph.D. (2012)
- Ačkar, Đurđica, Assist. Prof. Ph.D. (2013)
- Poljak, Mirko, Ph.D. (2013)
- Marčić (née Jurić-Kaćunić), Danijela, Ph.D. (2013)
- Mišković, Nikola, Ph.D. (2013)
- Serdar, Marijana, Ph.D. (2014)
- Pandžić, Hrvoje, Assist. Prof. Ph.D. (2014)
- Kirinčić, Vedran, Ph.D. (2014)
- Pilipović, Ana, Ph.D. (2014)
- Capuder, Tomislav, Ph.D. (2015)
- Pukšec, Tomislav, Ph.D. (2015)
- Belščak-Cvitanović, Ana, Ph.D. (2015)
- Marović, Ivan, Ph.D. (2015)
- Banjari, Ines, Assist. Prof. Ph.D. (2016)
- Jović, Alan, Assist. Prof. Ph.D. (2016)
- Hofman, Daniel, Assist. Prof. Ph.D. (2016)
- Mikulčić, Hrvoje, Ph.D. (2017)
- Marković, Ivan, Assist. Prof. Ph.D. (2017)
- Jozinović, Antun, Assist.Prof. Ph.D. (2017)
- Picek, Stjepan, Ph.D. (2017)

The Award for Successful Young Scientists from the Economy "Vera Johanides"

- Elez, Ante, Ph.D. (2012)
- Filipović-Grčić, Dalibor, Ph.D. (2013)
- Sučić, Stjepan, Ph.D. (2014)
- *The 2015 Award was not granted because there had been no applicants*
- Hrkovac, Martina, Ph.D. (2016)
- Penović, Tomislav, Ph.D. (2017)

MEMBERS OF THE ACADEMY IN 2018

Strika, M.

Business Secretary of the Academy (1999 – 2018)

Full Members of the Academy, Emeriti of the Academy and Associates of the Academy[1]

For Full Members of the Academy, Emeriti of the Academy and Associates of the Academy may be elected persons who meet conditions according to the Statute and the Bylaw on Membership of the Academy.

Full Member of the Academy may be a Croatian citizen with generally acknowledged scientific results and/or patents in the field of technical and biotechnical sciences, who has the status of a scientific advisor or Full Professor of a university, who is elected by the Presidency and who, on the occasion of submitting the candidature for a member according to the Statute commits himself/herself that after the election he/she will actively participate in the work of the Academy, take part in projects and activities of the Academy, contribute to its reputation and honor the Code of Ethics of the Academy.

Emeritus of the Academy becomes every Full Member of the Academy in the year in which he/she turns seventy five. Full Member of the Academy can become Emeritus of the Academy after turning seventy on personal request. Emeriti of the Academy are elected by the Presidency of the Academy.

Associate of the Academy may be a citizen of the Republic of Croatia with the title of research associate or some higher title in the field of engineering and/or biotechnical sciences, who is elected by the Assembly and who, when submitting the candidature for a member according to the Statute commits himself/herself that after the election he/she will actively participate in the work of the Academy. Membership in the Academy of the Associate Member ceases in the year when he/she turns seventy years of age.

Hereinafter is the list of members in the three categories of the elected members of the Academy (state in April 2018).

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[1] This article is an updated and ammended version of the article of the same title, which was published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013", on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

Full Members of the Academy

1. Andrassy Maja, Prof. Ph.D.
2. Andročec Vladimir, Prof. Ph.D.
3. Anžek Mario, Prof. Ph.D.
4. Babić, Darko, Prof. Ph.D.
5. Babić Jurislav, Prof. Ph.D.
6. Baletić Bojan, Prof. Ph.D.
7. Barbir Frano, Prof. Ph.D.
8. Bedeković, Gordan, Prof. Ph.D.
9. Begušić Dinko, Prof. Ph.D.
10. Bogdan Željko, Prof. Ph.D.
11. Bolanča Zdenka, Prof. Ph.D.
12. Bonefačić Davor, Prof. Ph.D.
13. Brnić Josip, Prof. Ph.D.
14. Cifrek, Mario, Prof. Ph.D.
15. Čaušević Mehmed, Prof. Ph.D.
16. Čavlina Nikola, Prof. Ph.D.
17. Čišić, Dragan, Prof. Ph.D.
18. Čorić Većeslav, Prof. Ph.D.
19. Ćosić Krešimir, Prof. Ph.D.
20. Dalbelo Bašić, Bojana, Prof. Ph.D.
21. Debrecin Nenad, Prof. Ph.D.
22. Domazet Željko, Prof. Ph.D.
23. Dragčević Zvonko, Prof. Ph.D.
24. Duić Neven, Prof. Ph.D.
25. Dujmović Darko, Prof. Ph.D.
26. Filetin Tomislav, Prof. Emer. Ph.D.
27. Franković Bernard, Prof. Ph.D.
28. Galović Antun, Prof. Ph.D.
29. Gaurina-Međimurec Nediljka, Prof. Ph.D.
30. Gold Hrvoje, Prof. Ph.D.
31. Granić Goran, Prof. Ph.D.
32. Grbac Ivica, Prof. Ph.D.
33. Grbavac Vitomir, Prof. Ph.D.

34. Grgić Mislav, Prof. Ph.D.
35. Grgić Sonja, Prof. Ph.D.
36. Herceg Zoran, Prof. Ph.D.
37. Horvat, Predrag, Prof. Ph.D.
38. Jambreković, Vladimir, Prof. Ph.D.
39. Jerbić Bojan, Prof. Ph.D.
40. Ježek Damir, Prof. Ph.D.
41. Jirouš-Rajković, Vlatka, Prof. Ph.D.
42. Jukić Tihomir, Prof. Ph.D.
43. Kos Serđo, Prof. Ph.D.
44. Kovač Mario, Prof. Ph.D.
45. Kovačević Zelić, Biljana, Prof. Ph.D.
46. Krajcar Slavko, Prof. Ph.D.
47. Kralj Damir, Prof. Ph.D.
48. Kujundžić, Trpimir, Prof. Ph.D.
49. Lapaine Miljenko, Prof. Ph.D.
50. Lipovac Vladimir, Prof. Ph.D.
51. Lončarić Sven, Prof. Ph.D.
52. Mandić Milena, Prof. Ph.D.
53. Margeta, Jure, Prof. Ph.D.
54. Marović Pavao, Prof. Ph.D.
55. Martinović, Goran, Prof. Ph.D.
56. Matejiček Franjo, Prof. Ph.D.
57. Matijašević Ljubica, Prof. Ph.D.
58. Medak Damir, Prof. Ph.D.
59. Medved Vladimir, Prof. Ph.D.
60. Medved-Rogina Branka, Prof. Ph.D.
61. Mihanović Ante, Prof. Ph.D.
62. Mikac Tonči, Prof. Ph.D.
63. Milković Marin, Prof. Ph.D.
64. Miloš Ivan, Prof. Ph.D.
65. Moguš Milanković Andrea, Prof. Ph.D.
66. Mornar Vedran, Prof. Ph.D.
67. Mrnjavac Edna, Prof. Ph.D.

68. Mrša Vladimir, Prof. Ph.D.
69. Mrša Zoran, Prof. Ph.D.
70. Munjiza Ante, Prof. Ph.D.
71. Obad Šćitaroci Mladen, Academician, Prof. Ph.D.
72. Ožanić Nevenka, Prof. Ph.D.
73. Pap Klaudio, Prof. Ph.D.
74. Pavić Ivica, Prof. Ph.D.
75. Pegan Srečko, Prof. Ph.D.
76. Penava, Željko, Prof. Ph.D.
77. Perić Nedjeljko, Prof. Ph.D.
78. Petrović Ivan, Prof. Ph.D.
79. Pribičević Boško, Prof. Ph.D.
80. Rimac Drlje Snježana, Prof. Ph.D.
81. Rogale Dubravko, Prof. Ph.D.
82. Skala Karolj, Prof. Ph.D.
83. Sorić Jurica, Prof. Ph.D.
84. Srbljić Siniša, Prof. Ph.D.
85. Stipaničev Darko, Prof. Ph.D.
86. Sućeska, Muhamed, Prof. Ph.D.
87. Šantek Božidar, Prof. Ph.D.
88. Šercer Mladen, Prof. Ph.D.
89. Šubarić Drago, Prof. Ph.D.
90. Šušković Jagoda, Prof. Ph.D.
91. Terze Zdravko, Prof. Ph.D.
92. Tomas Srećko, Prof. Ph.D.
93. Tomašić Vesna, Prof. Ph.D.
94. Tomšić Željko, Prof. Ph.D.
95. Tonković, Zdenko, Prof. Ph.D.
96. Ujević Darko, Prof. Ph.D.
97. Veža Ivica, Prof. Ph.D.
98. Virag Zdravko, Prof. Ph.D.
99. Vrkljan Darko, Prof. Ph.D.
100. Vujasinović Edita, Prof. Ph.D.
101. Zelenika Saša, Prof. Ph.D.
102. Zelić Bruno, Prof. Ph.D.

Emeriti of the Academy

1. Agić Darko, Prof. Ph.D.
2. Alfirević Ivo, Prof. Emer. Ph.D.
3. Androić Boris, Prof. Ph.D.
4. Aničić Dražen, Prof. Ph.D.
5. Auf-Franić Hildegard, Prof. Ph.D.
6. Ban Drago, Prof. Ph.D.
7. Beslać Jovo, Prof. Ph.D.
8. Biondić Božidar, Prof. Emer. Ph.D.
9. Bjegović Dubravka, Prof. Emer. Ph.D.
10. Bogunović Nikola, Prof. Ph.D.
11. Bolanča Stanislav, Prof. Ph.D.
12. Bošnjak Marijan, Prof. Ph.D.
13. Božičević Josip, Academician, Prof. Ph.D.
14. Butković Mirko, Prof. Emer. Ph.D.
15. Cerovac Vesna, Prof. Ph.D.
16. Črnko Josip, Prof. Ph.D.
17. Čunko Ružica, Prof. Ph.D.
18. Damić Vjekoslav, Prof. Ph.D.
19. Dvornik Josip, Prof. Ph.D.
20. Feretić Danilo, Prof. Ph.D.
21. Ferić Miljenko, Prof. Emer. Ph.D.
22. Figurić Mladen, Prof. Ph.D.
23. Frančula Nedjeljko, Prof. Emer. Ph.D.
24. Franekić Jasna, Prof. Ph.D.
25. Glasnović, Antun, Prof. Ph.D.
26. Golubović Adrijano, Prof. Emer. Ph.D.
27. Gomzi Zoran, Prof. Ph.D.
28. Grancarić Ana Marija, Prof. Emer. Ph.D.
29. Haznadar Zijad, Academician, Prof. Emer. Ph.D.
30. Hnatko Emil, Prof. Ph.D.
31. Hraste Marin, Academician, Prof. Ph.D.
32. Ilić Ivan, Prof. Ph.D.
33. Janović Zvonimir, Prof. Emer. Ph.D.
34. Jelaska Damir, Prof. Ph.D.

35. Jović Franjo, Prof. Ph.D.
36. Jurković Sonja, Prof. Ph.D.
37. Kalpić Damir, Prof. Ph.D.
38. Katavić Ivan, Prof. Ph.D.
39. Katović Drago, Prof. Ph.D.
40. Kelemen Tomislav, Prof. Ph.D.
41. Kniewald Zlatko, Prof. Emer. Ph.D.
42. Komadina Pavao, Prof. Ph.D.
43. Koroman Vladimir, Prof. Ph.D.
44. Kos Zorko, Prof. Ph.D.
45. Kovačić Davorin, Prof. Ph.D.
46. Krakar Zdravko, Prof. Ph.D.
47. Kralik Gordana, Prof. Ph.D., HonD
48. Križan Božidar, Prof. Ph.D.
49. Krumes Dragomir, Prof. Ph.D.
50. Kurtanjek Želimir, Prof. Ph.D.
51. Kviz Boris, Prof. Ph.D.
52. Lelas Vesna, Prof. Ph.D.
53. Liščić Božidar, Academician, Prof. Ph.D.
54. Lovrić Tomislav, Prof. Ph.D.
55. Ljuljka Boris, Prof. Ph.D.
56. Majdandžić Niko, Prof. Ph.D.
57. Markotić Anto, Prof. Ph.D.
58. Marušić Josip, Prof. Emer. Ph.D.
59. Mikula Miroslav, Prof. Emer. Ph.D.
60. Mikuličić Vladimir, Prof. Ph.D.
61. Milković Mateo, Prof. Ph.D.
62. Parac-Osterman Đurđica, Prof. Emer. Ph.D.
63. Roje Vesna, Prof. Ph.D.
64. Rotim Franko, Prof. Ph.D.
65. Rožić Nikola, Prof. Ph.D.
66. Salopek Branko, Prof. Ph.D.
67. Sečen Josip, Prof. Ph.D.
68. Senjanović Ivo, Academician, Prof. Ph.D.
69. Sever Stanislav, Prof. Ph.D.

70. Solarić Nikola, Prof. Emer. Ph.D.
71. Soljačić Ivo, Prof. Emer. Ph.D.
72. Somek Branko, Prof. Ph.D.
73. Sorić Zorislav, Prof. Ph.D.
74. Sršen Mate, Prof. Ph.D.
75. Štern Ivica, Prof. Ph.D.
76. Tomašić Ivan, Prof. Ph.D.
77. Tonković Stanko, Prof. Emer. Ph.D.
78. Tripalo Branko, Prof. Emer. Ph.D.
79. Ugarčić Žaneta, Prof. Ph.D.
80. Vasić-Rački Đurđa, Prof. Emer. Ph.D.
81. Verić Franjo, Prof. Ph.D.
82. Zovko-Cihlar Branka, Prof. Ph.D.
83. Zrnčević Stanka, Prof. Ph.D.
84. Žagar Zvonimir, Prof. Ph.D.
85. Žiljak Vilko, Prof. Emer. Ph.D.

Associates of the Academy

1. Afrić Winton, Prof. Ph.D.
2. Barić Adrijan, Prof. Ph.D.
3. Biondić Ranko, Assoc. Prof. Ph.D.
4. Bogdan Stjepan, Prof. Ph.D.
5. Bolf Nenad, Prof. Ph.D.
6. Burum Nikša, Prof. Ph.D.
7. Car Stjepan, Prof. Ph.D.
8. Ćurković Lidija, Prof. Ph.D.
9. Dragović Uzelac Verica, Prof. Ph.D.
10. Fajt Siniša, Prof. Ph.D.
11. Fertalj Krešimir, Prof. Ph.D.
12. Firšt Rogale Snježana, Assoc. Prof. Ph.D.
13. Frece Jadranka, Prof. Ph.D.
14. Galić Irena, Assist. Prof. Ph.D.
15. Grgić Davor, Prof. Ph.D.
16. Grladinović Tomislav, Prof. Ph.D.
17. Guzović Zvonimir, Prof. Ph.D.

18. Hocenski Željko, Prof. Ph.D.
19. Horvat Dubravko, Prof. Ph.D.
20. Hruškar Mirjana, Prof. Ph.D.
21. Joler Miroslav, Prof. Ph.D.
22. Jukić Ante, Prof. Ph.D.
23. Karšaj Igor, Assoc. Prof. Ph.D.
24. Kasum Josip, Prof. Ph.D.
25. Kliček Božidar, Prof. Ph.D.
26. Komen Vitomir, Prof. Ph.D.
27. Kos Blaženka, Prof. Ph.D.
28. Kovačević Meho Saša, Prof. Ph.D.
29. Kurajica Stanislav, Prof. Ph.D.
30. Kuzle Igor, Prof. Ph.D.
31. Lipovac Nenad, Prof. Ph.D.
32. Lulić Zoran, Prof. Ph.D.
33. Malbaša Niko, Prof. Ph.D.
34. Mandžuka Sadko, Prof. Ph.D.
35. Math Miljenko, Prof. Ph.D.
36. Meštrović Krešimir, Prof. Ph.D.
37. Mikulić Dinko, Prof. Ph.D.
38. Mlinarić Hrvoje, Prof. Ph.D.
39. Mrvac Nikola, Prof. Ph.D.
40. Muštra Mario, Assist. Prof. Ph.D.
41. Pavković Branimir, Prof. Ph.D.
42. Peran Zdravko, Prof. Ph.D.
43. Peroš Bernardin, Prof. Ph.D.
44. Pribanić Tomislav, Prof. Ph.D.
45. Pušić Tanja, Prof. Ph.D.
46. Puž Goran, Prof. Ph.D.
47. Rogošić Marko, Prof. Ph.D.
48. Sučić Viktor, Prof. Ph.D.
49. Szavits-Nossan Antun, Prof. Ph.D.
50. Šarolić Antonio, Prof. Ph.D.
51. Šerman Karin, Prof. Ph.D.
52. Šimić Zdenko, Prof. Ph.D.

53. Šljivac Damir, Prof. Ph.D.
54. Tušek Darovan, Prof. Ph.D.
55. Udiljak Toma, Prof. Ph.D.
56. Veršić Zoran, Prof. Ph.D.
57. Višković Alfredo, Prof. Ph.D.
58. Vražić Mario, Prof. Ph.D.
59. Vrček Neven, Prof. Ph.D.
60. Vujević Slavko, Prof. Ph.D.
61. Zeljko Mladen, Prof. Ph.D.
62. Zentner Radovan, Assoc. Prof. Ph.D.
63. Zrinjski Mladen, Assoc. Prof. Ph.D..
64. Žagar Drago, Prof. Ph.D.
65. Žagar Martin, Prof. Ph.D.
66. Žarko Damir, Prof. Ph.D.

International Members of the Academy[1]

International Members of the Academy may be distinguished Croatian or foreign scientists in the field of engineering sciences with international reputation, living abroad, who meet the criteria for membership in the Academy. When submitting the candidature for a member according to the Statute, they commit themselves that after the election they will participate in the work of the Academy according to their best abilities. International Members of the Academy are elected by the Presidency of the Academy.

Hereinafter is the overview of the international members of the Academy in April 2018.

1. Ahić-Đokić Melita, Prof. Ph.D.
2. Geršak Jelka, Prof. Ph.D.
3. Holzer Clemens, Univ.-Prof. Dipl.-Ing. Dr.mont.
4. Lipičnik Martin, Prof. Ph.D.
5. Kipphan Helmut, Prof. Dr.-Ing. Habil.
6. Mitra Sanjit Kumar, Prof. Ph.D.
7. Palik František, Prof. Ph.D.
8. Petrović Bojan, Prof. Ph.D.
9. Podhradsky Pavol, Prof. Ph.D.
10. Rajendrakumar Anayath, Prof. Ph.D.
11. Raspor Peter, Prof. Ph.D.
12. Soljačić Marin, Prof. Ph.D.
13. Vranešić Zvonko George, Prof. Ph.D.

[1] This article is an updated and ammended version of the article of the same title, which was published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013“, on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

Honorary Members of the Academy[1]

Honorary Member of the Academy may be a distinguished Croatian or foreign scientist, who meets the criteria for membership in the Academy and who, by his or her lifelong activity, has made a considerable contribution to the affirmation, recognition and reputation of engineering sciences in Croatia and abroad. Honorary Members of the Academy are elected by the Presidency of the Academy.

Hereinafter is the list of Honorary Members of the Academy in April 2018:

1. Boras Damir, Prof. Ph.D.
2. Gajski Daniel D., Prof. Ph.D.
3. Kirinčić Josip, Prof. Ph.D.
4. Ladanyi Branko, Prof. Emer. Ph.D.
5. Lončarić Rudolf, Prof. Ph.D.
6. Primorac Dragan, Prof.MD. Ph.D.
7. Richter Kurt R., Prof. Ph.D.
8. Rožanić Igor, Prof. Ph.D.
9. Sokolija Kemo, Prof. Ph.D.
10. Turk Vito, Prof. Ph.D.

[1] This article is an updated and ammended version of the article of the same title, which was published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013“, on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

Supporting Members of the Academy[1]

as stated by May 2018

Like all non-profit organizations, the Croatian Academy of Engineering has exceptionally limited financial resources. Regular costs of the Secretariat, maintenance of the building, computer and communication systems, web sites, membership fees in CAETS and Euro-CASE, etc. are unfortunately inevitable. The Supporting Members of the Academy mostly ensure the existence of the Academy, since membership fees, help of the Ministry of Science, Education and Sports as well as of sponsors of individual events are not sufficient. Each Supporting Member, a legal entity or private donor, is especially appreciated and registered in the Academy Archives. The person authorized to represent the Supporting Members of the Academy or private donor has a right to participate in the activities of the Academy and receives regular information about news from the work of the Academy. All suggestions are welcome in hope and desire that they will improve the work of the Academy.

Supporting Member of the Academy may only be a legal entity. Decision about its admission is made by the Presidency of the Academy. Representative of the legal entity for cooperation with the Academy is appointed by the person authorized to represent the legal person, and the Academy may elect him/her as an Entrepreneur Member of the Academy.

Supporting Members of the Academy

(admitted January 1993 – April 2018)

1. Faculty of Architecture, Zagreb, www.arhitekt.hr
2. Brodarski Institute Ltd., Zagreb, www.hrbi.hr
3. CARNet – Croatian Academic and Research Network, Zagreb, www.carnet.hr

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[1] This article is an updated, ammended and abbreviated version of the article of the same title, which was written by the Past-President of the Academy Prof. Emer. Stanko Tonković, Ph.D., published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013“, on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

4. Vehicle Center of Croatia, Inc., Zagreb, www.cvh.hr
5. National Meteorological and Hydrological Service www.dhmz.htnet.hr
6. EKO, Ltd., Zagreb, www.ekozg.hr
7. Energy Institute Hrvoje Požar, Zagreb, www.eihp.hr
8. Ericsson Nikola Tesla Inc., Zagreb, www.ericsson.hr
9. Faculty of Electrical Engineering, Osijek, www.etfos.hr
10. Faculty of Electrical Engineering and Computing, Zagreb, www.fer.unizg.hr
11. Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, www.fesb.hr
12. Faculty of Chemical Engineering and Technology, Zagreb, www.fkit.hr
13. Faculty of Transport and Traffic Sciences, Zagreb, www.fpz.hr
14. Faculty of Mechanical Engineering and Naval Architecture, Zagreb, www.fsb.hr
15. Faculty of Geodesy, Zagreb, www.geof.hr
16. Faculty of Civil Engineering, Osijek, www.gfos.hr
17. Faculty of Civil Engineering, Rijeka, www.gradri.hr
18. Faculty of Civil Engineering, Architecture and Geodesy, Split, www.gradst.hr
19. Faculty of Civil Engineering, Zagreb, www.grad.hr
20. Faculty of Graphical Engineering, Zagreb, www.grf.hr
21. HEP Inc., Zagreb, www.hep.hr
22. Hrvatske šume, Ltd., Zagreb, www.hrsume.hr
23. Croatian Chamber of Economy, Zagreb, www.hgk.hr
24. Croatian Association of Technical Culture, Zagreb, www.hztk.hr
25. Croatian Chamber of Civil Engineers, Zagreb, www.hkig.hr
26. Croatian Chamber of Mechanical Engineers, Zagreb,www.hkis.hr
27. INA Inc., Zagreb, www.ina.hr
28. INETEC – Institute for Nuclear Technology Ltd., Zagreb, http://www.inetec.hr/en/
29. INGRA AG Zweigstelle, Düsseldorf, Germany, www.ingra.hr
30. INSAKO, Ltd., Zagreb, www.insako.hr
31. Institute IGH Inc., Zagreb , www.igh.hr
32. Faculty of Chemical Technology, Split , www.ktf-split.hr
33. KONČAR – Power Plant and Electric Traction Engineering Inc., Zagreb, www.koncar.hr
34. KONČAR – Institute of Electrical Engineering Inc., Zagreb, www.koncar-institut.hr
35. Faculty of Metallurgy, Sisak, www.simet.hr

36. MIPRO – Croatian Society for Information and Communication Technology, Electronics and Microelectronics, Rijeka, www.mipro.hr
37. PAR LUX, Ltd., Donja Lomnica, www.parlux.hr
38. Petrokemija, Inc., Kutina, www.petrokemija.hr
39. Public Open University Zagreb, http://www.pou.hr/hr/index.php/home/about-us
40. Josip Juraj Strossmayer University of Osijek, www.unios.hr
41. Juraj Dobrila University of Pula, www.unipu.hr
42. Faculty of Maritime Studies, Rijeka, www.pfri.hr
43. Faculty of Food Technology and Biotechnology, Zagreb, www.pbf.hr
44. Faculty of Food Technology, Osijek, www.ptfos.hr
45. Faculty of Mining, Geology and Petroleum Engineering, Zagreb, www.rgn.hr
46. Faculty of Mechanical Engineering, Slavonski Brod, www.sfsb.hr
47. University of Applied Sciences Velika Gorica, www.vvg.hr
48. University North, Varaždin, www.unin.hr
49. University of Dubrovnik, www.unidu.hr
50. University of Zagreb, www.unizg.hr
51. Faculty of Forestry, Zagreb, www.sumfak.hr
52. Faculty of Engineering, Rijeka, www.riteh.hr
53. Polytechnics of Zagreb, www.tvz.hr
54. Faculty of Textile Technology, Zagreb, www.ttf.hr
55. SRCE – University Computing Centre of the University of Zagreb, Zagreb, www.srce.unizg.hr
56. Technical Museum Nikola Tesla, Zagreb, www.tehnicki-muzej.hr
57. TEHNIX, Ltd., www.tehnix.hr
58. Tehnomont, Inc., Pula, www.tehnomont.hr
59. Zagreb-Montaža-Gruppe, Düsseldorf, Germany, www.zagreb-montaza.hr
60. Zagrebačke otpadne vode, Ltd., Zagreb, www.zov-zagreb.hr

More detailed information and facts about **Supporting Members of the Academy** can be found either on the Academy web page (www.hatz.hr) or at their respective web pages.

Deceased Members of the Croatian Academy of Engineering (1993 – 2018)[1]

Strika, M.

On the occasion of the 25th anniversary of our Academy, with respect and gratitude we remember our members who died during this period and their contribution to the Academy, as well as the Croatian science and economy.

For certain deceased members we could not find certain data, although we did our best and searched our database and Archives, and therefore we apologize to the readers.

Ban, Siniša, Prof. Emer. Ph.D.
Born: 1914
Died: 2007
Department of Bioprocess Engineering
Honorary Member of the Academy (admitted 2000)

Bonefačić, Branko, Prof. Ph.D.
Born: 1923
Died: 1995
Department of Traffic and Transportation (admitted 1994)

Božičević, Juraj, Prof. Ph.D.
Born: 1935
Died: 2016
Department of Systems and Cybernetics
Emeritus of the Academy (admitted 1993)

[1] This article is an updated and ammended version of the article of the same title, which was published in 2014 in the Jubilee Monograph „Twenty Years of the Croatian Academy of Engineering (HATZ) 1993-2013“, on the occasion of the 20th Anniversary of the Croatian Academy of Engineering.

Brlić, Vladimir, Ph.D.
Born: 1949
Died: 2011
Department of Communication Systems
Associate of the Academy

Damjanić, Frano, Prof. Ph.D.
Born: 1944
Died: 1998
Department of Civil Engineering and Geodesy
Associate Member of the Academy (admitted 1994)

Domitrović, Hrvoje, Prof. Ph.D.
Born: 1959
Died: 2018
Department of Electrical Engineering and Electronics
Full Member of the Academy (admitted 2002)

Dujmović, Nenad, Prof. Ph.D.
Born: 1942
Died: 2013
Department of Transport
Member of the Academy (admitted 2009)

Duraković, Senadin, Prof. Ph.D.
Born: 1937
Died: 2017
Department of Bioprocess Engineering
Emeritus of the Academy

Džanić, Husein, Prof. Ph.D.
Born: 1933
Died: 1994
Department of Chemical Engineering
Full Member of the Academy (admitted 1993)

Filajdić, Mirko, Prof. Ph.D.
Born: 1920
Died: 1998
Department of Bioprocess Engineering
Honorary Member of the Academy (admitted 1994)

Fleš, Dragutin, Prof. Emer. Ph.D.
Born: 1921
Died: 2005
Honorary Member of the Academy (admitted 1998)

Fritz, Franjo, Prof. Ph.D.
Born: 1932
Died: 1996
Department of Civil Engineering and Mining
Associate Member of the Academy (admitted 1994)

Gamulin, Antun, Prof. Ph.D.
Born: 1931
Died: 1998
Department of Mechanical Engineering and Naval Architecure
Associate Member of the Academy (admitted 1994)

Glancer Šoljan, Margareta, Prof. Ph.D.
Born: 1944
Died: 2008
Department of Bioprocess Engineering
Associate Member of the Academy (admitted 2000)

Hrs, Ivo, Assist. Prof. Ph.D.
Born: 1937
Died: 1999
Department of Electrical Engineering and Electronics
Collaborating Member of the Academy (admitted 1994)

Janjanin, Simo, Prof. Ph.D.
Born: 1933
Died: 2017
Department of Systems and Cybernetics
Emeritus of the Academy (admitted 1998)

Jerič, Viljem, Prof. Ph.D.
Born: 1936
Died: 2015
Department of Communication Systems
Emeritus of the Academy (admitted 1994)

Johanides, Vera, Prof. Emer. Ph.D.
Born: 1917
Died: 2000
Department of Bioprocess Engineering
Honorary Member of the Academy (admitted 1994)

Karlović, Damir, Prof. Ph.D.
Born: 1938
Died: 2017
Department of Bioprocess Engineering
Emeritus of the Academy (admitted 2002)

Kniewald, Jasna, Prof. Ph.D.
Born: 1938
Died: 2018
Department of Bioprocess Engineering
Emeritus of the Academy (admitted 1994)

Kolombo, Marijan, Ph.D.
Born: 1925
Died: 2009
Member Amicus of the Academy (admitted 2002)

Konja, **Gordana,** Prof. Ph.D.
Born: 1944
Died: 1998
Department of Bioprocess Engineering
Associate Member of the Academy (admitted 1994)

Kordić, Zdenko, Prof. Ph.D.
Born: 1949
Died: 2004
Department of Mechanical Engineering and Naval Architecture
Associate Member of the Academy (admitted 1994)

Kos, Vesna, Prof. Ph.D.
Born: 1930
Died: 2015
Department of Electrical Engineering and Electronics
Emeritus of the Academy

Kostelić, Aurel, Prof. Ph.D.
Born: 1933
Died: 1997
Department of Mechanical Engineering and Naval Architecure
Associate Member of the Academy (admitted 1994)

Krpan, Mirko, Prof. Emer. Ph.D.
Born: 1924
Died: 2006
Department of Mechanical Engineering and Naval Architecure
Member Emeritus of the Academy (admitted 1993)

Lopašić, Vatroslav, Prof. Ph.D.
Born: 1911
Died: 2003
Honorary Member of the Academy (admitted 1994)

Lovrić, Josip, Prof. Ph.D.
Born: 1928
Died: 2012
Department of Transport
Emeritus of the Academy (admitted 1993)

Lovrić, Paško, Prof. Ph.D.
Born: 1931
Died: 1997
Department of Civil Engineering and Geodesy
Full Member of the Academy (admitted 1994)

Lukačević, Zvonimir, Prof. Ph.D.
Born: 1935
Died: 1998
Department of Mechanical Engineering and Naval Architecure
Associate Member of the Academy

Maljković, Darko, Prof. Ph.D.
Born: 1935
Died: 2003
Department of Chemical Engineering
Full Member of the Academy (admitted 1993)

Marić, Vladimir, Prof. Ph.D.
Born: 1939
Died: 2009
Department of Bioprocess Engineering
Full Member of the Academy (admitted 1994)

Marković, Ivan, Prof. Ph.D.
Born:
Died: 2005
Department of Traffic and Transportation
Associate Member of the Academy (admitted 1993)

Miliša, Ante, Prof. Ph.D.
Born: 1937
Died: 2006
Department of Electrical Engineering and Electronics
Collaborating Member of the Academy (admitted 1994)

Mlinarić, Tomislav, Prof. Emer. Ph.D.
Born: 1932
Died:
Department of Transport
Member Emeritus of the Academy (admitted 1993)

Muftić, Osman, Prof. Emer. Ph.D.
Born: 1934
Died: 2010
Department of Systems and Cybernetics
Member Emeritus of the Academy (admitted 1993)

Muljević, Vladimir, Prof. Emer. Ph.D.
Born: 1913
Died: 2007
Honorary Member of the Academy (admitted 1993)

Pilić-Rabadan, Ljiljana, Prof. Ph.D.
Born: 1930
Died: 2017
Department of Mechanical Engineering and Naval Architecture
Emeritus of the Academy (admitted 1994)

Plenković, Zlatko, Prof. Ph.D.
Born: 1917
Died: 2003
Honorary Member of the Academy (admitted 1994)

Podhorsky, Rikard, Prof. Ph.D.
Born: 1902
Died: 1994
Honorary Member of the Academy (admitted 1994)

Popović, Krešimir, Prof. Ph.D.
Born: 1940
Died: 2003
Department of Chemical Engineering and the Related Fields
Associate Member of the Academy (admitted 1994)

Prikril, Boris, Prof. Ph.D.
Born: 1915
Died: 1995
Honorary Member of the Academy (admitted 1994)

Radić, Jure, Prof. Ph.D.
Born: 1953
Died: 2016
Department of Civil engineering and Geodesy
Member of the Academy (admitted 1993)

Richter, Branimir, Prof.Ph.D.
Born: 1920
Died: 2012
Honorary Member of the Academy (admitted 2001)

Sertić, Vladimir, Prof. Ph.D.
Born: 1935
Died: 2002
Department of Chemical Engineering
Full Member of the Academy (admitted 1994)

Sladoljev, Želimir, Prof. Emer. Ph.D.
Born: 1932
Died: 2012
Department of Mechanical Engineering and Naval Architecture
Emeritus of the Academy (admitted 1993)

Smrkić, Zlatko,
Born: 1924
Died: 1995
Honorary Member of the Academy (admitted 1994)

Staniša, Branko, Prof. Ph.D.
Born: 1941
Died: 2013
Department of Power Systems
Emeritus of the Academy (admitted 1998)

Šantić, Ante, Prof. Emer. Ph.D.
Born: 1928
Died: 2008
Department of Electrical Engineering and Electronics
Full Member of the Academy (admitted 1994)

Štefanko, Stjepan, Prof. Ph.D.
Born: 1944
Died: 2013
Department of Electrical Engineering and Electronics
Associate Member of the Academy (admitted 1994)

Štulhofer, Mladen, Ph.D.
Born: 1924
Died: 2010
Honorary Member of the Academy (admitted 2001)

Valter, Zdravko, Prof. Ph.D.
Born: 1940
Died: 2016
Department of Electrical Engineering and Electronics
Emeritus of the Academy (admitted 1994)

Wolf, Radenko, Prof. Ph.D.
Born: 1919
Died: 1997
Honorary Member of the Academy (admitted 1994)

Topolnik, Dražen, Prof. Ph.D.
Born: 1927
Died: 2014
Department of Transport
Emeritus of the Academy (admitted 2001)

Zenter, Ervin, Prof. Ph.D.
Born: 1931
Died: 2014
Department of Communication Systems
Emeritus of the Academy (admitted 1998)

Zgaga, Zoran, Prof. Ph.D.
Born: 1956
Died: 2011
Department of Bioprocess Engineering
Associate of the Academy (admitted 2000)

A Short Overview of the Programme of Work of the Governing Board of the Croatian Academy of Engineering 2017-2021

Gaurina-Međimurec, N.

Secretary-General of the Academy

Due to its unique position as a scientific institution in the Republic of Croatia, which has 276 excellent scientists from all areas of engineering sciences, mostly university professors and other scientists elected to the highest scientific-educational titles, the Academy is able to respond to numerous challenges of the integration of the Croatian scientific community into the world of research developments, and in particular into the ERA (European Research Area).

The Programme of Work of the Governing Board of the Croatian Academy of Engineering for the 2017-2021 mandate is based on the continuation of previous activities and the results of the previous Governing Board, but also on a number of innovations and the introduction of completely new courses of action.

The members of the Academy Governing Board (Fig. 1):

1. Prof. **Vladimir Andročec**, Ph.D., President
2. Prof. **Zdravko Terze**, Ph.D., Vice-President
3. Prof. **Dubravko Rogale**, Ph.D., Vice-President
4. Prof. **Nediljka Gaurina-Međimurec**, Ph.D., Secretary-General
5. Prof. **Slavko Krajcar**, Ph.D., 5th member

will commit themselves deeply to the implementation of the programme work on the basis of which they were elected and will focus in the next four-year period, in addition to carrying out the activities necessary for the functioning of the Academy, on the following activities:

Fig. 1 – New Govering Board of the Croatian Academy of Engineering will be leading the Academy in the next four-year mandate starting from July 1, 2017: (from left to right) Prof. Slavko Krajcar, Ph.D., 5th member, Prof. Dubravko Rogale, Ph.D., Vice-President of the Academy, Prof. Vladimir Andročec, Ph.D., President of the Academy, Prof. Nediljka Gaurina-Međimurec, Ph.D., Secretary-General of the Academy, Prof. Zdravko Terze, Ph.D., Vice-President of the Academy

- **Increasing the scientific and technological influence and recognizability of the Academy in the Republic of Croatia as well as the ERA and positioning and operationalization of the HATZ within Croatian institutions** through further talks with the Ministry of Science and Education and the Agency for Science and Higher Education, but also through constant promotion of scientific excellence and social importance of the Academy by organizing open conferences, round tables and meetings of public interest, and the publication of the HATZ Bulletin and the HATZ Annual;

- **International cooperation of the Academy as a member of CETS and Euro-CASE, participation of the Academy as a member of the Euro-CASE in the SAPEA Project** and other new projects and the continuation of bilateral cooperation with other academies in the environment;

- **Maintenance and renovation of the office building of the Academy** and the gradual expansion of the infrastructure, purchase and installation of video surveillance systems for the building and backyard of the Academy and installation of the Eduroam system;

- **Maintenance and upgrading of the Academy webpage** with emphasis on significant dissemination of important information for members and the general public, but also a better interactivity among the members of the Academy;

- **Financial discipline and financial stability** by making timely payment of personal membership fees, by increasing the number of supporting members and by revenue generation based on grants and calls for proposals;

- **Mobilization of membership through**: timely information on all relevant events, promotion of publishing activities by editing thematic issues of the HATZ Bulletin , normative limitation of the number of functions and number of mandates in the Academy, monitoring the work of individual departments and their obligations to organize conferences, organizing the Open Door Day of the Department, evaluation of activities, organizing the presentation of prominent scientists of individual departments, establishment and work of the Centres for the purpose of vocational and scientific activities, organizing symposia and the like, using all the infrastructure of the Academy and other supporting members, and encouraging calls for proposals and implementation of domestic and European projects;

- **Increasing the efficiency of the use of EU funds and a possible proposal for a concrete structural project**, namely: by directly encouraging members to apply for projects funded by the EU Research Funds, by supporting the organization of information workshops of individual EU programmes, by networking the participants in the application process, by finding suitable partners for a particular project idea, by establishing contacts within relevant international organizations, by creating themes for future lines of research, by linking local research institutions to local authorities in order to successfully implement new technologies in everyday social practice (e.g. development of earthquake protection programmes and other disaster protection programmes, use of satellite images for civilian purposes, development of related software support, improvement of traffic connections, security and signalling, etc.);

- **Installing another statue at the Alley of the Distinguished of the Academy** as a sign of honour of meritorious Croatian engineering scientists;

- **Continuing cooperation between the Academy and the Croatian Academy of Sciences and Arts** with the aim of establishing and conducting joint projects;

- **Continuing cooperation between Croatian Academy of Engineering and Croatian Academy of Medical Sciences, Croatian Academy of Legal Sciences and Croatian Academy of Forestry Sciences** through the Council and Coordination of the Four Academies in a successful struggle for common status issues, joint publishing, joint holding of multidisciplinary conferences and multidisciplinary cooperation;

- **Continuing cooperation between the Academy and the Miroslav Krleža Institute of Lexicography and the Croatian Academy of Sciences and Arts** in a joint project for the publication of the new Croatian Technical Encyclopaedia;

- **Marking the 25th anniversary** of our existence and successful work and

- **Effectiveness in increasing ethics and moral integrity in engineering profession and society** in accordance with the Code of Ethics.

At the present moment of a long-term general crisis in Croatia, the previous and future tasks are extremely challenging and difficult to achieve without recognizing the importance of the Croatian Academy of Engineering by Government Institutions and economy, and which will be possible to achieve only based on the actual achievements of all members of the Academy and their engagement in the Management Bodies of the Academy and the Croatian public and the synchronizing activities of Governing Board, Presidency, Departments, Centers, Committees and Scientific Council of the Academy.

PART II

PAPERS OF THE MEMBERS OF THE ACADEMY AND THEIR CO-AUTHORS 2017

A Comparison between a Stationary and a Semi-Mobile Plant for Wet Processing of Crushed Stone

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Abstract: Crushed stone is the most important type of mineral resource in the Republic of Croatia and is mined in more than 350 exploitation fields. Crushed stone is most often used as aggregate for the production of concrete and asphalt, for which it must satisfy high standards, and thus it is necessary to process it. The wet processing technology in semi-mobile plants, which is increasingly frequent in Europe, has thus far not been used in the Republic of Croatia. This paper provides a comparison of the wet processing technology on an older, stationary and a newer, semi-mobile processing plant in the "Oršulica kosa" exploitation field. It also describes the process of waste wash water treatment and the newer high-pressure pre-washing chamber technology. The costs of extracting stone from a stone massif are the same in both cases; therefore, in comparing the two plants, the effect of the cost of transportation and stone processing was also taken into account. An analysis of the cheapest possible transportation showed that for the stationary plant, located at a distance of 1,950 m from the active worksite, the cost of transport was 4.01 kunas per tonne, or 1.7 million kunas per annum, while in the case of the semi-mobile plant this cost was non-existent. As for processing, it appears that the electric energy consumption of the stationary plant is three times higher than that of the new semi-mobile plant, which amounts to a difference of 0.85 million kunas per annum. As for water consumption, it appears that the water consumption of the old stationary plant is approximately ten times greater than that of a new semi-mobile plant, which amounts to a difference of 0.23 million kunas per annum. Taking into account the potential savings of around 2.1 million kunas per annum, the return of the total investment in the new semi-mobile plant should be realized in a relatively short period of 3.5 years. Beside the economic benefit, we should also emphasize the smaller environmental footprint of the new plant, which is evident in the decreased need for adding fresh water to the process, as well as the significantly decreased need for occupying space with settling basins, seeing as the new semi-mobile plant, as opposed to the old stationary one, purifies and recycles wastewater.

Keywords: *mineral processing, crushed stone, mobile processing plants, washing, wastewater treatment*

Introduction

In the Republic of Croatia, crushed stone is mined in more than 350 active exploitation fields. Surface mines (quarries) for crushed stone are the most common in the Republic of Croatia; they account for the largest number of approved exploitation fields and the greatest amount of mined material per annum. Crushed stone is a vital mineral resource for construction and is used in building materials, with the most important being aggregates for concrete construction, aggregates for asphalt construction, aggregates for bituminous mixtures and railroad track lagging. For crushed stone, carbonate (sedimentary) rocks are most often mined, with igneous (silicate) rocks being mined only rarely (Bedeković et al., 2005a). In the Republic of Croatia, crushed stone is processed mainly in stationary plants, using dry and wet techniques. Also of note is the widespread use of mobile plants for dry processing, especially in constructing infrastructure and business and residential buildings. In accordance with the current high standards for the quality of aggregates for the production of concrete and asphalt, along with certain natural properties (such as strength, stability under the effects of weather, and resistance to abrasion and blunt force, which are the result of various geological factors, which humans cannot influence, the produced stone material must have certain properties which humans can influence through the manner of extraction and processing (crushing, screening, dedusting, washing) of the mineral resource. These are the following important properties:

- Specific grain size distribution, as defined by the prescribed limits for individual grain sizes of material,
- Approximately cubic shape of the grain (the shape of the grain is defined as the ration of its largest and smallest dimension; the grains for which this ratio is higher than 3:1 are considered to be of unsuitable shape),
- Maximal purity, i.e. a minimal portion of mud and dust particles (particles smaller than 0.09 mm – filler) (Salopek et al., 2002).

Sometimes the material contains a larger portion of clay particles that need to be separated in processing in order for the aggregate to meet the prescribed standards. In such a case, the standard dry processing technique does not deliver satisfactory results and it is necessary to wash the material, i.e. to use the wet technique. Washing encompasses the processes in which hydraulic techniques are used to achieve a successful separation (release) of the smallest particles, which adhere to each other and to larger grains or connect larger grains to each other, and their subsequent separation from the mineral resource, either by using wash water or through overflow. Washing can be simple (e.g. washing on screens) or complex, using various equipment (e.g. trommel screens, attritors, hydrocyclones, spiral classifiers, classifiers with vanes). The wet process results in a higher-quality product than the dry one, no dust is emitted, and the screening capacity is greater by around 15 %; on the other hand, the downside is wastewater containing mud and clay particles (i.e. suspension) that it produces (Bedeković et al., 2005b). The wastewater needs to be treated, and the mud produced needs to be managed, in order to eliminate a potential harmful effect on humans and environment.

The technology of wet mineral processing on semi-mobile plants, which is becoming increasingly widespread in Europe, has thus far not been used in the Republic of Croatia. There are two basic concepts for wet processing on semi-mobile plants that are show in this paper: the concept in which a high-pressure chamber is used for washing and the concept of washing on screens. In both of these technological concepts, the process of wastewater treatment is crucial. The dolomite exploitation field "Oršulica kosa" near Orahovica, in the Nature Park Papuk, is the first site in the Republic of Croatia where, for the past year, the technology of wet mineral processing on a semi-mobile plant has been used (Vrkljan et al., 1996, 2006, 2011). This paper elaborates on the benefits, mainly economic and environmental in nature, which are achieved through the use of this type of processing technology. It also provides a comparison of the results of using the technology of wet processing on an old stationary plan, which has been used thus far, and the results achieved on a new semi-mobile plant.

Materials and Methods

Stationary processing plant

The existing procedure for mineral processing on a stationary plant is shown on the flowsheet in Fig. 1 and is described in more detail in this paragraph. The mined material is transported to the entrance bin *(1)*, which has a volume of 40 m^3. Exiting the bin, the material passes through the grizzly screen for pre-screening *(3)* with elongated apertures measuring 30 mm. The undersize material (the -30 mm grain size) goes on to be washed on the vibrating screen *(6)*. The oversize material is crushed in the jaw crusher *(4)*, with the output aperture set to 120 mm. After crushing, the material moves on to the primary resonance screen *(5)* with two screening surfaces (with apertures measuring 30 and 60 mm). The oversize material from the primary screen (the 120/60 mm grain size) moves on to secondary crushing in the hammer crusher *(8)* of the BL 6 type, with the output aperture measuring 15 mm. The intermediate grain size from the primary screen *(5)* of 60/30

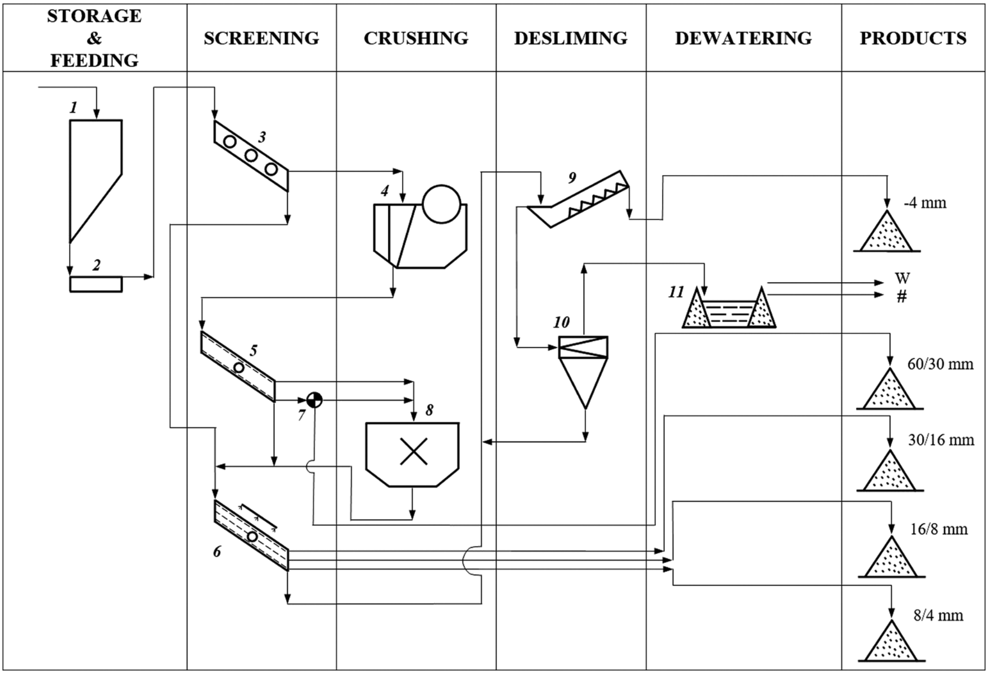

Fig. 1 – Flowsheet of the old stationary processing plant "Hercegovac"

mm can, using the material flow router *(7)*, be directed to secondary crushing with the oversize material or to the final products dump. The undersize material from the primary screen *(5)*, along with the material crushed in the secondary hammer crusher *(8)*, moves on to wet screening on the secondary vibrating screen *(6)* with the screen apertures measuring 16, 8 and 4 mm. After screening, the 30/16 mm, 16/8 mm and 8/4 mm grain sizes are separated as end products in storage. The undersize material from the screen *(6)* (the -4 mm grain size), along with the waste-water from washing, moves on to the spiral classifier *(9)*. The sand from the spiral classifier (the -4 mm grain size) moves on to storage as an end product, while the overflow goes to the retaining reservoir. The overflow from the retaining reservoir ends up in the settling basin *(11)*, while the coarse solids goe on to the hydrocyclones *(10)*. The vortex from the hydrocyclone (the -0.09 mm grain size) moves on to the settling basin *(11)*, while the apex goes back to the spiral classifier *(9)*.

Semi-mobile processing plant

The procedure of mineral processing on a semi-mobile plant (Figure 3) is shown in Fig. 2 and is described in more detail in this paragraph. The process begins by transporting the mineral resource to the entrance bin *(1)*, which has a volume of 36 m^3. Above the entrance bin, there is a stationary grizzly *(3)* with apertures measuring 225 mm. The oversize material from the grizzly (+225 mm grain size) goes to storage and is afterwards crushed using the mobile crushing plant Metso LT 105 S *(4)*. The size of the output aperture of the jaw crusher *(4)* of this mobile crushing plant is set to 31.5 mm, which is also the input grain size for the mobile screening and washing plant, the CDE Global M2500 E5X. The process of processing the material from the entrance bin (the -225 mm grain size) begins with screening on the primary single-deck vibrating screen *(5)* P1-36, with a single screening surface measuring 3.60 m^2. The oversize material from the screen (225/31.5 mm grain size) moves on to crushing in the mobile crushing plant Metso LT 105 S *(4)*. The undersize material from the screen (the -31.5 mm grain size) is combined with the material crushed in the mobile jaw crusher *(4)*, and then they move on to the triple-deck vibrating screen *(6)* P3-75, with a screening surface area of 7.5 m^2 per deck. All of the grain sizes are also washed on this screen during the screening process. The oversize material from the screen (the 31.5/16 mm grain size) and the two intermediate grain sizes (16/8 mm and 8/4 mm) then go to the appropriate final products dump. One of the special features of the screen is the adjustable incline along the screening surface. The input half of the screening surfaces is placed at an incline of around 11°, while the other, output half is placed at a somewhat greater incline of around 13°. This results in a somewhat shorter retention time of grains on the screen, while retaining the effectiveness of the screening. Another special feature is

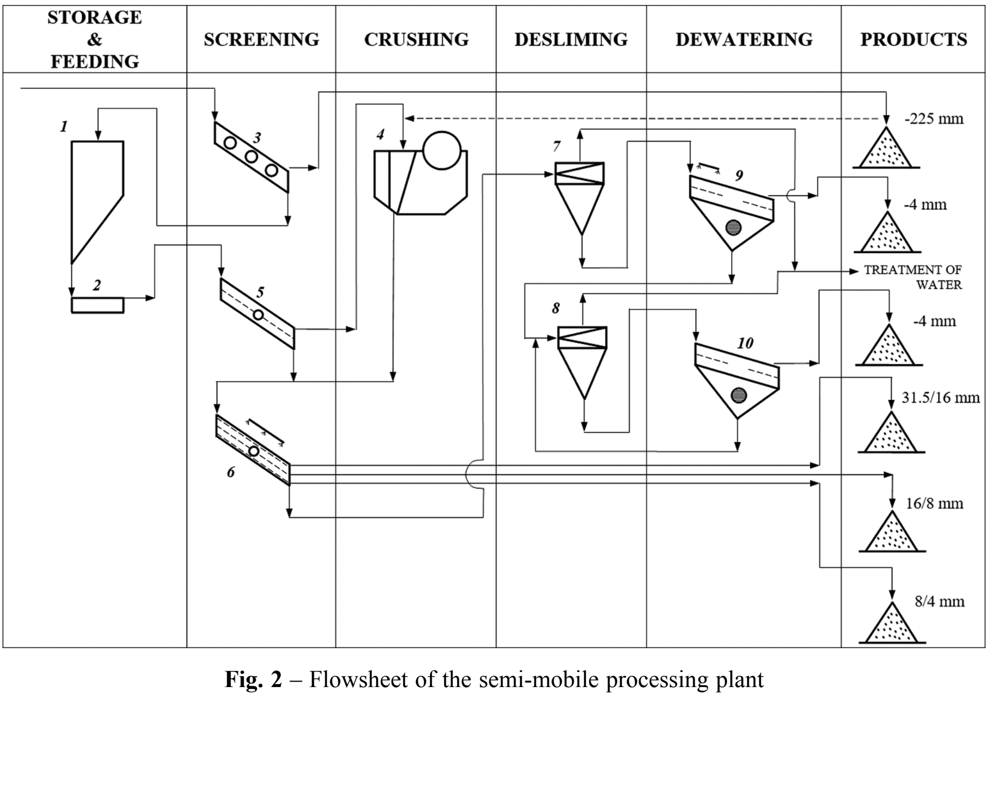

Fig. 2 – Flowsheet of the semi-mobile processing plant

that the last quarter of the screening surface has somewhat larger apertures, which allows for earlier separation of smaller particles and later separation of larger particles, which stay on the screening surface longer and are therefore more thoroughly washed. The nozzles can be adjusted individually (they can turn in different directions, independently from each other, and the pressure can be adjusted for each of them individually, with each having its own valve). The nozzle system is physically detached from the screen, which results in a lower risk of malfunctioning and greater durability. The rubber screen panels prevent an additional loss of water, the ejection of material from the screen, and the soaking of the area around the screen. The screening surface is made of polyurethane so replacing it is quick and simple. The undersize material from the screen *(6)* (the -4 mm grain size) moves on to the retaining reservoir, and from there to the first hydrocyclone *(7)*, with a diameter of 625 mm. The apex from the first hydrocyclone moves on to the dewatering screen *(9)*, where the nozzles for the washing control are also located. The oversize material from the dewatering screen (the -4 mm grain size) goes to final the products dump, while the undersize material, along with the wastewater, moves on to the second hydrocyclone, *(8)* with a diameter of 400 mm. After classification, the coarse solids from the second hydrocyclone goes to the second dewatering screen *(10)*, where the -4 mm grain size is also separated, but with a greater tiny particle content than in the previous hydrocyclone. The overflow from both hydrocyclones goes to the wastewater treatment plant. This plant consists of a flocculant preparation unit and a thickener (sedimentation pool), where the finest particles are sedimented. The overflow from the thickener is clean enough to be reused as wash water.

Fig. 3 – Semi-mobile processing plant M2500 E5X

Wash water treatment

Wash water treatment, i.e. solid-liquid separation, already begins in the hydrocyclones as part of the processing procedure. Although the hydrocyclones are used in this case to reduce the loss of fine particles of the -4 mm grain size to a minimum, they also contribute to eliminating solid particles from the water. Most of the solid particles are separated in the apex from the hydrocyclone and thereby end up in final products dump, while most of the water containing the finest particles (-0,063 mm) is separated in the vortex from the hydrocyclone. These finest particles are then separated in the thickener (sedimentation pool). The separation of the solid-liquid two-phase system has long been the focus of many researchers (Burger et al., 2001, Garrido et al., 2003, Somasundaran et al., 2003, Svarovsky, 1990), who state that the settling of tiny particles follows Stokes's law and depends on the diameter of the particle, the density of the particle, and the viscosity of the medium in which the settling occurs. Seeing as fine particles have a small settling velocity, the process needs to be accelerated by adding a flocculant. In order to avoid a harmful effect on the environment, this plant uses a starch-based polyelectrolyte as a flocculant, which is usually used in the production of potable water. The flocculant preparation chamber consists of three parts. In the first part, clean water enters the chamber; in the second, a flocculant in powder form is added and dissolved in the water; this prepared flocculant then goes to the third part, where it is retained until use. The prepared flocculant solution is added to wastewater in a special container, which results in a reaction between the flocculant and the solid particles in the suspension (Figure 4). The reaction occurs very quickly (around 9 seconds) and is followed by sedimentation in the thickener (sedimentation pool).

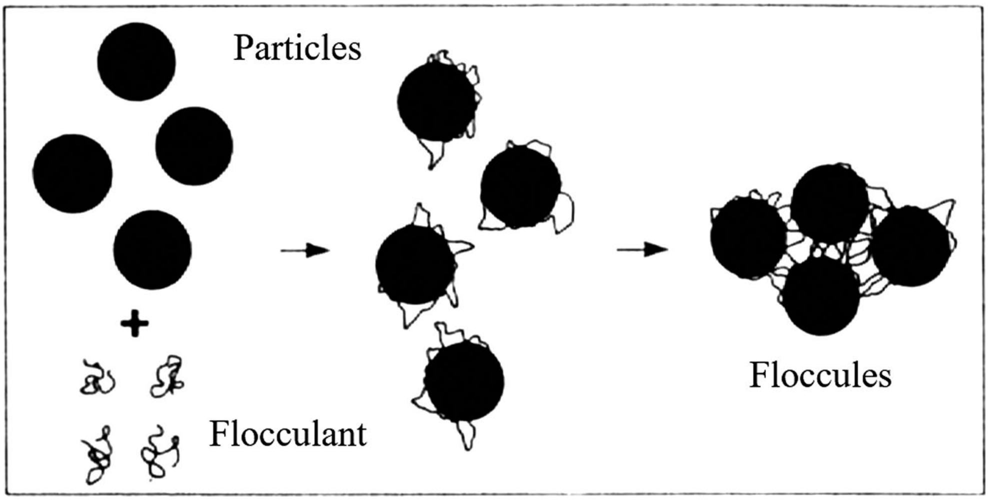

Fig. 4 – Combining of tiny particles into floccules (Bedeković & Stipetić, 2007)

After the addition of the flocculant, tiny particles combine into larger particles, or floccules. Due to their larger diameter, the floccules have a significantly higher settling velocity (the settling velocity increases with the root of the particle diameter) so sedimentation occurs much faster. The overflow from the thickener is clean water which is then reused for mineral processing, while mud settles on the bottom and is occasionally emptied into a settling basin, measuring 85 x 30 x 2.5 m. After it dries sufficiently, the sedimented mud is used to recultivate surface mines and as raw material in the ceramics industry. The capacity of the thickener is 400 m^3/h, while the total water needs of the processing plant amount to 250 m^3/h, from which 221 m^3/h (88.4 %) is acquired through wastewater treatment and 29 m^3/h (11.6 %) comes from adding fresh water into the process.

High-pressure pre-washing chamber

Eliminating fine particles of clay from the material, which stick firmly to larger grains or in agglomerates, is one of the tasks of mineral processing that can be further improved through the use of the high-pressure pre-washing chamber HYDRO-CLEAN®. This chamber is usually implemented into the mineral processing procedure before the usual washing on vibrating screens. The operating principle of the chamber is shown in Fig. 5.

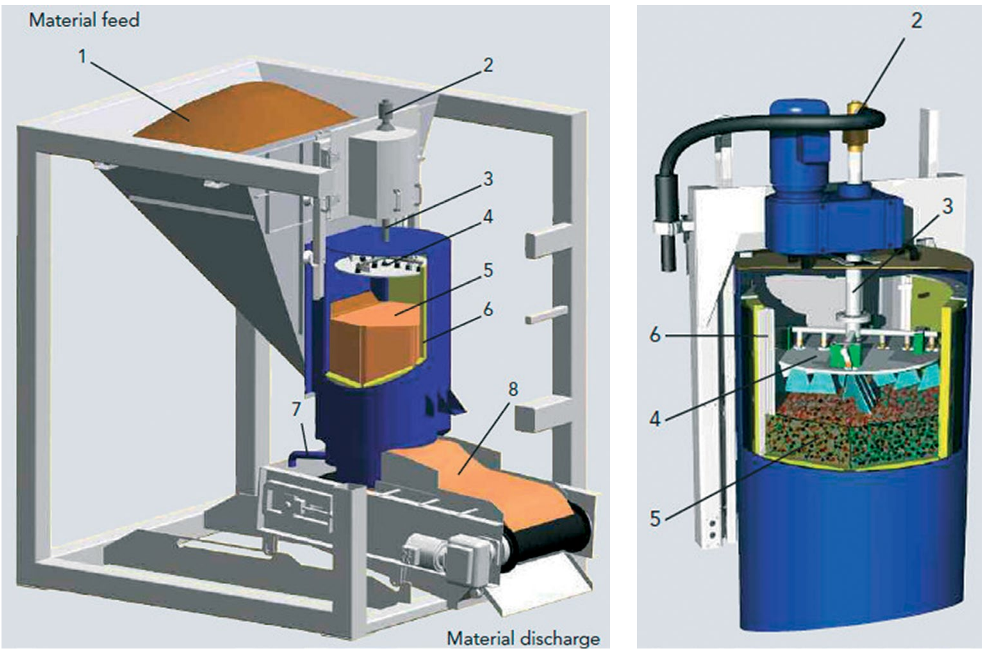

Fig. 5 – The HAVER Hydro-Clean high-pressure pre-washing chamber and a close-up of the washing drum (Haver & Boecker, 2014)

Dry material with a grain size of up to 120 mm, contaminated with fine particles, enters the chamber through the receiving hopper *(1)* and goes to the washing drum with a rotating disc *(4)* which holds high-pressure nozzles. The high-pressure water input *(2)* is located above the drum and reaches the nozzles through the drive shaft *(3)* of the rotor. Due to the high speed of the rotor (100 rpm) and the high water pressure (up to 150 Bar) the material is constantly mixed, which results in friction between individual grains, scattering, swirling and intensive shifting of the material bed *(5)* in the washing drum. The jets of water penetrate into the pores and fissures of mineral particles. Thus, cleaning is the consequence of the impact of the jets of water into individual grains and the mixing of the grains inside the bed. The material is retained in the washing chamber for approximately 3 seconds, during which time the mineral grains are exposed to the high-pressure water jets multiple times. Water containing fine particles passes through the PU filter *(6)* located along the edge of the chamber. The purified water exits through a separate pipe *(7)*, while the washed material falls onto the conveyor *(8)* and exits the chamber in this manner.

Wear and tear inside the device is minimal, as the moving parts (the rotor with the nozzles) are placed outside the flow of the material through the device. Water consumption is small and amounts to 0.1 to 0.2 m^3 per ton of material, so the amount of wastewater produced is small as well. The capacity for material washing is relatively high (up to 320 t/h), while the effectiveness of washing has been confirmed in various industries, such as mining, industrial mineral processing, construction waste recycling, solid waste recycling, etc. Implementing the high-pressure pre-washing chamber into the mineral processing procedure would further improve the purity of the crushed stone.

Results and Discussion

This chapter presents a comparison of the vital technical and economic indicators in the mining and processing of crushed stone in the old stationary and new semi-mobile plant, using the example of the “Oršulica kosa” exploitation field. Crushed stone is a mineral resource which does not have a high market price. Therefore, the costs of the individual technological stages can have a significant impact on the mining and processing of crushed stone. When comparing two different aforementioned variants, the costs of extracting the mineral resource from the stone massif in the stage of removing the overburden, drilling, mining, and loading are the same in both variants. The differences in the costs stem from the different length of the transportation route and the processing technology.

Transportation costs

In regard to transportation costs, the differences stem from the length of the transportation route. The length of the transportation route to the stationary processing plant is 1950 m (Figure 6), while the semi-mobile processing plant is located on the main working plateau of the quarry, where the final products dump will also be located (Vrkljan et al. 2011). This "added cost" of transportation due to the location of the semi-mobile plant will be borne in total by the buyer, but since transportation is the primary activity of buyers in any case, for them these costs will be negligible. From the point of view of the quarry's costs, the acquisition and maintenance of dumpers and trucks which would perform the transportation only in the area of the exploitation field amounts to a significant increase in transportation costs. The planned annual production of crushed stone is 150,000 m^3 in solid rock and the costs of the stationary and the semi-mobile plant will be compared in accordance with this figure. Out of the total annual production, it is scheduled that 60 % of the mineral resource be processed using the wet procedure (stone aggregates for the manufacture of concrete and asphalt).

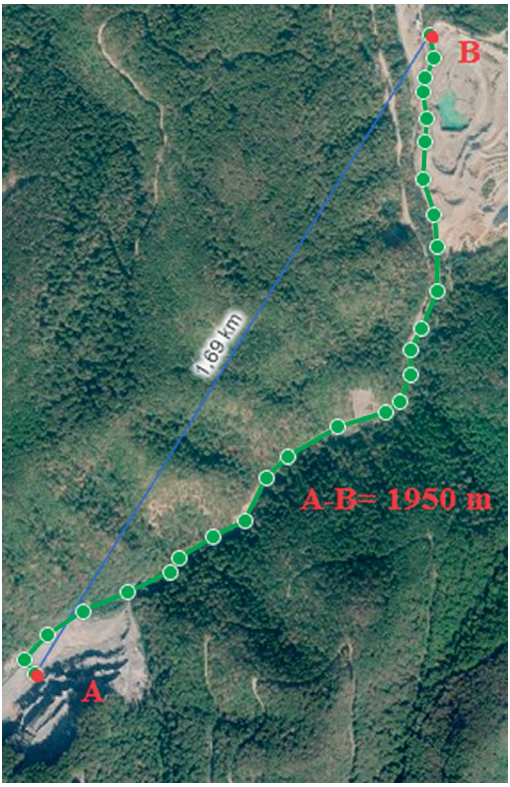

Fig. 6 – Transportation route (A-B) from the "Oršulica kosa" exploitation field to the "Hercegovac" stationary processing plant (ARKOD, 2018)

The transportation length can vary depending on the progress of mining work and the position of the mining sites; in our calculation, the median distance of 1,950 m during the mining period was used. The unit-based transport costs are expressed on an annual level per tonne of end stone products. Experiential data on the cost of a working hour of a Bell 40 dumper, which is used for transportation to the stationary plant, was used in the calculation. Out of the existing machinery in the quarry, the Bell 40 dumper has the greatest skip capacity and is one of the newest machines; if a dumper with a smaller load capacity and/or skip volume were used, the transportation costs would be even greater.

Calculation of transportation cycle t_c

$$t_v=(2\cdot s_{pr}\cdot 60)/V_d=(2\cdot 1950\cdot 60)/23=10.2 \text{ min}$$

$$t_c=t_{ud}+t_v+t_p+t_m+t_{\sim}+t_z=4.1+10.2+1.0+0.5+0.3+0.5=16.6 \text{ min}$$

where t_v is the duration of driving of the full and empty dumper (min); s_{pr} is the average transportation length (km); V_d is the volume of the dumper's skip (m^3); t_c is the duration of the dumper's cycle (min): t_{ud} is the duration of loading the dumper (min); t_p is the duration of emptying the dumper (min); t_m is the duration of manoeuvring the dumper (min); $t_{\sim}$ is the waiting time for loading and emptying (min); t_z is the duration of unexpected delays (min).

Calculation of hourly transport capacity Q_{hd}:

$$Q_{hd}=(60\cdot G_{ds}\cdot k_v)/t_c=(60\cdot 36\cdot 0.9)/16.6 = 117 \text{ t/h}$$

where Q_{hd} is the hourly capacity of the dumper (t/h); G_{ds} is the load capacity of the dumper (t); k_v is the time efficiency coefficient; t_c is the duration of the dumper's cycle (min).

Calculation of effective working hours of the dumper per annum:

$$h_{hg}=(Q_g\cdot \rho) / Q_{hd} = (150\,000 \cdot 2.834) / 117 = 3633 \text{ h}$$

where h_{hg} is the number of effective working hours of the dumper (hours); Q_g is the extraction of crushed stone per annum (m^3); ρ is the bulk per unit of volume of crushed stone (t/m^3); Q_{hd} is the hourly capacity of the dumper (t/h).

Transportation costs per annum:

$$T_{tg}=h_{hg}\cdot T_h=3640\cdot 469.37= 1\ 708\ 252 \text{ kn}$$

where T_{tg} are the transportation costs per annum (kn); h_{hg} is the number of working hours of the dumper per annum (h); T_h is the cost of a working hour for the Bell B40D dumper (kn).

Unit cost of transportation:

$$T_t=T_{tg} / (Q_g\cdot \rho) = 1\ 708\ 252 / (150\ 000 \cdot 2.834) = 4.01 \text{ kn/t}$$

where T_t is the unit cost of transportation (kn/t); T_{tg} are the transportation costs per annum (kn); Q_g is the extraction of crushed stone per annum (m^3); ρ is the bulk per unit of volume of crushed stone (t/m^3).

Costs of processing crushed stone

Mineral processing is performed using machines that run on electricity; therefore, the costs of processing are expressed through electric energy consumption. Moreover, seeing as this is wet processing technology, along with the electric energy consumption, the costs of water consumption also need to be taken into account.

The electric energy costs were calculated for both the stationary and the semi-mobile plant. The input data for the calculation were reduced to the hourly capacity of the plant and electric energy consumption per hour.

Rate of electric energy consumption:

The "Hercegovac" stationary plant	The M2500 semi-mobile plant
$N_{el.}=P_{el.} / Q_h = 400/80 = 5$	$N_{el.}=P_{el.} / Q_h = 250/150 = 1.67$

Unit cost of electric energy:

The "Hercegovac" stationary plant	The M2500 semi-mobile plant
$T_{el.j}=T_{el.}\cdot N_{el.}=1\cdot 5= 5$ kn/t	$T_{el.j}=T_{el.}\cdot N_{el.}=1\cdot 1.67= 1.67$ kn/t

where $N_{el.}$ is the rate of electric energy consumption (kWh/t); $P_{el.}$ is the electric energy consumption (kWh); Q_h is the plant capacity (t/h); $T_{el.j}$ is the unit cost of electric energy (kn/t); $T_{el.}$ is the cost of electric energy (kn/kWh); $N_{el.}$ is the rate of consumption (kWh/t).

We have already mentioned that due to the properties of the mineral resource, a wet processing procedure is used; it is, therefore, necessary to add the cost of water to the costs of crushed stone processing. Thus, what follows is the calculation of the costs of water for the stationary and the semi-mobile processing plants.

Rate of water consumption in processing:

The "Hercegovac" stationary plant	The M2500 semi-mobile plant
$N_v=P_v / Q_h = 160/80 = 2\ m^3/t$	$N_v=P_v / Q_h = 30/150 = 0.2\ m^3/t$

Unit cost of water:

The "Hercegovac" stationary plant	The M2500 semi-mobile plant
$T_{vj}=T_v \cdot N_v=0.5 \cdot 2= 1$ kn/t	$T_{vj}=T_v \cdot N_v=0.5 \cdot 0.2= 0.1$ kn/t

where N_v is the rate of water consumption (m^3/t); P_v is the water consumption (m^3/h); Q_h is the plant capacity (t/h); T_{vj} is the unit cost of water (kn/t); T_v is the cost of water (kn); N_v is the rate of consumption (m^3/t).

From the first set of results, we can see that the unit cost of transportation to the "Hercegovac" stationary processing plant amounts, at best, to 4.01 kn/t, while with the semi-mobile plant this cost is non-existent, seeing as it is located on the main work plateau of the quarry.

From the calculation of the processing costs, we can see that using the M2500 semi-mobile plant, as opposed to the old "Hercegovac" stationary plant, it is possible to achieve savings in the unit cost of electric energy of 3.33 kn/t of processed crushed stone. Despite a greater mineral processing capacity, the use of new technologies and tighter performance, i.e. reduced transportation of resources within the plant and, thereby, reduced load, result in a significant decrease in electric energy consumption.

Additional savings will be achieved through reduced maintenance costs, which would be accrued with the stationary plant due to its age and the worn-out condition of the equipment. Savings can also be achieved in the number of necessary jobs, seeing as one worker-operator is sufficient for the new semi-mobile plant, while the older plant required more workers due to its large size and surface area.

From the calculation of the processing costs, we can see that it is possible to achieve savings in the unit cost of water of 0.9 kn/t. Given the significant increase in capacity of the new semi-mobile plant and the recirculation of wastewater, the consumption of fresh water entering the system has been reduced tenfold. In addition, the process of washing employed thus far was done by purifying the water through sedimentation in large settling basins. By using the new semi-mobile plant and the system for wastewater treatment, the existing settling basins will be replaced by a single, smaller settling basin. Therefore, despite the costs of purchasing flocculant and maintaining the wastewater treatment plant, there will be a significant decrease in the costs related to maintaining large settling basins, as well as a decrease in the space that is used up by them.

The projected production of crushed stone in the "Oršulica kosa" exploitation field per annum is 150,000 m^3 in solid rock. Out of this amount, 60 % is planned to be used for the production of aggregate for the manufacture of concrete and asphalt, while the remaining 40 % would be sold as mixtures or ballast. Therefore, with a bulk per unit of volume of 2,834 t/m^3, the production of aggregate per annum (P_g) in the semi-mobile processing plant would amount to:

$$P_g = 150\,000 \cdot 2.834 \cdot 0.6 = 255\,060 \text{ t}$$

In order to determine the time period in which there would be a return on investment through savings, it is necessary to compare the total investments with the savings per annum. Therefore, Tables 1 and 2 present an overview of the costs of investment and the pertaining savings.

Table 1 – Savings per annum

Savings parameter	Savings in unit cost kn/t	Production per annum t	Savings per annum kn
Transportation	4.01	255 060	1 022 790
Water	0.90	255 060	229 554
Electric energy	3.33	255 060	849 349
		Total:	2 101 693

Table 2 – Costs of investing in a semi-mobile processing plant

Type of investment	Amount, kn		
Purchasing the plant	6 375 000		
Setting up the plant	375 000		
Preparing the ground surface	187 500		
Installing electricity and water at the exploitation field	187 500		
		Total:	7 125 000

Based on the data in Tables 1 and 2, we can calculate the time required for the return on investments through savings:

$$G_p=U_i / U_u = 7\ 125\ 000 / 2\ 101\ 693 =3.39 \approx 3.5 \text{ years}$$

where U_i is the total amount of investment; U_u are the total savings; G_p is the number of years for the return on investments.

Conclusions

Crushed stone is a mineral resource that does not have a high market price, which makes it more susceptible to the effects of extraction costs. The method of mining the stone from the stone massif is the same in both of the compared variants; thus, there is no difference in cost in that stage of extraction. Based on the comparison of the results on the crucial technical and economic indicators manifested in the stationary and the semi-mobile plants in processing crushed stone, the following conclusions can be derived.

A significant advantage of the semi-mobile plant is that it can be brought to any location and can thus virtually eliminate the transportation costs within the exploitation field, as opposed to the stationary plant, to which the material needs to be transported for processing. The calculations show that the median transportation cost to the stationary plant during extraction amounts to 4.01 kn/t. Thus, with a median transportation length of 1,950 m to the stationary plant and an effective production capacity of 150,000 m^3 in solid rock, by using a semi-mobile plant, it is possible to achieve direct savings of 1.7 million kunas per annum on average.

The largest consumer of electric energy in the quarry is the processing plant. The unit cost of electric energy in the stationary plant is three times higher than that of the semi-mobile plant (5 kn/t compared to 1.67 kn/t). By using the semi-mobile plant, it is possible to achieve savings in electric energy consumption amounting to approximately 0.85 million kunas per annum.

Seeing as we deal with a wet processing procedure, water consumption has also been taken into account. The unit cost of water in the stationary plant is ten times higher than in the semi-mobile plant (1 kn/t compared to 0.1 kn/t). Savings in water necessary for processing when using the semi-mobile plant amount to approximately 0.23 million kunas per annum.

Taking the aforementioned savings into account, we can conclude that by using the new semi-mobile plant instead of the old stationary one, it is possible to achieve savings of approximately 2.1 million kunas per annum. Considering the total investment cost is approximately 7.1 million kunas, the return on investment should be realized in a relatively short period of 3.5 years.

Besides the aforementioned direct economic benefit, we should also emphasize the environmental benefits. The new semi-mobile plant is equipped with a system for purifying and recirculating wastewater and works with a minimal addition of fresh water into the system, amounting to 29 m^3/h (11.6 %), while the mud that is a by-product of purifying the water contains far less moisture than the mud created in the stationary plant. Another consequence of the greater amounts of wastewater in the old stationary plant was a larger surface area occupied by settling basins, while that surface area is significantly decreased when using the new semi-mobile plant. The mud created during the processing is used for recultivating quarries or is sold as a raw material for the ceramics industry. From all of the above, we can conclude that using the new semi-mobile plant will significantly decrease the production costs of crushed stone and will decrease the environmental impact of production.

Acknowledgements

We would like to thank the IGM “Radlovac” d.d. corporation for giving us access to the data used in the paper.

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Nanotechnology Applied to Create a New Generation of Multifunctional Construction Materials

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Abstract: Nanotechnology is a technology which uses particles whose size is a billionth part of a metre. Nanotechnology has become one of the most influential technologies in this century, since it is successfully applied in a growing number of industries, including construction industry, mostly in the production of construction materials. Among all the materials used in construction, concrete makes almost 70%. Nanotechnology has helped produce concrete of high performance properties. In the production of concrete, nanotechnology is used for producing and adding nanoparticles to concrete in appropriate proportions by appropriate methods.

This paper gives an overview of how nanotechnology is used to create multifunctional construction materials, such as a new generation of cement composite concrete, steel, glass, coatings, plastic, insulation, fire protection materials and others. The paper concludes with the review of benefits and challenges for a wider industrial application of nanotechnology in the construction industry.

Keywords: nanosilica powder, nanotitanium dioxide, nanoclays, nanocarbon tubes

Introduction

Nanotechnology was primarily developed in physics and chemistry, and is still developing under the name of nanoscience in these fields, but also in engineering. Generally speaking, nanotechnology is a technology that uses particles whose size is a billionth part of a metre, and nanoscience deals with measuring and characterization on the level of nano and micro structures of materials, with the aim to better understand the impact of such structures on properties on the macro level, as well as on the properties when structures are used by applying advanced techniques and by modelling on the atomic and molecular levels. Today, nanotechnology within nanoengineering is a part of applied science in almost all materials. In the construction industry it is mostly applied in the production of construction materials and in the protection from environmental effects, Figure 1. (1).

Nanoengineering uses materials and techniques of nanosizes with the purpose of producing multifunctional composite materials of superior mechanical properties and durability and also of considerably modified properties, such as low electrical resistance, self-sensing, self- cleaning, self-repairing, high ductility, self-control of cracking etc. So the key to nanotechnology is particle size, because material properties change under the influence of particle size in nanometres (10^{-9} metre).

<table>
<tr><td rowspan="12">Nanotechnology axes enable</td><td rowspan="5">Materials</td><td colspan="2">Structural materials</td><td>Non-structural materials</td></tr>
<tr><td colspan="2">Nanotech cement/ concrete</td><td>Glass</td></tr>
<tr><td colspan="2">Steel</td><td>Plastics and polymers</td></tr>
<tr><td colspan="2">Wood</td><td>Dry wall</td></tr>
<tr><td colspan="2">New structural materials</td><td>Roofing</td></tr>
<tr><td rowspan="7">Protection</td><td colspan="3">Filtration, Air purification
(Indoor air quality - Outdoor air purification)</td></tr>
<tr><td colspan="3">Coatings
Self-cleaning (Lotus-Effects - Photocatalysis), (ETC), Antibacterial</td></tr>
<tr><td rowspan="3">Energy</td><td rowspan="2">Reduction of energy consumption</td><td>Lighting</td></tr>
<tr><td>Insulation
VIPs - Aerogel - Nanogel and High performance day lighting - Thin-film Insulation - PCMs</td></tr>
<tr><td colspan="2">Electronics / Sensors</td></tr>
<tr><td colspan="3">Energy production</td></tr>
</table>

Fig. 1 – Nanotechnology in construction materials (1)

When particles are nanosized, the proportion of atoms on the surface increases with respect to the atoms inside, causing nanoeffects which modify all known properties if the material is viewed macroscopically. The RILEM TC 197-NCM report, "Nanotechnology in construction materials" (2), is the first document which clearly defines the potential of nanotechnology in developing construction materials in the following fields:

- Application of nanoparticles, carbon nanotubes and nanofibres with the purpose of enhancing strength and durability of cement composites, as well as for pollution reduction,
- Production of cheap and corrosion resistant steel,
- Production of thermal insulation,
- Production of cladding, coatings and thin filaments with the property of self-cleaning, self-adhesivity and/or reduction of energy consumption

Also, according to (2) compared to the use in practice research has far advanced as shown in Tables 1 and 2.

Table 1 – Nanomaterial in research and application (2)

Awareness of nanorelated research and applications	% of those responded	
	Academics/ researchers	Industrial personnel
Understanding phenomena (e. g. cement hydration) at nanoscale	82	58
Nanoparticles, fillers and admixtures	80	37
Nanostructure modified materials (e. g. steel, cement, composites)	73	26
New functional and structural materials	61	26
Surface/ interface assessment, engineering	55	21
Special coatings, paints and thin films	45	21
Integrated structural monitoring and diagnostic systems	39	11
Self-repairing and smart materials	31	11
New thermal and insulation materials	20	11
Intelligent construction tools, control devices/ systems	22	11
Energy applications for buildings - new fuel cells and solar cells	24	0
Biomimic and hybrid materials	20	0

Table 2 – Application of nanotechnology by fields in the construction industry (2)

Involvement in nano-related activities which are potentially applicable to construction	% of those responded	
	Academics/ researchers	Industrial personnel
High performance structural materials	80	37
Understanding phenomena at nanoscale	69	21
Multifunctional materials/ components	40	11
Modelling/ simulation of nanostructures	38	5
Nanoscale techniques/ instruments	31	11
Smart materials and intelligent systems	29	16

This paper gives a wide overview of the use of nanotechnology in construction materials, cement composites, steel, glass, coatings, plastic, insulation, fire protection materials and other latest applications. A summarized table overview of nanotechnology in the construction industry is given in Table 3, and some basic, and according to authors, most possible applications in the construction industry are described in detail.

Table 3 – Review of nanoparticles and their application in construction industry (60)

Nano particles	Application areas
Nano-silica (SiO_2)	Replaces part of the cement to densify the concrete and gain early strength Improving pavement surface characteristics
Micro silica (silica fume)	Increase compressive strength and flexural strength in concrete
Carbon nanotubes (SWCNTs or MWCNTs)	Increase compressive strength and flexural strength in concrete It can be utilized self-sensing concrete for monitoring the structural conditions
Nanophosphorus	Improving road visibility
Nano TiO_2	Self-cleaning of concrete pavement
Polymer fibre matrix using nanosilica	Self-structural health monitoring system in repairs & rehabilitation
High performance steel using copper nanoparticles	In bridges for corrosion resistance & better weld ability
Nanotechnology enabled sensors	To monitor and control temperature, moisture, smoke, noise, stresses, vibrations, cracks and corrosion

Nanotechnology in cement composites

Cement composites are all composite construction materials in which cement is used as binding, coating, mortar and plaster and concrete. Concrete, as the most widely used material in the world, is a multiphase composite material whose properties change with time, therefore it should be investigated by using 4D approach. The amorphous phase of concrete, C-S-H gel, is a crystal structure, the size of crystals ranging from a nanometre to a micrometre, in concrete it serves as an "adhesive" by keeping other components of concrete together (3).

Nanomaterials can be added to cement composites in the following forms:

- Nanoparticles,
- Nanoreinforcements: nanofibres and carbon nanotubes.

According to literature (3-12), it can be stated that the application of nanosilica results in a multifunctional effect, as shown in Fig. 2 (11).

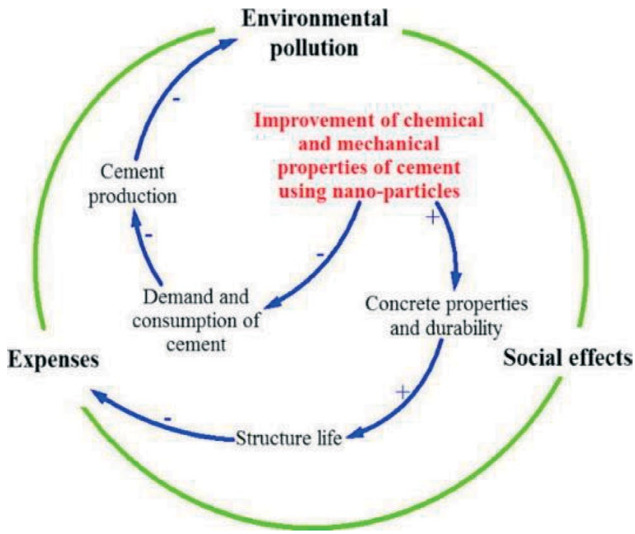

Fig. 2 – The role of nanoparticles in the sustainable development of construction industry (11)

Nanoparticles

Nano particles, Fig. 3, (3), have a large specific surface, and thus a large potential for physical-chemical reactions.

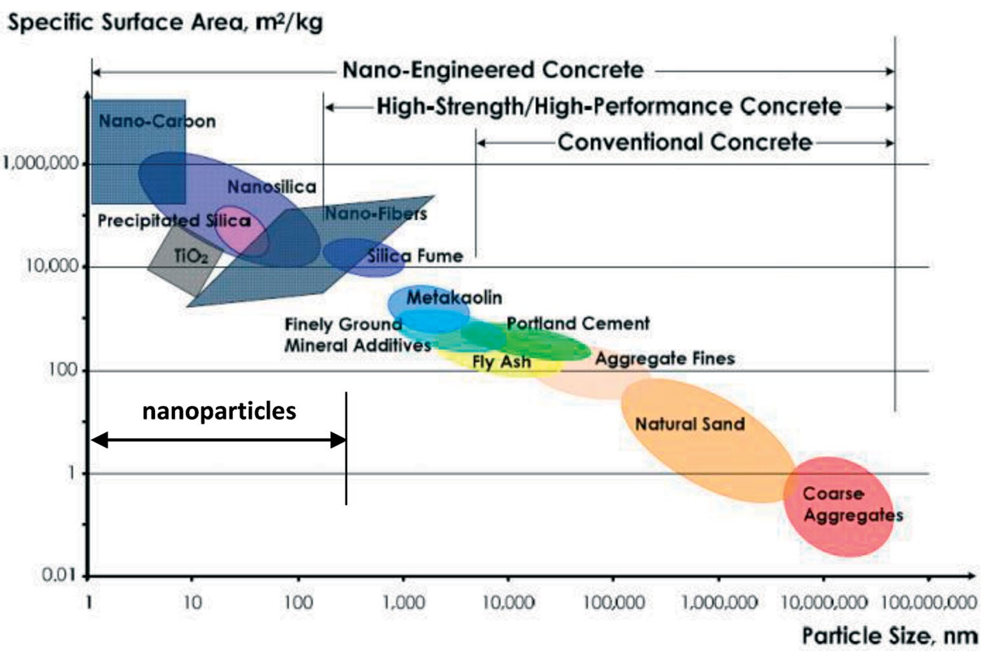

Fig. 3 – The size of particles and specific surfaces of concrete components (3)

Apart from the advantages of nanoparticles in cement composites there is one disadvantage, and this is a tendency to create nanoparticle aggregates, Fig. 4 (4). Therefore, it should be noted that every research into the impact of nanoparticles on properties of, e.g. cement composites, has emphasized the need for preliminary pre-treatment in special solutions and the dispersion of nanoparticles in water before they are added to the mixture of fresh composite. Dispersion is produced by a special method of using ultra sound waves, so called ultrasonification. Ultrasonification is an effective method of dispersing nanoparticles and, as can be seen in Fig. 5 (5), the method successfully breaks nanoparticle aggregates.

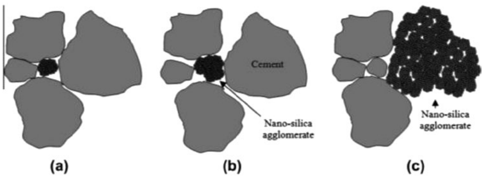

Fig. 4 – Illustration of the filling effect of nano-silica agglomerates (4)

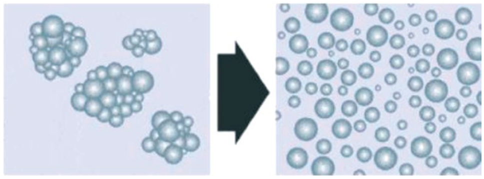

Fig. 5 – Dispersion and deagglomeration by ultrasonication (5)

Nanosilica powder

Silica powder is a by-product of producing silica and ferrosilicon alloys in electric arc furnaces, of a very fine granulation, and ranging from light to dark grey colour (3), Fig.6a.

Nanosilica powder or nano-SiO_2, Fig. 6a (6), with a very fine granulation, Fig. 6b (7), fills the gaps between C-S-H gel particles in cement composites, and acts as a nano-filler. Nano- SiO_2 does not only behave as a filler, filling a microstructure, but also as a

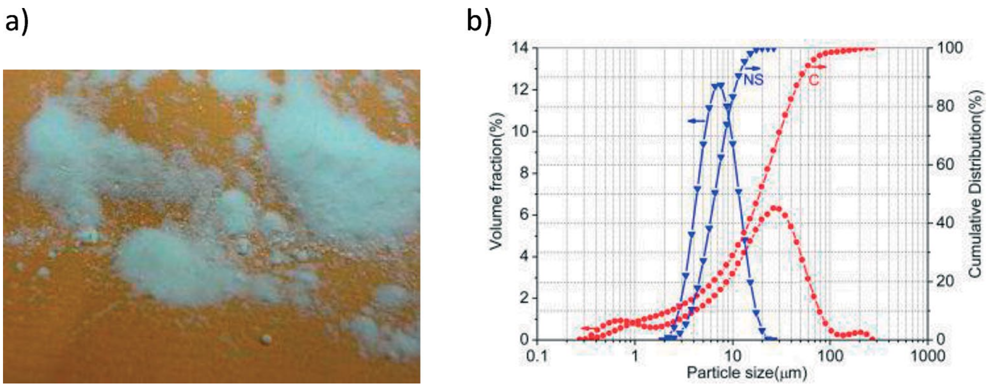

Fig. 6 –. Nano-silica, a) Nano silica sample (6), b) Particle size distribution of cement (C) and nano silica powder (NS) in laser diffraction analysis (7)

pozzolanic reaction stimulant. The pozzolanic reaction with calcium hydroxide increases the quantity of C-S-H gel, Fig. 7 (8), which results in higher matrix density, which increases workability, decreases porosity, increases strength and durability of the composite, increases impermeability and reduces the possibility of leaching (8, 9).

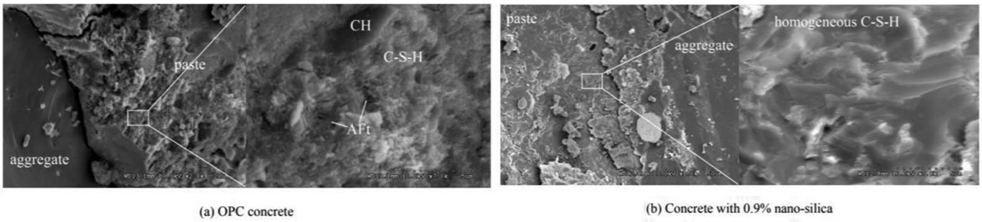

Fig. 7 – Microstructure morphologies at the interfacial transition zone (8)

Even the addition of small quantities of nanosilica, for instance, 0.25% in concrete, increases compressive strength by 10% and bending strength by 25%. Only 15 to 20 kg of nanosilica added achieve the same strength as 60 kg silica powder added (2). Still, the stated results largely depend on the manner of production and the conditions of nano SiO_2 synthesis, e.g. molar ratio of reagents, type of substances used for reaction, the duration of reaction of the so called sol-gel process and the dispersion of nano SiO_2 in cement paste.

Nanotitanium dioxide

Nanotitanium dioxide, nano TiO_2, Fig. 8 (12) has turned out to be very effective for self- cleaning of concrete and also has an additional positive impact on the environment. Photocatalytic efficiency of nanoparticles TiO_2 depends on different parameters, which will determine two basic processes of photocatalysis, that is, absorption of molecules of pollutant substances and the separation after absorption of UV photons (13, 14), Fig. 9 (14).

Fig. 8 – Nano TiO_2 powder (12)

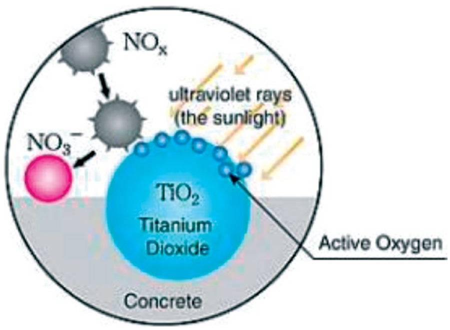

Fig. 9 – Photocatalytic cicle of nano TiO_2 activity (14)

Since the properties of absorption and charge separation depend on the basic properties of TiO_2 particles and the chemical properties of the pollutant, there is no universally acknowledged TiO_2 photocatalyst. Instead, there are many types of nano TiO_2 particles, each of different properties which make them variable, depending on the specific type of pollutant.

Concrete consisting of nano TiO_2 acts through photocatalysis to degrade traffic pollution and industrial emissions (3). The Italian concrete industry has produced white cement consisting of TiO_2 nanoparticles with photocatalytic properties which allow the maintenance of aesthetic features of architectural and decorative concretes over time with the additional benefit of removing pollutants. White cement containing photocatalytic self-cleaning nanoparticles has been used to construct the modernist church *Dives in Misericordia* in Rome, Fig. 10a, *Music and Art City Hall*, Chambery, France, Fig. 10b, *Via Porpora*, Milan, Italy, *Umberto I* tunnel, Rome, Italy, Fig. 10c, *Camden Council*, London UK, *Toyota Tsunami* plant, Saitama, Japan and others.

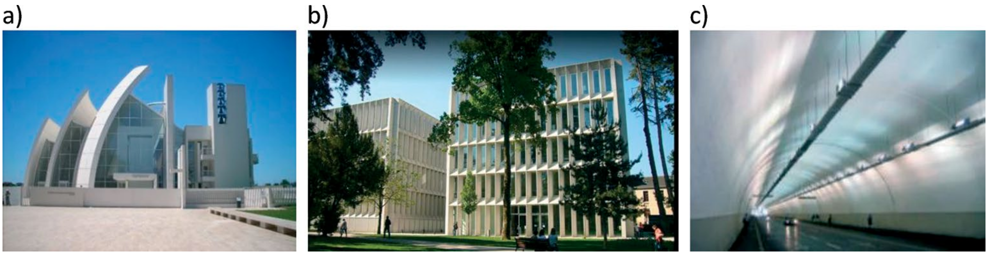

Fig. 10 – a) Church *Dives in Misericordia* in Rome, Italy (14), b) *Music and Art City Hall*, Chambery, France, (15), c) *Umberto tunnel I*, Rome, Italy (15)

In research (15) nano- modified Portland cement paste with water to cement ratio of 0.4, was prepared by adding TiO_2 nanoparticles of 0.1, 0.5 and 1.5 % per cement mass. Bending

strengths of the prepared composites were investigated, and breaking surfaces were observed afterwards by a scanning electron microscope (SEM). Bending strength of nano- modified TiO_2 Portland cement paste reached the highest value at dozes of 1.0% per cement mass. SEM scans show that the added TiO_2 nano particles considerably reduce the quantity of inner micropores in cement paste, and that nanoroughness of hardened cement paste with added TiO_2 nanoparticles is much lower compared to the ones without TiO_2, Fig. 11 (16).

According to (17-22) there is an increased use of nanotitanium dioxide in porous concretes on road surfaces for the purpose of reducing environmental pollution.

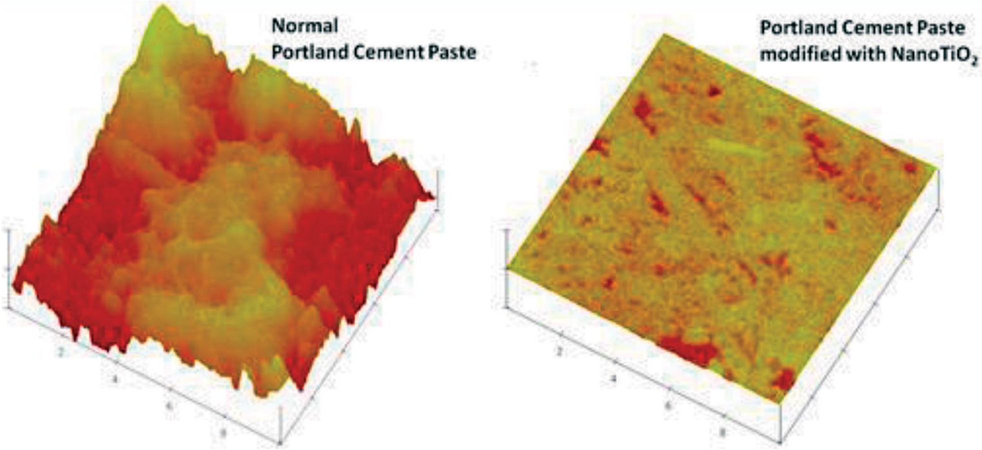

Fig. 11 – The surface nanoroughnes of cement paste on breaking surface after testing bending strength (16)

There are two efficient ways of introducing nano TiO_2 into concrete pavements which degrade exhaust gases from vehicles. One way is when nano TiO_2, together with concrete additives, is added to the concrete of the upper layer of pavement structures, and the other is when nano TiO_2, with added penetrates and dispersers, is sprayed over the surface of pavement structures. At present, there are several pilot projects of photocatalytic sidewalks, of which some are being planned and some have been built. One example is a highway section built in 2011 in St. Louis, MO, USA (18), and another one is in Japan, Fig. 12 (22). The trial sections will be monitored and compared with similar data collected throughout the year on the neighbouring part of the highway containing no nano TiO_2. The air quality will be also monitored on and near the highway on multiple levels. Testing in Europe has also shown that the material helps reduce smog in urban areas.

Fig. 12 – The use of TiO_2 photocatalytic material on a pavement structure for the purpose of reducing pollution in Japan, a) application of coating b) pavement structure with the lighter part where coating has been applied (22)

Research in (19) has shown that over time, as carbonization of concrete occurs, self-cleaning property is reduced, but further research is being conducted with the aim to find the effect of recreating self-cleaning property. Like nanosilica, the addition of nano TiO_2 to concrete accelerates early cement hydration, enhances pressure and tensile strength of concrete and increases wear resistance (3).

Nanoiron oxide

Nanoiron oxide, nano Fe_2O_3, when added to concrete, gives it the property of self-sensing. Detecting the change of electrical resistance while testing the compressive strength of concrete with added nano Fe_2O_3 has offered the possibility of monitoring concrete structures in real time by using the same principle (23). However, more extensive tests into the impact of nano Fe_2O_3 on concrete properties are required. Nazari and others (24) point out that, apart from the favourable effect on the compressive strength of concrete when nano Fe_2O_3 is added, concrete also loses its workability, and the percentage of optimal dosage has not been yet investigated.

Nanoaluminum oxide, nanozinc oxide and nanozirconium oxide

The addition of nano Al_2O_3, nano-ZnO_2, nano-ZrO_2 to concrete with an optimum dosage of 1 to 3% per cement mass improves the properties of fresh concrete by filler effect, and improves almost all properties of hardened concrete by pozzolanic reaction (25-27).

Concrete and reinforcement bond is fundamental in providing the behaviour of reinforced concrete elements, that is, in providing durability and ultimate limit states. In research (28) it has been concluded that the addition of Al_2O_3 and SiO_2 nanoparticles to concrete ensures the increased strength of bonding of concrete and reinforcement for the mixtures with a higher cement content (~ 300 kg/m^3). It has also been established that Al_2O_3 nanoparticles have a positive effect on reducing cracking.

Nanoclays

Nano clays are cheaper than other nanomaterials because the basic material comes from easily accessible natural resources and because they are produced in existing production plants. Organically treated clays are often used in many industrial branches due to their specific particle activity and attractive adsorptive properties. Organically modified montmorillonite clays (OMMT), which are widely used in polymer/clay nanocomposites (PCN), since the beginning of the 21st century have been intensively investigated as fillers and reinforcement in cement mortars (29). Namely, due to their hydrophilic properties montmorillonite nanoclays cannot be directly used in concrete because the water absorbed in interlayers between silicate boards cause unfavourable expansion, which can be extremely unfavourable and harmful to concrete. OMMT micro and nanoparticles modified by cation exchange become hydrophobic and as such suitable for use in concrete in which they enhance its strength and permeability. Research into the application of nanoclay in self- compacting concrete has shown that even in small doses (1%) concrete has the property of "spreading" and at the same time it is of a stable shape with a minimum flow loss (30). Nano clay particles improve the mechanical properties of concrete, its resistance to chloride penetration, Figs. 13, 14 (3, 27, 28), and the properties of self-compacting concrete regarding reduced permeability and shrinkage.

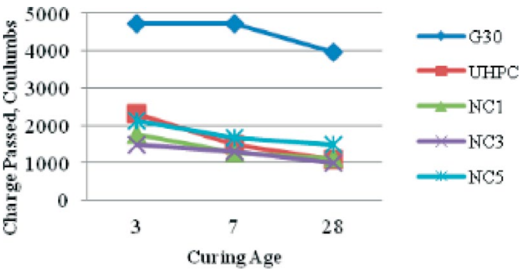

Fig. 13 – Chloride penetration in concrete without and with nanoclay (30)

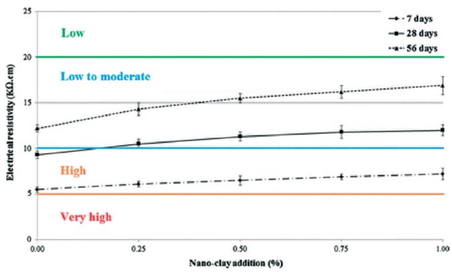

Fig. 14 – Electrical resistance of concrete without and with nanoclay added (31)

Nanocalcium carbonate

Nano $CaCO_3$ (NC) was first used in the form of a filler as a cement replacement, however, additional positive effects of $CaCO_3$ were proved regarding strength and hydration speed of cement composites. Engineering properties, including micro hardness and elasticity module, are largely improved in an early phase by adding nano $CaCO_3$ to concrete. It is evident that the size of nano $CaCO_3$ particles and C-S-H nucleation cause the development of mechanical properties (32). The paper (33) shows the testing of the effect of nano $CaCO_3$ (NC) on cement paste properties.

Experimental results have shown that NC has no effect on the need for water in normal consistency of cement. However, with the increased NC content heat is reduced and so is the time of fresh cement paste setting, Fig. 15 (33). Testing of mechanical properties has shown the increased bending strength and the compressive strength of hardened cement paste and the optimal content of NC was 1%.

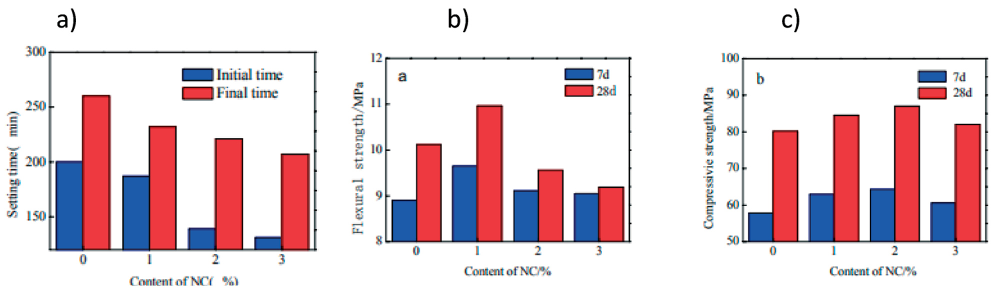

Fig. 15 – The effect of nano $CaCO_3$ on cement paste properties a) setting time, b) bending strength, c) compressive strength (33)

Testing of micro hardness of concrete also shows a considerable increase in micro hardness in concretes with mixed cement and nano $CaCO_3$, but more detailed research into the impact of nano $CaCO_3$ on deformation properties of concrete is required, since testings discussed in (34) owed increased shrinking.

Nanoreinforcements

In the last few years a number of materials for micro reinforcement were systematically investigated for the application in micro reinforced concretes. Nanoreinforcement properties of materials are summarised in (3) and in Table 4 (35).

Table 4 – Properties of nanoreinforcements (35)

Material	Elastic modulus (GPa)	Tensile strength (GPa)	Elongation at break (%)	Density (kg/m^3)	Diameter/ thickness (nm)	Surface area (m^2/g)
Graphene	1000	~130	0.8	2200	~0.08	2600
GO	23 – 42	~0.13	0.6	1800	~0.67	700 – 1500
CNTs	950	11 – 63	12	1330	15 – 40	70 – 400

Carbon nano tubes and nano fibres are potential materials for nanoreinforcement or nanoreinforcement of concrete. Fig. 16. (3, 35).

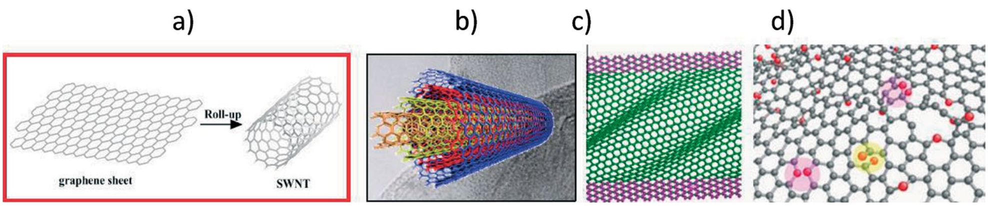

Fig. 16 – Carbon reinforcement, a) Single layer nanotubes, b) multi-layer nanotubes, c) wrinkled grapheme, d) grapheme oxide (GO) (3, 35)

Carbon nanotubes and nanofibres are of an extremely high strength, elasticity modulus and of unique electronic and chemical properties. All the above makes them the most promising nanoparticles, particularly as regards resistance to cracking, electromagnetic protection and self-sensing. Research into mechanical properties of nanocomposites conducted by testing bending at three points and by analysing by fracture mechanics and SEM scans (36) proved increased resistance to cracking, Figs. 17 and 18.

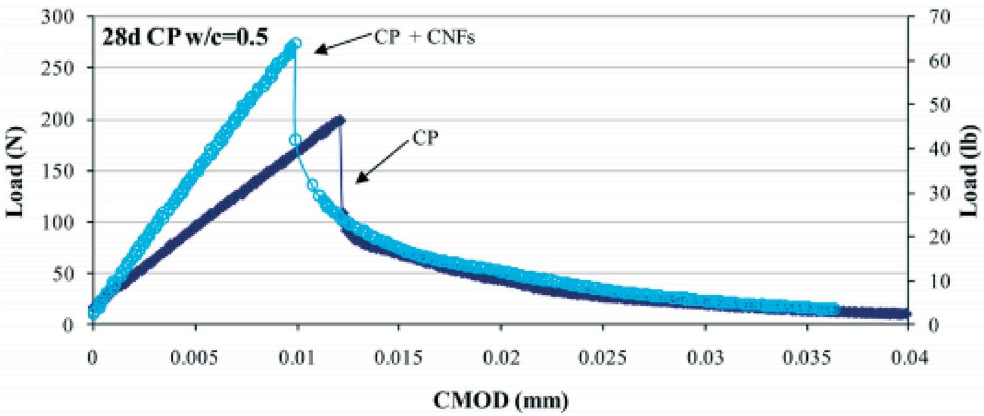

Fig. 17 – Load curves of CMOD cement paste without and with CNF (nanofibres) (36)

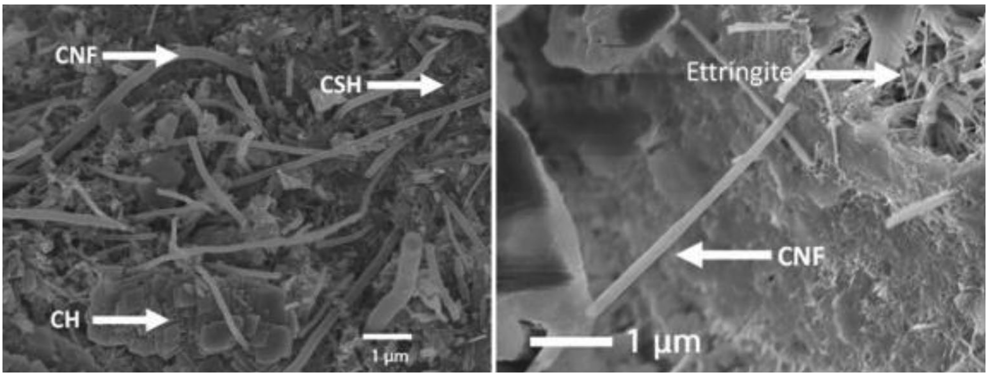

Fig. 18 – SEM scan of the fracture surface of the cement paste with added nanocarbon fibres (37)

Nanocarbon tubes, CNT, also have interesting electromechanical properties. When sample load varies, CNT will show electrical properties which change with the level of strain, showing linear and reversible piezoresistive response. Electromechanical properties of carbon fibres, CF, were irreversible due to fibre breakage when strain was higher than 0.2%. Since CNT properties are superior to the properties of CF, there is possibility of developing smart concrete with excellent piezoresistive response by using CNTs as additive. Recently Li and others used multi layered, chemically treated carbon nanotubes (MWNTs), to make piezoresistive composites based on cement and measured the piezoresistiveness of this composite under uniaxial pressure (38). According to their results and analysis, self-sensing CNT sensors were made and installed into a concrete pavement. Sensors were made from cement mortar with added piezoresistive MWNTs, and installed at definite distances into a concrete pavement, Fig. 19. Sensors have a considerable potential for traffic tracking, like finding vehicles, taking measures in motion and detecting vehicle speed.

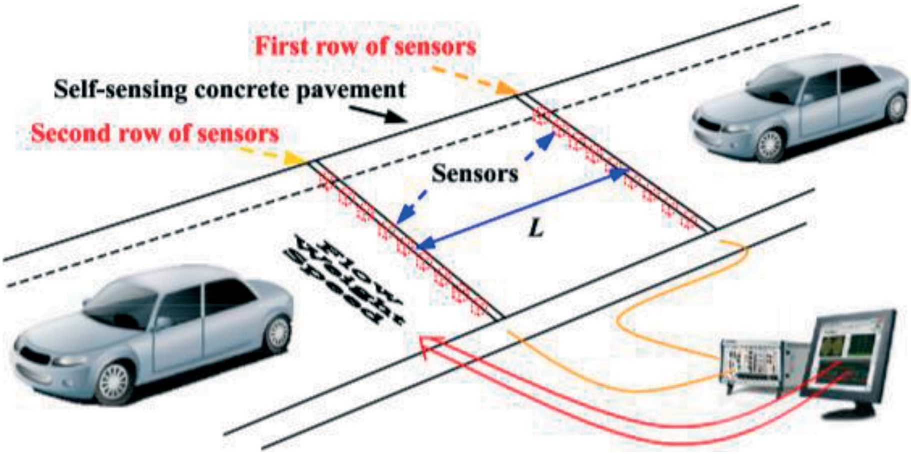

Fig. 19 – Traffic tracking on self-sensing concrete pavement (38)

Nanotechnology and steel

Steel has played an important role in the construction industry for the last two hundred years, and it still does today, which means that steel is one of the most important and essential materials in the construction industry (39). Although steel has a very good strength at tensile stress, it has problems with fatigue when cyclically loaded. Steel fatigue will decrease if copper nanoparticles are added. When copper nanofibres are applied to steel surface, the surface of finished steel becomes smooth and flat. The flat surface can reduce stress, and breaking caused by fatigue. A new steel generation also has higher resistance to corrosion. Two relatively new products are available today, SandvikNanoflex and MMFX2 steel.

They have very different mechanical properties and resulted from two different applications of nanotechnology. They are resistant to corrosion, have higher resistance to deformability and fatigue, and can help prolong the lifespan in corrosive environment and thus lower the costs in the life span of a building (41, 42). Fig. 20 shows the façade of a nanomodified steel building (40).

Fig. 20 – Nanosteel in facades (40)

Nanotechnology and glass

It is a constant problem how to clean glass. Glass with titanium dioxide is the best solution of this problem. Titanium dioxide dissolves organic waste, and rainwater or automatic sprinkling of facades with water cleans the dirt from glass facades and thus reduces maintenance costs, Fig. 21a (43). Also, nanotechnology is successfully used to produce fire resistant glass. Since TiO_2 has hydrophobic properties, it can be used in anti-fog coatings.

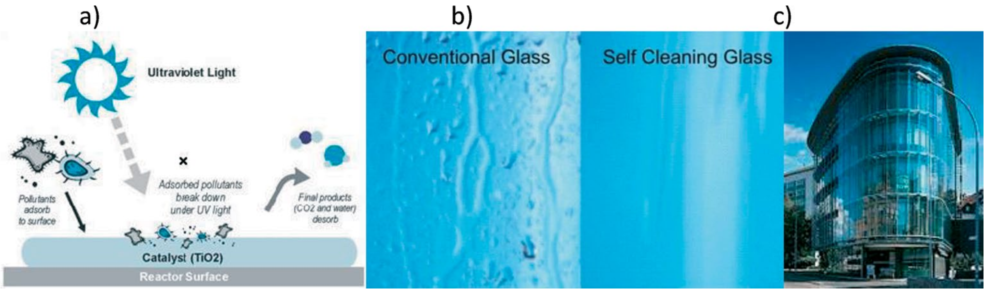

Fig. 21 – Self-cleaning glass, a) Process scheme (43), b) Glass with and without treatment (44), c) A self-cleaning facade (45)

Photocatalytic coating has a secondary use in warmer climates. Instead of waiting for rain, glass surfaces are washed by sprinkling water on glass surfaces which has a dual effect: windows are self-cleaned and the temperature inside the building is reduced. The International Narita Airport in Japan used photocatalytic membrane when its Terminal 1 was refurbished in 2006, Fig. 22a (14). The coating reduced cleaning costs.

Fig. 22 – Examples (14), a) The roof of Terminal 1, Narita International Airport, Tokyo, Japan, b) MSV Arena Soccer Stadium with Pilkington glass facade, Duisburg, Germany

Along with self-cleaning, antireflective properties are developed by use of SiO_2-TiO_2 coatings on glass beddings by applying the combined dual layer sol-gel tip coating process. These materials are practical to use since they are bifunctional, antireflective and self-cleaning. They are also suitable for large facades and particularly for solar cells, Fig. 23, (46, 47).

a) b)

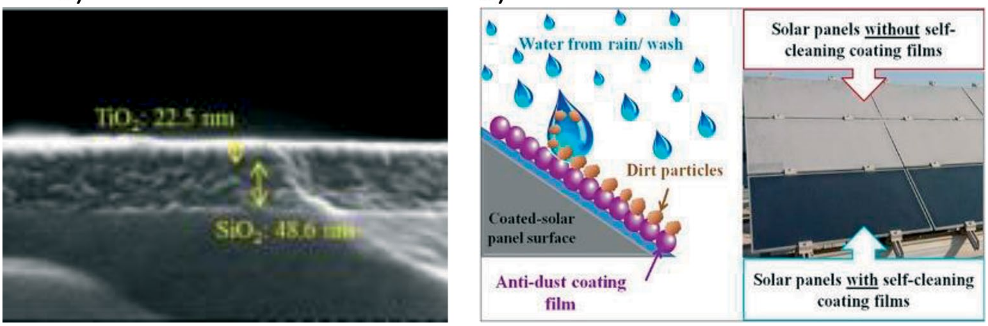

Fig. 23 – Glass with antireflective and self-cleaning properties, a) layer scan (46), b) Schematic view of the self-cleaning effect on solar panels in polluted regions (47)

Fire resistant glass is another example of applied nanotechnology. It is produced by using an interlayer which is heated through glass panels, and which consists of nanoparticles saturated with silica gel (SiO_2) (48). Also, thin layer coatings are being developed for use on window glass which has a potential to filter unwanted infrared light frequencies which warm up the space and reduce temperature in buildings (49).

Nanotechnology on wood

Carbon nanotubes are an innovative, new material, while wood is an ancient material which has been used since the very beginnings of the civilization. However, wood in its structure also has nanotechnology and wood can result in interesting uses. Strong waterproof coatings are used for wood, integrated nanoparticles, of silica and aluminium oxides with hydrophobic polymer (52), and as nanofungicidal coatings TiO_2 nanoparticles are applied on a wooden surface (53). The application of nanotechnology on wood has created self- sterilizing surfaces and internal electronic lignocellulosic devices (50), and successful trials to copy natural structures are shown in Fig. 24 (51).

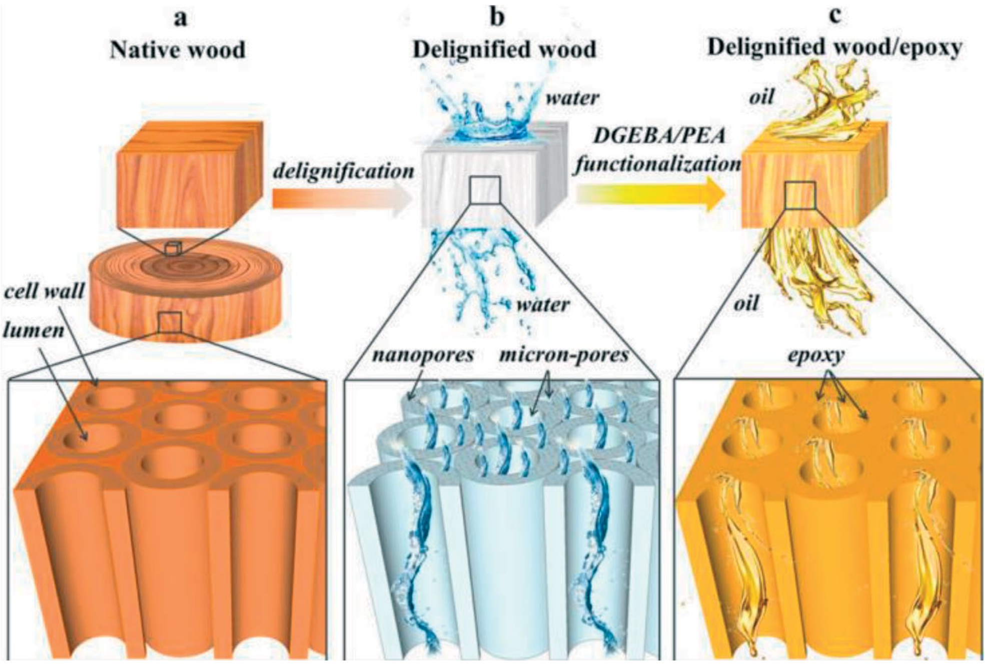

Fig. 24 – Schematic illustration of structural design of porous and functional wood materials for selective separation of oil-water mixtures: (a) native balsa wood, (b) delignified wood template, (c) delignified wood/epoxy biocomposite

Nanotechnology in coatings

Coatings also play an important role in the construction industry; in buildings coatings are widely used on walls, doors and windows, and in infrastructure facilities they are used as protection from moisture, corrosion and fire (54-57). Nanotechnology is used in coatings by adding nanoparticles which have been described above.

Nanotechnology in sensors

Nano and microelectromechanical systems (MEMS) were developed and used in structures with the purpose of following and/or monitoring the state of the environment and the properties of materials in structures. One of their advantages is their size (10^{-9}m do 10^{-5}m) (58). These sensors can be installed into an aggregate grain and/or into a structural element during the construction process, and they are used to monitor early-age properties of concrete such as moisture, temperature and the development of strength in the early phase (59). Sensors can also be used to monitor reinforcement cracking and corrosion.

Conclusion

Instead of a conclusion, a review of basic advantages and obstacles to the application of nanotechnology in construction is given. Although it should be said that nanotechnology has contributed to the strong development of construction materials, there are still numerous challenges in practice, and health and ecological issues are the most important ones that have to be investigated. It is known that nanoparticles can penetrate into human cells, so regardless of the beneficial effects of these materials, they also have negative and dangerous impacts on living organisms which must be identified and should be avoided and monitored by establishing effective methods.

Table 5 – Benefits and barriers for the use of nanotechnology in the construction industry (61)

Benefits	Materials and properties	Strength and durability (e.g. cementitious composites) Wear and tear resistance Corrosion resistance (e. g. coatings) Fire resistance and retardants Aesthetics Heat insulation (e. g. glass) Self-cleaning (e. g. concrete, glass) Bactericidal capacity (e. g. coatings) Photocatalytic activity - Promotes air pollution reduction (e. g. cements and coatings)
	Economic	Improves life-cycle and maintenance costs Pricing and profit Customer satisfaction Market value and brand image
	Sustainability	Energy efficiency Reduces material consumption Social and ethical benefits Reduced levels of several environmental pollutants (e. g. CO_2 associated with cement production) - “Green nano-construction”
Barriers	Costs and manufacturing	Costs of materials and equipment Costs of commercialization High initial investment by nanotechnology companies Lack of properly trained personnel and costs of training
	Environmental	Safety and security concerns Potential toxicity to the workers
	Social	Regulatory and legal issues Scepticism of the main industry stakeholders and consumers

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Material Recovering from Offset Prints on Paper with Alternative Fibers

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Abstract: The development of non-wood fibers has been one of strategies to ensure a sustainable fiber supply, including plantation management, reforestation and recycling. Some of alternative fibers are algae that can be used as raw material for papermaking. The Shiro Alga Carta papers made from algae in combination with Forest Stewardship Council certified fibers (FSC - fibers) were used in this research. Offset inks used in printing are vegetable-based (different amount of renewable raw materials) and mineral oil-based.

The aim of this research was to contribute to the explanation of the ink/substrate interaction in printing on the detachment of ink from substrate and removal, as well as to study the recovered fiber characteristics. In our research we used the three-loops method.

Generally, satisfactory characteristics of the recovered fibers were obtained in experimental conditions for all samples, as it is expected from environmentally friendly, with algae speckled paper. The research was supported by setting environmental sustainability.

Keywords: Paper, algae, different inks, re-pulping, fibers recovering, handsheets characteristic

Introduction

The growing demand for sustainable business is significant in the graphic industry. The waste and influence on environment depends on the printing technics and the used materials. In offset printing techniques waste includes: substrates, inks, fountain solution, metal plates, volatile organic compounds, biocides, varnish and energy (Bolanča Mirković, Bolanča, 2007; Bolanča Mirković, et al. 2011; Amon-Train, et al., 2012; Bolanča Mirković, et al., 2015; Bolanča, Bolanča Mirković, 2017).

Some life cycle reports on offset printed matter points to the paper production stage, with forestry and pulp production and delivering the paper product, as the dominating contributor to the estimated potential environmental impacts from the LCA (life cycle assessment) of offset prints (IFRAS, 1998; Larsen et al., 2006; Bousquin et al., 2011). The analysis of the impacts on damage level shows that the paper production is significant to the AoPs (damage areas of protection): global warming, acidification and eutrophication, and dominates the specific contribution to the AoP ecosystem. The printing stage has a higher share both to human health and resources related impact categories.

Another source states that in the life cycle assessment it is found that the offset printing process is the largest contributor to the environmental impact, more than the impact of paper and inks (printing 52%, paper31%, ink 17%) (Dougherty, 2008).

Larsen and coauthors studied the life cycle assessment of offset printed matter with EDIP 97 method. Emphasis in that research was on how important are emissions of chemicals (Larson et al., 2009)? This study includes the newest knowledge about emissions from the printing industry and knowledge about the composition of the used printing materials. The results show that the use of paper no longer becomes the overall dominating factor causing the environmental impact.

The pulp and paper industry is the resource intensive industry and contributes to many environmental problems, including global warming, ecotoxicity, human toxicity, photochemical oxidation, acidification, eutophication and solid waste (Bajpai, 2010). Ecological advantage is focused on pollution prevention rather than on end-of-pipe clean up. Sustainable development includes cleaner production measures in raw material storage and preparation, in pulping processes, in bleaching, recovery, papermaking, emission and in recycling.

KrishnaManda and Patel investigated whether the use of micro and nano TiO_2 as coating and different pulp types could bring savings in wood, energy, GHG emissions in comparison with conventional printing paper (KrishnaManda, Patel, 2012). The results show that the nanoparticle coated recovered fiber paper saves nonrenewable energy use by 100% and generates GHG emission reduction by 75%.

By the application of innovative manufacturing strategies using advanced sheet structure design and fiber modifications, the reduction of GHG emission by 22.9 % for SC paper and by 20.3 % for LWC paper can be achieved. (Jorgel, Juan, 2015).

Recycled paper is better for the environment than virgin paper: it preserves forests, conserves resources, generates less pollution during manufacturing and reduces solid waste. In literature, this issue is being investigated a lot, and Baypan states that for a tonne of recycled paper, compared to a tonne of virgin paper, it reduces the use of: wood 100%, wastewater 33%, energy consumption 27%, air particulate emissions 28% and solid waste 54% (Bajpai, 2014).

Recycling of waste printed matter has also negative environmental impacts: it requires the removal of inks from prints and plastic polymer from office waste paper and often contains dioxins (Kesalkar, 2012). Furthermore, wastepaper recycling produces sludge that contains small fibers, ink from de-inking process and fillers. Printing inks contain heavy metals (copper, lead, zinc, chromium and cadmium) and solvents.

Michaud and co-authors studied the carbon balances between paper recycling, the disposal of landfill and incineration (Michaud et al. 2010). They concluded and published within the framework Waste and Resources Action Program (WRAP) that recycling 1 tonne of paper will avoid 1.4 tonnes of CO_2 equivalent compared with landfill, and 0,62 tonnes of CO_2 equivalent compared with incineration.

In recent years with growing of environmental awareness, there is an increasing number of investigations in the field of alternative non-wood fibers for papermaking. In literature it has been reported on wheat straw, sisal, banana sten, kenaf, corn, bamboo, elephant grass as the basis of pulp and paper (Shivhare et al., 2012; Sibani et al., 2012, Qin et al., 2011; Mosseto et al, 2010; Egbewole, et al., 2015; Gomes, et al,. 2013). LCA studies show that this type of fiber little contributes to almost none of the environmental impact categories compared with pulp mill operations. The energy and environmental impacts of both pulping and paper can dominate the overall environmental impacts; these impacts can matter more than the choice of fiber and should be considered in an overall evaluation of agricultural inputs (Favero et al., 2017). New, alternative pulping processes were studied because of highly contaminant classical treatments for obtained paper with acceptable properties coming from unconventional pulping raw materials treated with alternative processes which is a way to sustainable and economic production.

Algae are an alternative aquatic raw material for papermaking, and it is a solution to global environmental issues: deforestation and global warming. Algae contain low lignin-like compounds in cell walls, and there are no problems associated with lignin removal as with cellulose obtained from trees and other vascular plants (Knoshaug, et al. 2013).

Paper produced from red algae as Gelidium takes lower cooking temperature, shorter time and less chemical usage compared to wood pulp (Mukherjee, Prakash Keshri, 2018). Algae fibers are finer and more uniform in length, which improves its utilization as reinforcing fibers in the manufacturing of both virgin and recycled paper. Lee et al. found that the bleached red algae fiber showed higher thermal stability than that of crystalline cellulose (Lee et al., 2008).

Seo and coauthors compared the algae-based handsheets to wood handsheet of the same weight (Seo, et al., 2010). They found that density and breaking length were lower for the algal handsheets, while the brightness and stretch values were comparable, and smoothness and freeness were higher, but you can mix the fibers with softwood fibers for better paper properties.

A particular interest is devoted to the study of green algae and seaweeds, respectively (*Cladophora sp., Ulva sp., Rhizoclonium)* as a raw material for paper making. Thus, pulping procedure, physicochemical properties, structural characteristics, unit cell parameters, degree of crystallinity and mechanical properties of algae cellulose were investigated (Lopez et al. 2013; Martone et al., 2009; Mukherjee, Prakash Keshri, 2018, Marsin, 2005; Mihranyan, 2010).

In our extensive research we used a printing substrate containing a certain amount of green algae genus Ulva. These algae are found in the Adriatic Sea because of eutrophication. In this article, we are presenting only a part of our results relating to the domain of the offset print life cycle. The aim of this research was to make a contribution to the explanation of the ink/substrate interaction in printing on the detachment of ink from the substrate and the removal from pulp, as well as to study the recovered fibers characteristic. The research was supported by settings of the environmental sustainability.

Materials and methods

Samples were made on the five-color offset machine with a coating unit Roland 705. The printing form contained different printing elements: a standard CMYK step wedge in the 10-100% tone value range, a standard ISO illustration for visual control, textual positive and negative microelements, wedges to determine greyness and the standard wedge with 378 patches to produce ICC profiles and 3D gamut.

In the research materials based on renewable raw materials in line with one of the essential sustainable development settings were used. The Shiro Alga Carta paper made from algal blooms which grow in the Adriatic Sea (patented and manufactured by Favini, Italy) was used in this research (marked P_2) FAVINI, 2012). Eutrophication is a process which causes an excessive algal growth and it becomes enriched with an increase in pollution, organic effluents and temperature. Algae were dried and ground in a colloid mill to a size less than 500μm.The algae were used in partial substitution of pulp and combined with FSC fibers (FSC - Forest Stewardship Council, certified forest, so they are grown according to sustainability principles). This paper is environmentally friendly grayish-green speckled paper where the speckles are the milled algae.

The prints were prepared with the offset inks different composition, produced by SunChemical® Europe. Inks that were used are available as a four-process color offset ink set. The inks marked withB_1 contain 78-82% of renewable raw materials. These inks are based on an innovative resin/oil combination. Inks dry by absorption and oxidation. Inks marked with B_2 are vegetable-based and free of mineral oils and dry by penetration and to a high degree by oxidation. The inks marked with B_3 are mineral oil-based and are free of cobalt based drying catalysts. These inks are dried by penetration and to a high degree by oxidation.

Print varnishing was performed with water-based dispersion varnish Hi-Tech. Coat W6000 Heidelberg Group (marked L_2). According to the manufacturer's statement, the amount of lead, chromium, cadmium and mercury is in accordance with the total maximum below threshold given by Directive 94/62/EC. The regulation concerning the restriction of use of certain epoxy derivatives was applied.

The flow of the experiment is shown in Fig. 1. The fibrous material recovery process in one part uses INGEDE method 11 (INGEDE 11, 2012). In our research we used re-pulping (loop I, loop II, loop III), rather than collector oleic acid and flotation method, like that described in INGEDE 11 method.

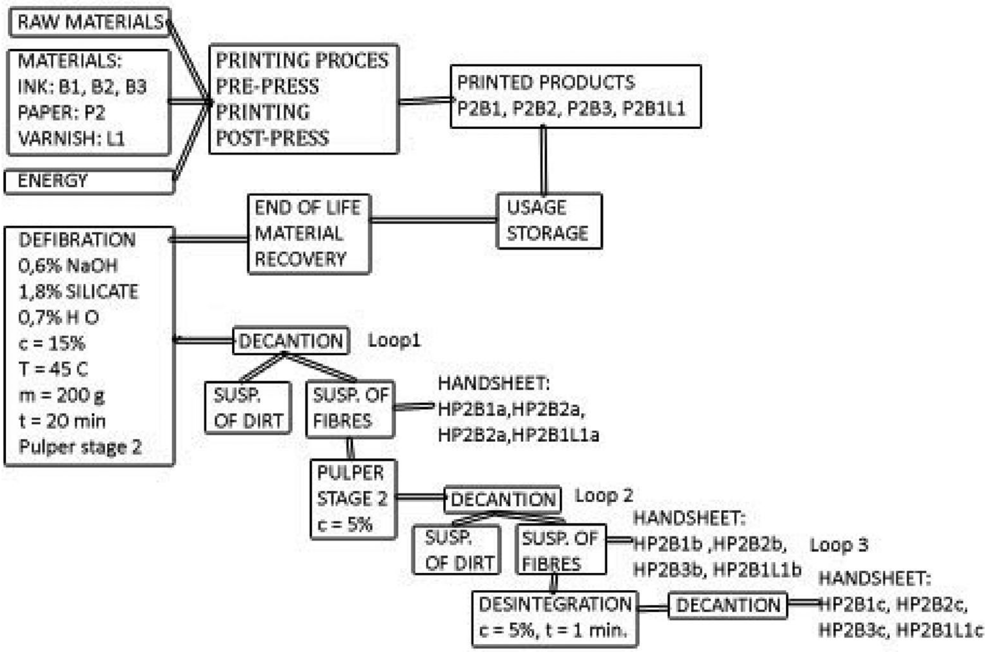

Fig. 1 – Scheme of the experimental flow

The handsheets were made by using the Rapid-Köthen sheet former according to standard ISO 5269-2 (ISO 5269-2, 2002) The following methods were used for measuring the optical characteristics of laboratory handsheets: diffuse blue reflectance factor according to ISO 2470 and effective residual ink concentration-ERIC according to TAPPI T 567 pm-97 (ISO 2470, 2005, TAPPI T 567, 2009).

The count of the residual dirt particles and area were assessed by using the Spec*Scan Apogee System image analysis software (ISO 13322, 2014). This system utilizes a scanner to digitalize an image. The threshold value (100), white level (75) and black level (65) were chosen after comparing the computer images to the handsheets.

Environmental sustainability is significant for development, and it includes energy and material flow, closed loop systems and clean technology. Having that in mind, and in order to optimize the reusing fibers from substrate which contain algae, research was conducted to determine the characteristics of the obtained fibers. Thus, print P_2B_1 (substrate with algae, ink containing about 80% of the renewable raw material) is overprinted with water dispersion varnish. The aim was to determine the influence of varnish on the efficiency of the material return and the characteristics of the obtained fibers. The specks count on handsheets from loop I, II and III according to the scheme of the experimental flow is shown in Fig. 2.

The results showed a noticeable dependence of the process stages on the total count of specks on handsheets as follows: $HP_2\,B_{1a}/HP_2\,B_{1b}$ = 39.8%, $HP_2\,B_{1b}/HP_2\,B_{1c}$ =

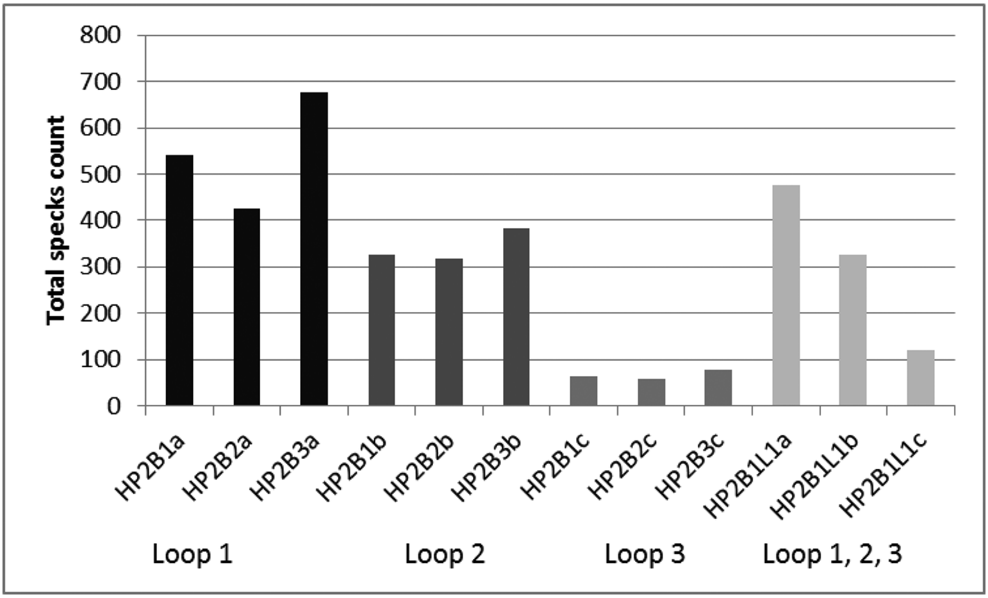

Fig. 2 – Total specks count on handsheet versus process stages

88.4%; $HP_2 B_{2a}/HP_2 B_{2b}$ = 19.3%, $HP_2 B_{2b}/HP_2 B_{2c}$ = 86.6%; $HP_2B_{3a}/HP_2 B_{3b}$ = 43.6%, $HP_2B_{3b}/HP_2 B_{3c}$ = 88.5%.The efficiency of the specks removal from fibers is dependent on the number of loops and on the formulation of inks. Thus, the efficiency of the specks removal is increased in the third loop in comparison to the second loop as follows: HP_2B_1=48.6%, HP_2B_2=64.2%, HP_2B_3=44.9%. Specks removal efficiency is achieved by the described process including all stages, as follows: HP_2B_1= 88.4%, HP_2B_2= 86.1%, HP_2B_3= 88.5%.

The highest fragmentation of inks was noted for prints with mineral oil-based inks ($B_{3\ total\ specks}$ = 677), and the lowest for prints with the vegetable-basis inks without mineral oil ($B_{2\ total\ specks}$ = 426).

The print with ink containing about 80% of the renewable raw material is overprinted with water-based dispersion varnish. Varnishing is used to heighten a gloss or matt finish and to protect the surface of a printed product from scuffs, scratches and fingerprints. Varnishing affects the total count of specks in all stages of the process. The efficiency of the specks removal is smaller for the varnished pattern compared to non-varnished as follows: loop1/loop2 = -8.4 %, loop 2/loop 3 = -15.2%.

The purpose of understanding the mechanism of the ink detachment from the substrate is determined. The specks surface that they occupy the handsheets made of fiber from different stages of the process is described (Fig. 3).

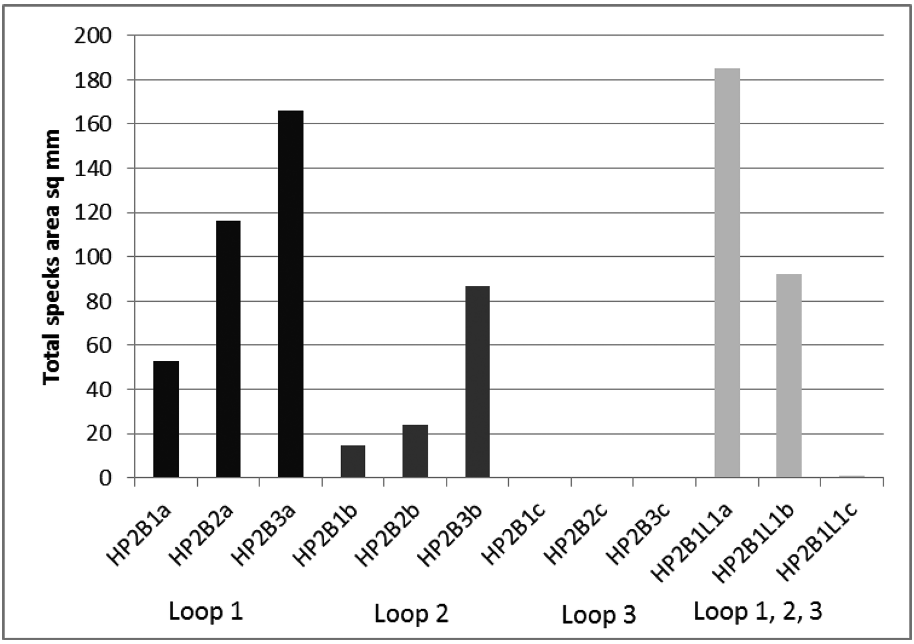

Fig. 3 – Total specks area on handsheet versus process stages

These results confirmed the previously displayed dependence of the loop number as well as inks formulations on the detachment and removal of the inks from substrate. The largest total area covered with specks was determined for the handsheet made from recovered fibers from sample $P_2 B_1 L_1$ (substrate with algae, ink containing about 80% of the removable raw material, prints overprinted with water-based dispersion varnish) after loop 1 ($HP_2 B_1 L_{1\ a}$ = 185.1 mm^2).

The handsheet made from recovered fibers from the non-varnish sample $P_2 B_{3a}$ (substrate with algae, mineral oil-based ink) after loop1 ($HP_2 B_{3a}$ = 166.00mm^2) follows.

The dependence of the total area of specks on the number of the loop and the formulation of inks is as follows $HP_2 B_{1a}/HP_2 B_{1b}$ = 77.3%, $HP_2 B_{1b}/HP_2 B_{1c}$ = 95.6%; $HP_2 B_{2a}/HP_2 B_{2b}$ = 79.7%, $HP_2B_{2b}/HP_2 B_{2c}$ = 97.9%; $HP_2B_{3a}/HP_2 B_{3b}$ = 4.9%, $HP_2B_{3b}/HP_2 B_{3c}$ = 99.3%.

The efficiency of the specks removal is increased in the third loop in comparison to the second loop as follows: $HP_2B_{1\ =}$= 9.2%, HP_2B_2= 18.6%, HP_2B_3 = 42.2%. In summary, the specks removal efficiency is achieved by the described process including all stages is as follows: HP_2B_1 = 95.6% HP_2B_2 = 97.9% and HP_2B_3 = 99.3%.

For the procedure of recovering fiber one of the primary quality criteria is cleanliness of the handsheet. The criteria for cleanliness are a minimum dirt count or specks. The optical inhomogeneity of the handsheet is significant for the specks of a size >= 0.04mm^2. The specks of a size < 0.04mm^2 are primarily relative to the optical properties of the handseet and refer to the surface grayness. Figures 4 and 5 show ink removable efficiency for the described phases of the fibers recovery process, for the specks class of a size >= 0.04mm^2 and < 0.04mm^2.

There is a significant difference in the efficiency of the process with regard to the size of the specks. Generally, specks in the class >= 0.04mm^2 are better removed, compared to specks in the class size < 0.04mm^2 by the values as follows: $HP_2B_{1ac,>= 0.04mm2\ -\ < 0.04mm2}$=9.5%, $HP_2B_{2ac,>= 0.04mm2\ -\ < 0.04mm2}$=12.6% and $HP_2B_{3ac,>= 0.04mm2\ -\ < 0.04mm2}$=7.0%. The larger specks compared to the smaller ones can be removed easily, considering that the process is mechanical precipitation.

The ERIC (effective residual ink concentration) measurement is dependent on the distribution of ink particle sizes, being most effective for submicron particles. Determination of the effective residual ink concentration on a handsheet requires the measurements of reflectance in the infrared area of the spectrum where the absorption coefficient for the ink is several orders of magnitude greater than the absorption coefficient for the fiber, filler, fines and other components. The largest difference in the ERIC appears system HP_2B_{2a} – HP_2B_{2c} = 317.2.

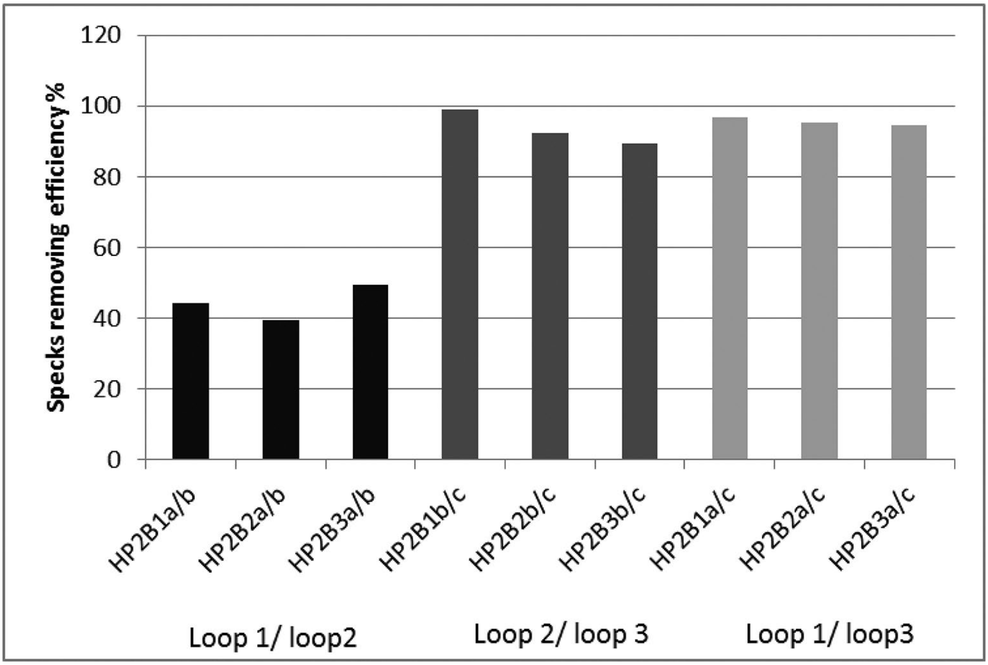

Fig. 4 – Specks removing efficiency for the class of a size >= 0.04mm^2

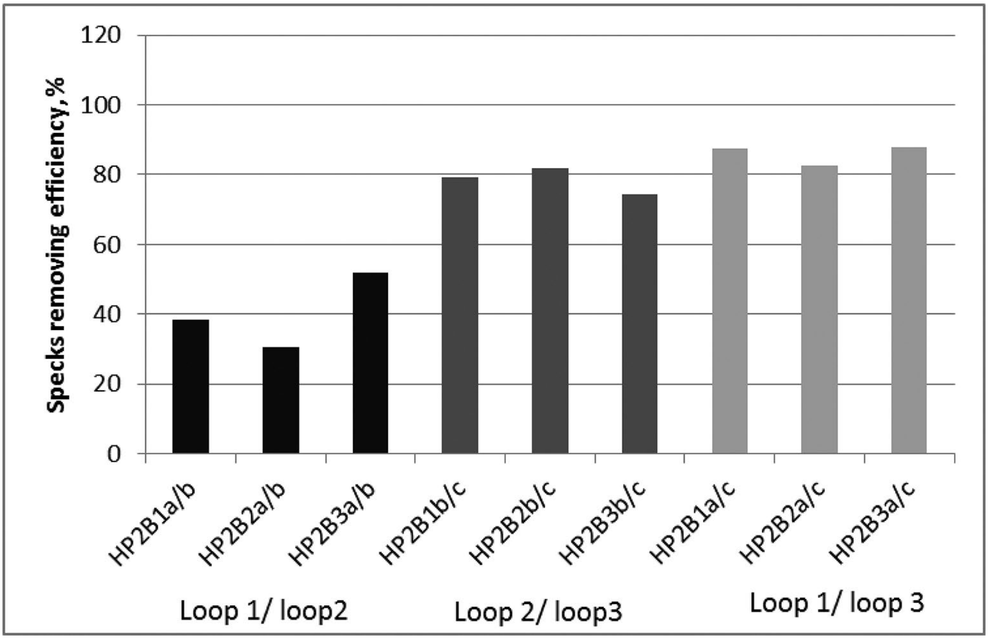

Fig. 5 – Specks removing efficiency for the class of a size < 0.04mm^2

The same sample confirms the highest gain in brightness ($B_{gain\ HP2B1}$= 10.3)**.** The differences in the ERIC successfully show the efficiency of the described stages in the experimental flow, and confirm the results obtained using other methods.

The offset printing process and drying mechanisms influence on ink detachment from substrate. Sheet fed offset ink has oxidable components in the formulation because it is necessary for the printing process. Vegetable-based inks, especially some unsaturated vegetable oils, can cause ink detachment problems and specks. Some resins added into the ink can also lead to the strong attachment of the ink onto fibers.

The organic structure of mineral-oil based inks was relatively unchanged due to oxidation compared with rapid oxidation and cross-linking of vegetable- based inks. For mineral oil-based inks the drying process is absorption with lingering oxidation.

Conclusions

Based on the results obtained from the three-loop process, recovering fibers from the offset prints on substrates made from FSC fibers and algal blooms in combination with different ink compositions, the following conclusions were reached.

Just a little better efficiency of specks removing with the three-loop process was determined for prints with mineral-oil based ink on the substrate with algae in comparison with the other two samples. A slightly lower efficiency of specks removing was determined for prints with vegetable - based ink because the oxidable components by drying the ink in printing causes the cross- linking structure to appear. Improved vegetable ink appears almost as good results (better for speck contamination) compared with mineral oil–based ink.

It was found that specks in the class >= $0.04mm^2$ are better removed compared to specks in the class size < $0.04mm^2$, especially in the print with ink containing more than 70% of the renewable raw material. Handsheets obtained from the recovered fibers of this print have the highest Δ ERIC and brightness gains.

The print with ink containing about 80% of the renewable raw material overprinted with water-based dispersion varnish has a slightly lower efficiency of speck removing compared to the unvarnished prints.

Generally, satisfactory characteristics of the recovered fiber were obtained in experimental conditions for all samples, as it is expected from environmentally friendly, with algae speckled paper.

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Computer-Supported 3D Kinematic Patterns Capture and Analysis in Handball

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Background

Gross human movement biomechanics resides on a well-known inverse dynamics paradigm, established for the first time in times when high-speed photography served as a motion capture technique (Braune & Fischer 1895). Since then, the high-speed photography method has successfully served for years to accurately record and accumulate kinematic data that were subsequently either directly interpreted or processed. The 20th century, being the age of electronics, brought the first technical solutions to automatically detect characteristic points (markers) in a TV picture frame (in 1967, transition from black to white detection principle) as the starting point for gathering kinematic data (Furnee 1989). This marks the beginning of the development of a plethora of commercial technical solutions to realize accurate and rapid (semi)automatic 3D kinematic data capture (Medved 2001). The beginnings of our Biomechanics Laboratory at the Faculty of Kinesiology, University of Zagreb, were also marked with using a 64 frames/sec Bolex photographic camera for that purpose (Mejovšek 1989). However, later, with the coming of 2000-ies and up to our times we have equipped our Lab with the commercial optoelectronic 3D kinematic measurement system ELITE, by BTS Bioengineering Technology (Milan, Italy; ELITE goes for ELaboratore di Immagini Televisive). The first version of our system was sited initially at the Faculty of Mechanical Engineering and Naval Architecture - and later given at our disposal by courtesy of late professor Muftić, doyen of biomechanics in Croatia and one among founders of the HATZ - where data acquisitions and analyses already were provided, supported by the computer software of that time (Terze 1996). The actual system provides adequate support both for measurement and data processing and analysis purposes (Mahnić et al. 2014).

In the locomotion biomechanics community at one moment in time computers had begun to significantly overtake processes of both data capture - enabling a computer vision of sorts - and processing (succinctly presented in Medved 2001, Chapter 4.2.1.5). Thus, for instance, in 2007, a paper by Baker appeared entitled: „The history of gait analysis before the advent of modern computers“, properly marking this transition. Today's state of the art, which in addition to classical inverse dynamics approach witnesses more and more the introduction of novel methodologies like neural networks, data mining, etc. (Begg & Palaniswarmi 2006). Profits of availability of high power and elegant computer graphics solutions in this realm, as evidenced for example by contributions of the collaborating lab at the University of Salerno (Vastola et al. 2016). Wartenweiler Memorial Lecture by Cappozzo at International Society of Biomechanics (ISB) meeting in Glasgow in 2015 (Cappozzo 2015) properly illustrates the depth and sophistication of the methodology of the field, albeit limitations also caused principally by difficulties in the faithful biomechanical representation of complex human body anatomy.

We present an example from the handball sport game, where 3D kinematic data are (semi)automatically captured and stored to enable further processing in order to study complex sports movement patterns manifested. It was originally reported in (Pažin et al. 2016). This kind of motion capture technology establishes itself as an important component of a quantitative analysis vehicle of respective movement patterns. It is understood that, besides utilising multiple rigid body representation of human body enabling inverse dynamics approach, ultimately one strives to arrive at the kinesiological interpretation of performed movements at the neuro-muscular level. The handball game reaches in this manner a higher level of exactness and precision in the description and understanding of its various postures and movement patterns exhibited. The flexibility of our system, enabling various positioning schemes of body markers, as well as the simultaneous introduction of other measurement modalities such as multichannel surface electromyography (sEMG) (Medved & Cifrek 2015) enables to empirically assess the in depth biomechanical and physiological function of the neuro-musculo-skeletal system. This system is under great pressure when executing energetically demanding and skilful handball movement patterns, so that each contribution to its better definition and understanding is potentially applicable in the training process. We particularly strive to apply this methodology for improved training procedures.

Measurement Example and Discussion

Handball is one of the most complex kinesiological activities. Handball movement patterns and techniques have a high degree of performance variability. Their focus on generating maximum speeds and forces is always attempted to be realized by well-known motor patterns of running, jumping and throwing. In our institution kinematic analyses of handball techniques have a certain tradition. These analyses followed all recognized achievements of the Croatian handball which marked World's top quality performance for the last three decades. Initially, the commercial APAS system was used (APAS goes for Ariel Performance Analysis System). (Zvonarek & Hraski, 1997, Zvonarek et al., 1997, Šibila et al., 2005, Pori et al., 2005, Ohnjec, Antekolović & Gruić, 2010). Anatomical reference points within the International Biological Program (IBP, Mišigoj-Duraković, 2008) were determined manually. The 3D reconstruction required at least two VHS cameras with 50 - 60 Hz sampling rate depending on the velocity of movement measured. So far, the analysis of kinematic parameters was mainly done on jump-shot techniques with specific phases of skidding (moving the body's centre of gravity) (Zvonarek et al., 1997, Ohnjec et al., 2010, et al.), not on the basic stance shot, feints, defensive activity, etc. The obtained results generally had a moderate application in training practice.

The present kinematic model for analysis of handball techniques uses the optoelectronic ELITE system (Pažin et al., 2016). It contains 8 cameras, operates at 100 Hz sampling rate, and has an integrated force platform Kistler (Swiss firm), embedded into the floor of the Laboratory. One of the possible protocols that has so far been most commonly used in our laboratory is the Davis protocol developed for the needs of gait analysis (Medved & Kasović 2007). By taking the Davis model as a reference with the initial 20 markers, retro-reflecting markers were deployed to further 12. Figure 1 shows the subject equipped with markers, ready for measurement.

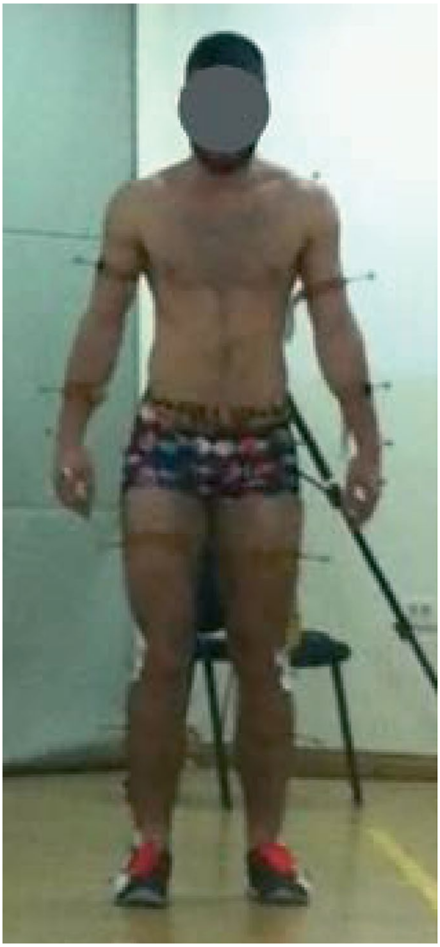

Fig. 1 – Experienced younger senior handball player, specialized to be the central backcourt attacker and organizer, performed a selection of most relevant specific throwing, jumping and moving handball techniques, amongst which "stance-shooting" technique was chosen (as a representative of most important basic throwing techniques) to be visualized along with a newly articulated "extended Davis kinematic" used for registration and analyses (in Pažin et al, 2016).

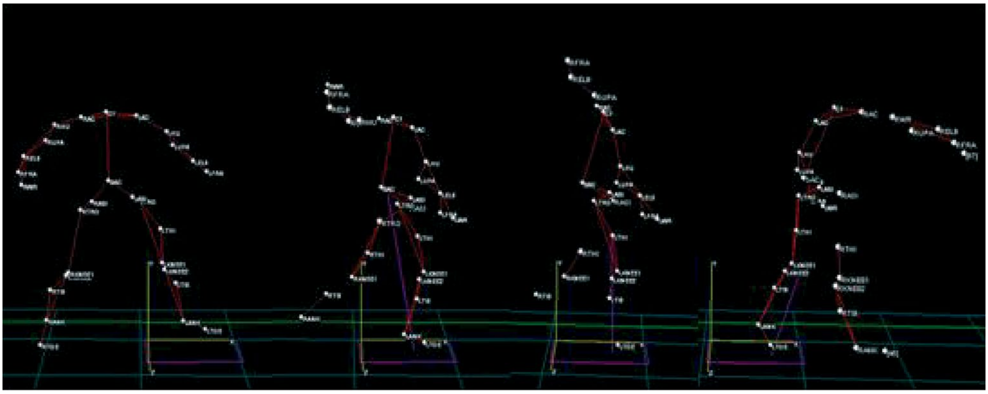

Fig. 2 – 3D kinogram: Phases of basic stance-shot kinematics: 1) preparatory phase, 2) phase of initiation of throwing kinetic chain, 3) phase of crossing coronal (frontal plane) and 4) end of throwing phase. Combining this kind of graphic visual representation with computer-stored numerical values of temporal and spatial movement variables enables a quantitative analysis and interpretation by an expert, i.e. trainer. This particular recorded simulated shot is characteristic of a skilled handball player. (Figure reproduced from Pažin et al. 2016.)

Figure 2. shows four successive 3D recordings of body kinematics in an attempted stance shot in the Laboratory (simulation, no ball). The most important information on the obtained motion capture shots and their analysis is given in figure caption.

Among additional measurement and sensing possibilities at disposal in our institution we would like to mention the 8-channel telemetric sEMG system TELEMG by BTS and pedobarograph pressure measuring device (Zebris Medical, Gmbh) that can be included according to modified measurement protocols. In addition to the equipment existing in the Biomechanics Laboratory, there are also other systems that might be used such as the Microsoft Kinect Sensor, property of Kinanthropometry Laboratory, acquired through the project "Development of System for Digital Measurement of Human Body" (Gruić et al. 2018). There is the Xsens 3D Motion Tracking System, recently acquired by the Laboratory for Sports Games. Finally, within the partnership program with the Section for Biomechanics, Kinesiology and Applied Computer Science and the Department of Sport Science at the University of Vienna, Austria, (they house the VICON system in the Laboratory. VICON goes for Video CONvertor for biomechanics) we strive to quantify elementary dynamics and contact between two teams through the synthesis of large scale standard biomechanics with a small scale sport game analysis. The framework of this research project is entitled "System Dynamics and Contact between Teams in Handball".

Conclusion

Accurate angle measurements in individual joints, angular velocities, accelerations and internal forces and moments of forces in the centres of the individual joints, together with the accompanying standard diagnostic information, are needed in the learning process, both from sportive and from physiological and medical standpoint (energy expenditure, traumatology) to provide feedback on subjects' own performance, to provide reliable criteria for performances evaluation and to enable analysis of differences in performance levels. However, the greatest benefit of the findings of previously conducted and assumed future research arises from the assumption that knowledge of the limit values of handball performances, which implies exertion of maximum velocities and forces, would enable multilayer transfer of knowledge to physiological and medical aspects of human locomotion in this sports game and vice versa.

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Weathering Resistance of Modified Wood – A Review

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Abstract: Wood in exterior structures undergoes certain chemical and physical changes which cause slow degradation of its surface commonly known as weathering. Major aspects of the weathering of wood are aesthetic effects such as discolouration, loss of lightness, surface roughening, cracking, checking, dirt uptake, wood cell erosion and growth of mould and staining fungi. Wood modification becomes an ever-popular method of enhancing wood properties, primarily dimensional stability and biological resistance. The wood modification processes that have been successfully commercialized in Europe in the past two decades are presented briefly. To what extent modification of wood affects the resistance of wood to weathering is also an important aspect for exterior wood applications, especially where appearance is important. The aim of this paper is to review the literature on weathering resistance of wood modified by today's commercial modification techniques including thermal modification in various shield media, acetylation, furfurylation and modification with N-metylol compound 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU). The effect of modification on the weathering performance of wood during natural or artificial exposure was analysed with respect to optical appearance, surface erosion, crack formation, mould growth and performance of system coating - wood.

Keywords: weathering, thermally treated wood, acetylated wood, furfurylated wood, DMDHEU-modified wood

Introduction

Wood modification is an increasingly popular approach to improving wood properties such as dimensional stability, water resistance and durability (Hill, 2006). Due to environmental issues related to the use of toxic preservatives and tropical hardwood the research on wood modification has intensified in the last two decades although the first research on wood modification dates back to the first half of the 20th century (Stamm, Hansen, 1935, Stamm, 1946, Tarkow, 1946).

Among numerous methods of wood modification described in the literature, only a few of them have found successful industrial application. Among them are thermal treatment, acetylation, furfurylation and modification with N-methylol resin.

Modified wood is used for both interior and exterior applications, especially for decks and patios, outdoor claddings, facades, garden furniture, noise barriers, fences, ship decks etc. For these applications weathering resistance which affects aesthetic service life is very important to users. Weathering is the general term used to define the slow degradation of materials exposed to the weather (Williams, 2005). Sunlight (especially UV and visible light) and water play a major role in weathering of wood, although the synergistic contribution from the other factors (temperature, oxygen, pollutants) plays a significant role (Raczkowski, 1980, Derbyshire et al., 1997, Tolvaj et al., 2015, Varga et al., 2017). Photochemical degradation is manifested by an initial colour change, followed by loosening of wood fibers and gradual erosion of the wood surface (Williams et al., 1995). In addition to the slow erosion process (5-6 mm/century), other processes like checks developing, raising grain and mildew colonizing the surface also occur. The boards may warp and cup, particularly in decking applications (Williams et al., 1995). Chemical deterioration involves a complex sequence of free-radical reactions (Feist, 1988). Lignin has been found to be a major reactant in photochemical degradation where free radicals are involved (Hon, Feist, 1986, Hon, Ifju 1978, Hon et al., 1980). The photo degradation mechanism of lignin is complex with different pathways giving various types of phenoxy radicals leading to chain cleavage and coloured quinonoid molecules (Georg et al., 2005). It has been established that free radicals and singlet oxygen play important roles in discoloration and deterioration reactions of wood surfaces (Feist, Hon, 1984). At a microscopic level, the chemical nature of the weathered wood surface is changed, and the ultra structure of wood cell walls is damaged (Chang et al., 1982). Lignin is a much better absorber of light than cellulose and is therefore degraded faster than cellulose. Leaching of photo-degraded wood fragments (mainly from lignin) by rain results in increased surface roughness (washboard effect) and thereafter underlying cell layers are exposed to further erosion (Feist, 1988). Under artificial weathering conditions this process causes bleaching of wood due to the predominance of surface cellulose (Xie et al., 2008). However, another mechanism of surface greying of naturally weathered wood surfaces usually predominates, particularly in the presence of moisture, which is due to the colonisation so staining fungi. The most frequently observed species is *Aureobasidium pullulans*, which under favourable conditions grows not only on wood surfaces but also on the surface of coatings (Feist, 1988). This silver-gray adversely affects the appearance of wood even though does not degrade it. Although this weathering process develops primarily on the surface of wood, the susceptibility to photochemical degradation significantly reduces wood´s aesthetic values and performance (Jirous-Rajkovic et al., 2004).

Wood modification is carried out in order to improve biological resistance and dimensional stability of wood and to a secure high-performing, sustainable wood material. To what extent modification of wood affects the resistance to weathering is also an important aspect of wood application in outdoor conditions, especially as facade materials. This paper reviews the literature with regard to the weathering resistance of thermally modified wood, acetylated wood, furfurylated wood and DMDHEU modified wood.

Thermal modification

In recent years, wood products that do not contain toxic preservatives and which have increased performance and sustainability are increasingly demanded by customers, thus contributing to the popularity of thermally modified wood. Thermal modification or heat treatment is controlled pyrolysis of wood being treated at high temperatures between 180 °C and 240 °C under the oxygen free atmosphere to avoid burning, involving either steam, nitrogen or oil (Homan, Jorrisen, 2004). The treatment temperature and atmosphere are critical variables and the thermally induced chemical changes in the wood differ between various processes (Tjeerdsma et al., 2002). Higher temperature is known to lead to more severe degradation of the material. The process is selected to optimise the level of the thermally induced changes in the wood keeping the strength reduction and increase in brittleness under control (Homan, Jorrisen, 2004, Ormondroyd et al., 2015). Thermal modification changes the chemical composition of wood to some degree, resulting in mass loss of thermally treated wood, improvement in dimensional stability, reduction in the equilibrium moisture content, improvement in dimensional stability, improvement in decay resistance, reduced abrasion resistance, cracking tendency, reduction in impact toughness and modulus of rupture (MOR) for more intense treatments (Tjeerdsma et al., 1998, Kamdem et al., 2002, Mayes and Oksanen, 2002, Yildiz et al., 2005a, Yildiz et al., 2005b, Srinivas, Pandey, 2012, Xie et al., 2013, Ormondroyd et al., 2015). The process induces a darker coloration of wood depending to the type, duration and temperature of the process. The longer the treatment and the higher the temperature, the more intensive is colour change. Ddarkening during thermal modification is often attributed to the formation of coloured degradation products from hemicelluloses (Sehlstedt–Persson, 2003, Sundqvist, 2004) and to extractives that seem to participate in the colour formation of heat treated wood (Estevez et al., 2008, Sundqvist, Morén, 2002). This dark colour change is often seen positively, especially in hardwoods resembling tropical wood species (Chen et al., 2012, Bekhta, Niemz, 2003, Mitsui et al., 2003). It was shown that exposure of wood to high temperature changes both its chemical properties and its appearance (Nuopponen et al., 2004). Heat treatment is known to promote a range of chemical changes of different wood constituents (Tjeerdsma et al., 1998). Thermal stability of the polymeric wood constituents of wood differs according to their chemical structure: hemicelluloses present a lower degree of polymerization and higher reactivity due to their amorphous structures, which are degraded first, followed by lignin and cellulose (Hakkou et al., 2005, Hakkou, 2006). The environmental impact of the heat treatment process is low, heat is introduced into the treatment system and smokes emitted from wood thermal degradation can be retrieved, condensed and purified (Petrissans, 2007 as cited in Candelier, 2016). It was reported that thermal modification generally reduced most of the strength properties of wood. Mechanical properties (bending strength, MOR, and bending stiffness, MOE) of heat-treated wood decreased regardless of process parameters. A decrease in hydroxyl groups reduced the hygroscopic nature, resulting in increased dimensional stability of thermally modified wood (Srinivas, Pandey, 2012). Reduction in the modulus of elasticity (MOE) is generally less than the modulus of rupture (MOR). Both the MOR of bending and impact strength decrease by up to 50 % (Xie et al., 2013). The mode of failure of thermally modified wood in mechanical tests is in most cases brittle and thermally modified wood and should therefore not be used in load-bearing structures (Hill, 2006). The degree of strength losses depends on temperature, treating period and shield gas used in the process (Xie et al., 2013).

Thermal modification processes are the most common and established wood modification methods, now commercialised in several European countries. Over the last decade, thermal modification has been developed in five main product markets in Europe; hardwood flooring, siding/cladding, decking, saunas/wall paneling, and specialties. Wood treated at a high temperature has always strong smell just after the treatment which decreased in intensity after a few days, but could remain for several months. It is believed to be related to the release of furfural (Militz, 2002). Miklečić et al. (2016) studied the influence of thermal modification of beech wood (*Fagus sylvatica* L.) on surface properties and reported that acidity and water contact angle on beech wood was higher and polar component of surface free energy was lower after the thermal modification, which might have an impact on wetting and adhesion of waterborne coatings.

The main commercial thermal modification processes are covered by patents, and products are treated under names such as *ThermoWood, Platowood*, *Retiwood* , *Le Bois Perdure* and, *Oil-Heat-Treated Wood* - OHT (Ormondroyd et al., 2015).

The *ThermoWood* process is the most common commercial thermal modification process. It is licensed to the members of the Finnish Thermowood Association and is divided into three phases: Phase 1. The kiln temperature is raised at a rapid speed using heat and steam to a level of around 100 ºC. Phase 2. Once the high temperature kiln drying has taken place the temperature inside the kiln is increased to a level between 185 ºC and 230 ºC, and maintained at the target temperature for 2-3 hours. Phase 3. The final stage is to lower the temperature down using water spray systems and then once the temperature has reached 80-90 ºC remoisturising and conditioning takes place to bring the wood moisture content to a useable level over 4 % (Hill, 2006). ThermoWood is recommended for use in hazard classes 1 to 3 in accordance with EN-335-1 without the need for any further chemical protection.

The *Plato* process is a two –stage hygroterhmal process in relatively mild conditions. This process leaves high cellulose content in wood which is crucial to ensure final mechanical properties. The process was developed and is used by the Plato Company in the Netherlands for the production of flooring, cladding, decking and rough sawn timber (Ormondroyd et al., 2015, Sandberg et al., 2017).

The retification process is mild pyrolysis of wood in nitrogen atmosphere, industrialised in France and sold under name *Retiwood*. The name of process comes from the French word rétification, which is the abbreviation of réticulation (creation of chemical bonds between polymeric chains) and torréfaction (roasting).The second French process is named Le Bois Perdure (the Perdure process). This process is relative close to the retification process and the properties of modified wood processed with both methods are similar. The wood is heated up to 230 °C in a steam atmosphere, the steam being generated from the water from the green wood (Sandberg et al., 2017). The paint adhesion on this wood is drastically reduced (Homan, Orison, 2004).

The oil heat treatment process involves heating of wood in vegetable oil (sunflower, rape seed oil or linseed oil). Wood is immersed into hot oil and heated to temperatures between 180 and 220 °C to ensure optimal durability without strength reduction. The process was developed in Germany and is sold under name *Menz Holz –OHT.*

Weathering of thermally treated wood

It has been established that the brownish colour of thermally modified wood is not stable against light exposure (Jämsä, Viitaniemi, 2001, Temiz et al., 2006, Nuopponen et al., 2004, Hill, 2009). Wood treated at high temperature turns grey in colour after the exposition to sun and UV, for a few weeks and it is generally assumed that such grey colour is more homogenous than for untreated wood.

It was reported that short-term colour stability of retified ash, beech, poplar and pine wood exposed to artificial weathering was better than that of unmodified wood

(Ayadi et al., 2003).However, the original dark brown colour of the uncoated thermally treated spruce (*Picea abies*) and pine wood (*Pinus sylvestris*) panels were not stable when exposed outdoors and turning grey (Jämsä et al., 2000). The performance of the coated thermally modified and unmodified spruce wood and pine wood was monitored during five years of exposure. Although the moisture content of thermally modified wood was found to be at a lower level compared to unmodified wood, no decrease in surface growth of coated wood was detected. The thermally treatment used did not have an influence on mould and blue stain growth on coated wood in service (Aloha et al., 2002).

Thermally modified beech (*Fagus sylvatica*) in a nitrogen atmosphere was more resistant to natural and artificial weathering than unmodified control and showed a reduction of photochemical degradation and an improvement of the resistance against discolouring mold fungi during natural weathering. European spruce (*Picea abies*), conversely, exhibited minor part of these improvements (Feist, Sell, 1987). However, thermal modification of either species had small, but measurable effects on the performance and durability of semitransparent and film forming stains applied to the samples. Feist and Sell (1987) assume that reduced photochemical degradation after thermal modification might be due to low equilibrium moisture content of thermally modified wood because the wood moisture content strongly influences photochemical degradation (Hon, 1981). Nuopponen et al. (2004) studied chemical changes of thermally modified and unmodified Scots pine samples after 7 years of natural weathering in Finland and reported that the lignin content of thermally modified samples remained higher than of unmodified samples and degradation products did not leach out as easily as in the case of the unmodified samples. It might be due to the increased condensation of lignin induced by thermal treatment.

Miklečić et al. (2011) measured discoloration of uncoated and clear coated thermally modified three wood species: beech (*Fagus silvatica* L.), ash (*Fraxinus excelsior* L.) and hornbeam (*Carpinus betulus* L.) and established that modified wood samples discoloured slowly compared to unmodified samples. Accordingly, FTIR spectra of thermally modified ash, beech and hornbeam wood samples exposed to UV light showed similar chemical changes as unmodified wood samples exposed to UV light, but less pronounced.

Thermally treated Oriental beech (*Fagus orientalis* L.) wood also showed better colour stability compared to non treated samples after three months of natural weathering during winter. Natural weathering affected thermally modified beech wood samples less than unmodified samples in terms of gloss loss and surface roughness. Also, higher temperature and duration of thermal modification yielded better surface properties after natural weathering (Turkoglu et al., 2015).

Photo degradation of both thermally modified and unmodified Larix spp. wood was evaluated in terms of colour, microstructure, and chemical changes during accelerated weathering tests. Ultraviolet radiation caused immediate colour change and SEM observation showed deformations and cracks in both modified and unmodified samples. It was found that thermal modification was effective in improving colour stability only in the first stage of exposure to artificial weathering, but was ineffective in improving UV resistance of wood over long-term photo degradation conditions (Xing et al., 2015).

Thermally modified Scots pine (*Pinus sylvestris*) showed better surface characteristics than unmodified Scots pine after artificial weathering. Artificial weathering caused an increase in surface roughness and a decrease in glossiness of Scots pine wood. In general, higher temperature and duration of thermal modification resulted in lower surface roughness and higher gloss of Scots pine wood after artificial weathering (Baysal et al., 2013).

Deka et al. (2008) found that colour changes of thermally modified spruce wood (*Picea abies* L.) were lower than unmodified spruce wood after long term artificial UV-light exposure. It might be due to an increase in lignin stability by condensation at the time of the thermal modification process at 210 C. Similarly, oil-heat-treated pine wood (Pinus sylvestris) exhibited lower colour differences after one year of outdoor exposure in comparison to colour changes of weathered untreated wood (Petrič et al., 2007).

Yildiz et al. (2011) studied colour stability and chemical changes of thermally treated alder wood (*Alnus glutinosa* L.) after natural weathering. They reported that thermal modification delayed/decreased the rate of colour change caused by weathering factors but did not prevent it. FTIR-ATR spectroscopy showed significant deformation and degradation in wood components, especially in the hemicelluloses of thermally modified samples. Increasing the heat temperature and exposure time affects degradation of hemicelluloses.

There is inconsistency in the literature about whether thermally modified wood is susceptible to cracking when it is exposed outdoors.

Vernois (2001) reported that cracking due to dimensional changes was reduced by heat treated wood in comparison to natural wood.

Conversely, cracking of the thermally modified spruce and pine wood exposed outdoors without coating was at the same level as that of the unmodified wood and application of unpigmented or low build stains and oils did not prevent cracking of the thermally modified wood (Jämsä et al., 2000).

Miklečić et al. (2010) reported that uncoated unmodified samples of all three wood species (oak, ash and beech) had less surface cracks than thermally modified uncoated samples during accelerated weathering. Oil treatment reduced the cracking of thermally modified samples. Since the oil finish is also susceptible to photochemical degradation, the regular maintenance according to the manufacturer´s instructions is essential for a pleasant appearance of oiled surface during outdoor use.

Feist and Sell (1987) found more cracking and grain-raising on thermally modified spruce wood in nitrogen atmosphere than on unmodified wood, and surfaces were noticeably rougher after 14 months of outdoor exposure. On the contrary, thermally modified beech wood samples were smoother than unmodified ones with little noticeable differences in cracking. Both semitransparent penetrating and film-forming stains performed worse on thermally modified spruce samples than on the unmodified samples. The semitransparent stains performed somewhat better on thermally modified beech wood than on unmodified samples, while the film-forming stain performed poorly on both thermally modified and unmodified samples (Feist, Sell, 1987.). Vernois (2001) reported that surface tension of wood is drastically affected after heat treatment and that painting and finishing usually used for untreated wood cannot be used. Regardless of that, Jämsä et al. (2000) reported that thermally modified wood is comparable to untreated wood as a substrate for coatings and no alterations in coating recommendations are needed when considering coating of thermally modified wood.

Normal painting processes present no problems, but when electrostatic painting is used, heat-treated wood requires extra moisturising (Jämsä, Viitaniemi, 2001). Deka and Petrič (2008) studied the effect of two water-borne acrylic coating on photo degradation of thermally modified wood and unmodified wood and established that whole substrate-coating system showed better photo stability when thermally modified wood was used as substrate.

Pavlič (2009) studied the compatibility of nine different coatings with thermally modified Scotch pine wood (*Pinus sylvestris* L.). Coatings applied on thermally modified wood exhibited better performance than coatings on unmodified wood. This could be explained by the changed characteristics of thermally modified wood such as lower equilibrium moisture content, lower water permeability, increased dimensional stability, better UV stability and resistance to blue stain fungi in comparison to unmodified wood.

Better penetration of the coating into modified wood and better wetting of thermally modified wood with coatings were also shown. After one year of exterior weathering the solvent borne coatings exhibited better performance than waterborne coatings (Pavlič, 2009).

After more than 10 years of using *ThermoWood* products in a built environment the assessment results showed that colour changed to gray and that fibre erosion and surface shakes were quite common for *ThermoWood* products (Ala-Viikari, Mayes, 2009). Pigmented film- forming coating for decking had very short life span and required regular maintenance, although oil based finishes were a better option despite the fact that the colour would not be maintained. Miklečić et al. (2017) studied the interaction of thermally modified beech wood with nanoparticles-modified waterborne polyacrylate coating during outdoor and artificially exposure. The results showed that addition of TiO_2-rutil and ZnO nanoparticles to the coating improved the colour stability of thermally modified beech wood. However, nanosized ZnO increased peeling and cracking of coating, and caused a reduced adhesion of coating on thermally beech wood.

Acetylation

The acetylation of wood is a chemical modification of the wood cell wall using acetic anhydride. The reaction of acetic anhydride with wood polymers results in the etherification of the accessible hydroxyl groups in the cell wall with the formation of by-product, acetic acid (Rowell, 2006). This reduces the moisture sorption and improves the dimensional stability of the wood due to the reduction of free sites able to bind water through hydrogen bonds and bulking the cell wall back to its green volume (Rowell, 2016). The standard impregnation process basically consists of an impregnation of oven-dried wood with liquid phase acetic anhydride followed by conventional or microwave heating to initiate the chemical reaction with wood polymers (Rowell, 2006, Homan, Jorrisen, 2004). The reaction can be carried out with or without catalyst in a range of temperatures between 100 and 130 °C (Gerardin, 2016). After reaction, the mixture of acetic acid and acetic anhydride is removed from wood (Homan, Jorissen, 2004). Acetylation is a single-addition reaction, which means that one acetyl group is on one hydroxyl group with no polymerization (Rowell, 2016). Acetylated wood consists only of carbon, hydrogen, and oxygen, and it contains absolutely of nontoxic constituents (Hill, 2006). Acetylated wood is presently commercialised by the company Accsys Technologies in Arnhem, The Netherlands (Mantanis, 2017) and is marked under commercial name Accoya for solid wood utilizing the radiate pine (*Pinus radiata*) and alder (*Alnus* spp.) (Sandberg et al., 2017). *Accoya's* advantage over other modified wood materials is, in some applications, bright colour (Larrson Brelid, 2013).There is a slight wood colour change (usually darkening) upon acetylation with uncatalysed acetic anhydride (Rowell, 1983, Dong et al., 2016). It was found that acetylated wood had improved dimensional stability and decay resistance (Rowell, 1983, Rowell, 2006) and improved resistance to attack by termites and marine organisms

(Alexander et al., 2014, Jonson, Rowell, 1988). Studies performed with different wood species showed that equilibrium moisture content decreased as the degree of acetylation increased and that wood species had no significant effect on dimensional stabilisation as long as similar weight percent gain levels were obtained (Gerardin, 2016).

Weathering of Acetylated Wood

There are many researches related to the effects of acetylation on the resistance of wood to weathering.

Many researches have demonstrated that acetylation increases the weather resistance of wood.

(Plackett et al., 1992) reported that acetylation provided some protection to radiata pine (Pinus radiata) against accelerated weathering. Radiata pine veneers were more colour stable and resistant to surface checking than untreated veneers during accelerated weathering (Plackett et al., 1992). Dunningham et al. (1992) confirmed the results of improved checking resistance of acetylated veneers when compared with untreated veneers after 28 weeks natural weathering, but found that acetylated radiata pine veneer was only slightly less grey than untreated radiata pine veneer after 28 weeks of natural weathering. The degradation of lignin could be hindered due to acetylation and increased moisture resistance and dimensional stability could also restrain the photo degradation mechanism of wood. Immamura (1993) reported that erosion rate of earlywood and latewood and wood substance loss during weathering of acetylated spruce wood (*Picea jezoencis* Carr.) and sugi (*Cryptomeria japonica* D.Don) were significantly reduced compared to unmodified wood. Blocking accessible hydroxyl groups of lignin and holocellulose by using acetyl units reduced water uptake and retarded subsequent leaching of wood degradation products. Feist et al. (1991) established that acetylation of aspen wood helps protect wood from photochemical degradation during accelerated weathering. Erosion due accelerated weathering was reduced by 50 % compared to that of untreated wood. He found that acetylation protects the lignin component in wood to a small extent and the hemicelluloses component to a larger extent. The free radical process may be disrupted during weathering when these components are acetylated and the weathering process is then retarded.

However, Kalnins (1984) found that acetylated redwood was not resistant to photo degradation.

Anyway, it was found that the photo degradation of acetylated modified wood differs from unmodified wood but is not prevented (Hon 1995, Torr et al., 1996). Acetylated wood only shows initial stability against UV radiation and thereafter it begins to fade and grey.

Honn (1995) reported that acetylated southern yellow pine (*Pinus* spp.) wood exhibited a colour stabilization effect better than untreated wood after the initial 28 days of irradiation and after that this stabilization effect diminished steadily and discolouration started. Electron spin resonance (ESR) of photo irradiated acetylated wood revealed that active methyl and stable phenoxy radicals are generated. X-ray photoelectron spectroscopy (XPS) studies on acetylated Pinus radiata wood exposed to ultraviolet light have shown that de-acetylation occurs and that acetylation is ineffective in preventing photo-oxidation of wooden surfaces (Torr et al., 1996). Evans et al. (2000) found that depolymerisation of cellulose and erosion of the middle lamella still takes place after acetylation but mass loss is reduced and latewood cells maintained their structure. They also reported that acetylation of scots pine (*Pinus sylvestris* L.) veneers to low weight gains from 5 – 10 % increased the degradation of the modified veneers during natural weathering, but at a higher weight gain of 20 % the photostabilty of acetylated wood increased. The substitution of lignin phenolic hydroxyl groups, which occurs preferentially at low weight gains, appears to reduce the photo stability of wood. The substitution of hydroxyl groups on cellulose in wood, which occurs as a result of acetylation to high weight gains, appears to have beneficial effects on the photo stability of cellulose. However, photo protective effects of acetylation were reduced with a prolonged exposure of modified wood to weather because deacetylation of wood surface occurred (Evans, 2000).

Ohkoshi (2002) used Fourier transform infrared photoacustic spectroscopy analysis to characterize the surface changes in acetylated wood during light irradiation. He found that generation of carbonyl and lignin degradation diminished in the acetylated wood in comparison with unmodified wood, indicating that acetylation restrained the photochemical degradation of wood.

Temiz et al. (2006) also reported that acetylated scots pine wood (*Pinus sylvestris* L.) exhibited lower colour changes compared to unmodified, thermally modified and silicon modified wood. Acetylation possibly provides better colour resistance to wood surface by blocking the reactive sites of photo-induced degradation. The ability of acetylation to reduce checking and erosion of wood during weathering could be explained by the increased dimensional stability and hydrophobicity of the modified wood. (Evans, 2009). Lathela and Kärki (2015) reported that artificial weathering changed the colour of acetylated scots pine (*Accoya*) rapidly, after which the surfaces remained stable, as well as lighter and cleaner by visual review.

Acetylation of wood was shown to have positive effects on performance of coatings.

Reduced swelling and shrinkage of wood results in reduced stress in the coating, which enhances durability of the exterior wood coating system and thereby decreases the maintenance frequency (De Meijer, 2002).

This stability could be due to the higher checking resistance of acetylated wood when exposed outdoors which is result of the bulking of the cell wall of the modified wood by the acetyl substituents (Hill, 2006).

Schaller and Rogez (2007) studied light stabilization of acetylated wood and reported that acetylation partly protects lignin from photo degradation but there is still need to protect the acetylated wood with coating that has sufficient UV-VIS light protection with UV absorber and lignin stabilizer for better long term performance in terms of colour retention. The colour of acetylated Radiata pine (*Pinus radiata*) *Accoya* wood was bleached during artificial weathering. Mitsui (2010) stated that photo bleaching of acetylated wood was mainly caused by visible light. Scots pine (*Pinus sylvestris* L.) panels coated with an alkyd primer and two layers of acrylic top coats showed a considerably improved service life than unmodified coated panels after 13 years of outdoor exposure in Sweden (Larsson Brelid, Westin, 2007).The alkyd coating system (alkyd primer and alkyd topcoat) performed slightly poorer on the acetylated panels compared to unmodified panels indicating that the more acidic surface of the acetylated panels increased the aging of the alkyd coating making it more brittle (Larsson Brelid, Westin, 2007).

Bongers et al. (2005) were also reported that acetylated wood had a significantly better result with respect to long term coating performance compared to unmodified wood. Especially the acrylic white opaque coating was in good condition even after nine years of outdoor exposure.

It has been reported that acetylated hornbeam wood (*Carpinus betulus* L.) was less prone to crack during natural weathering and accelerating checking test (Fodor et al., 2017), but the modification did not hinder the fading and greying caused by ultraviolet light (Fodor, Nemeth, 2015). The photo degradation of lignin was confirmed by the FTIR spectra. Coating the samples with boiled linseed oil decreased the rate of colour change and checking (Fodor, Nemeth, 2015).

The development of staining fungi and mould on wooden surfaces is of great economic importance due to the loss of surface quality and a negative perception of wood (Gobakken et al., 2014). The results of the research concerning the resistance of acetylated wood surfaces to mould and blue stain fungi are very different (Bongers, De Meijer, 2012, Gobakken et al., 2014). It has been shown in several studies that acetylated wood is not resistant against mould and blue stain fungi (Beckers et al., 1994, Wakeling et al., 1992, Gobakken, Lebow, 2010, Gobakken et al., 2010, Gobakken, Westin, 2008). The similar result was obtained by Gobakken et al. (2014) in an outdoor test, but in a laboratory test the result was completely different. Acetylated wood had the least growth of mould and staining fungi of the modified wood substrates in the laboratory test, but the opposite was recorded for the outdoor test. These differences in the results indicate the importance of testing both in laboratory and in outdoor conditions.

Furfurylation

Chemical modification of wood with furfuryl alcohol, known as furfurylation of wood, has been known for several decades (Goldstein, 1959, Stamm, 1977).

The process is based on in situ polymerisation of furfuryl alcohol which is a bio derived chemical (Gerardin, 2016). The acid catalyst reaction chemistry of furfuryl alcohol is very complex resulting in a highly branched and cross-linked furan polymer grafted to wood cell wall polymers (Homan, Jorissen, 2004, Xie et al., 2013, Mantanis, 2017). Furfuryl alcohol molecules penetrate into the wood cell wall and polymerize in situ. This results in a permanent swelling of the wood cell walls. It is unclear whether or not chemical bonds exist between the furfuryl alcohol polymer and the wood (Sandberg et al., 2017, Mantanis, 2017).

The properties of furfurylated wood depend on the retention of grafted/polymerised furfuryl alcohol in the wood (Gerardin, 2016). Wood modified with furfuryl alcohol to certain weight percent gains (WPGs) showed greatly improved dimensional stability, reduced water uptake and increased resistance to biological degradation (Lande et al., 2004, Epmeier et al., 2004, Treu et al., 2009) while leachates from furfurylated wood had low toxicity (Pilgard et al., 2010). The rich, brown colour of furfurylated wood is attractive and makes it possible for light-coloured woods to simulate dark, expensive wood. The advantage of dark colour is the ability to mask many blemishes and discolorations of native woods. Furfurylated wood is characterized by greater hardness, elastic and rupture moduli, as compared to untreated wood but, on the other hand, it is more brittle (Mantanis, 2017).

Nowadays, the industrial production of furfurylated wood is carried out by Kebony AS in Norway. The process is based on the full cell (vacuum/pressure) impregnation with a chemical solution followed by an intermediate vacuum drying step before steam curing and drying/post curing (Larrson Brelid, 2013). The impregnation liquid is a waterborne solution containing 40 % furfuryl alcohol, buffer agents, maleic anhydride and citric acid catalysts (Pilgård et al., 2010). *Kebony Clear*, furfurylated wood is produced from radiata pine, southern yellow pine and maple and is used for flooring. *Kebony Character*, furfurylated wood is produced from Scots pine wood and is used for decking, siding, roofing and outdoor furniture. It has been established that wood species with more open pits and loose and ordered structures were best suited for furfurylation (Dong et al., 2016). Furfurylated *Kebony* wood is, like acetylated *Accoya* wood, also recommended for windows production by the German Association of Windows and Facades (VFF).

Weathering of furfurylated wood

It was shown that the modification of Scots pine (*Pinus silvestris* L.) wood with furfuryl alcohol was ineffective in reducing the discoloration and delignification of wood exposed to artificial accelerated weathering (Temiz et al, 2007). Furfurylated samples showed positive ΔL^* values thus indicating that the wood surface became lighter after 800 hours of accelerated weathering.

A three-year outdoor weathering test of furfurylated (*Kebony*) wood decks of radiata pine (*Pinus radiata*), maple (*Acer* spp.) and southern yellow pine (*Pinus* spp.) was performed in order to evaluate physical and structural properties of modified wood decks and to compare with a control deck of Ipe wood (*Handroanthus* spp.) decks. The furfurylated radiata pine deck generally showed minor surface cracks, while the furfurylated maple decks presented the lowest degree of surface and end splitting. After three years of outdoor weathering the furfurylated wood decks tested exhibited extensive greying effects and showed no signs of black staining (except for southern yellow pine deck) and no fungal or mould decay (Mantanis, Lykids, 2015).

In the study of resistance to artificial weathering of three commercial modified wood products (*Accoya, Kebony* and *Q-Treat*) the total colour change was the largest with the *Kebony* specimens, the lightness of which increased the most. This is consistent with the results of Temiz et al. (2007).

Modification with DMDHEU

N-methylol compound 1,3-dimethylol-4,5-dihydroxyethyleneurea (DMDHEU) is widely used in the textile industry as an anti- wrinkling agent. It can react with hydroxyl groups of lignin and of hemicellulose, but it can also form complex polymers with itself as a cross linking agent (Homan, Jorissen, 2004). It is consequently expected to increase the resistance of wood to weathering due to cross-linking the cell wall and dimensionally stabilizing the wood. Although indications of cross linking with the cell wall polymers are found, the mechanisms of the reaction between DMDHEU and the wood cell wall are still unknown (Larson Brelid, 2013). The use of DMDHEU as an agent for modifying wood is reported for improving the dimensional stability, durability, coating properties and weathering resistance of wood (Militz, 1993, Xie et al., 2005, 2006, 2008, Xie et al., 2013, Tomažič, 2006). The improvement of wood properties as well as formaldehyde emissions of modified wood are positively correlated with the DMDHEU concentration applied. Experiments with ether-modified DMDHEU derivatives (mDMDHEU) reacted with methanol or diethylene glycol as formaldehyde scavengers exhibited good results in wood applications showing reduced formaldehyde emission and fixation and wood characteristics similar to DMDHEU treatment (Emmerich et al., 2017). The modification process includes the vacuum-pressure impregnation of wood with aqueous solutions of DMDHEU and catalysts such as magnesium chloride followed by curing step by polycondensation at a temperature of 100-120 °C under humid conditions, after which water is released (Xie et al., 2013). Molecular size of DMDHEU is small enough to penetrate cell walls. Modification of solid wood is limited to permeable wood species that are easy to impregnate (Emmarich et al., 2017). The modification process is developed and optimized for Scots pine (*Pinus sylvestris* L.), but investigations on other permeable wood species such as Rubber wood (Hevea brasiliensis Müll. Arg., Radiata pine (*Pinus radiata* D.Don), European beech (*Fagus sylvatica* L.), Sweetgum (*Liquidambar styraciflua* L.), Balsam poplar (*Populus ussuriensis*, Komarov) have also confirmed a high level improvement of durability and dimensional stability by DMDHEU modification (Emmerich et al., 2017). There is a need for optimization of curing processes for specific wood species. However, process development and optimization to industrial scale were limited to Scots pine until now, since modified beech showed increased crack formation (Emmarich et al., 2017). Commercial application of wood modification process with DMDHEU has been achieved in Germany and marketed by BASF Company under commercial name *Belmadur* (Sandberg et al., 2017). Key applications for DMDHEU modified *Belmadur* wood are decking and garden furniture and laminated Belmadur product has gain acceptance by the German association of Windows and Facades for use in exterior windows (Sandberg et al., 2017). The hygroscopic properties of DMDHEU-modified products are reduced (Larsson Brelid, 2013, Papadopoulos, Mantanis, 2012). Optical and haptic appearance of the modified wood was found to be almost unchanged besides slight darkening compared to unmodified wood (Emmerich et al., 2017). ASE values of 30 to 40 % are in range at 40 % WPG (Homan, Jorissen, 2004). However, brittleness may limit its use as load bearing structural elements (Xie et al., 2013). Other drawbacks are tendency to crack and high emission of formaldehyde from the products (Larrson Brelid, 2013).

Weathering of DMDHEU treated wood

DMDHEU was used to modify Scots pine veneers to different weight percent gains (WPG) and exposed to artificial weathering. Evidence from FT-IR spectra and weight losses of weathered veneers indicated that at higher weight gain (48 %) the treatment stabilized lignin to some extent. The lower percentage of strength loss observed for DMDHEU modified veneers in comparison to unmodified veneers suggested that DMDHEU modification reduced the degradation of cellulose during weathering. Electron microscopy revealed that DMDHEU modification was highly effective at preventing the degradation of the wood cell wall during weathering (Xie et al., 2005).

Several authors investigated the effects of wood modification with modified DMDHEU (mDMDHEU) on the performance of water- borne and solvent-borne stains and paints. The modified DMDHEU (mDMDHEU) Scots pine (*Pinus sylvestris*) sapwood was compatible with both water-borne and solvent-borne coating system and caused no significant change in wet-adhesion, blocking and drying rate (Xie et al., 2006). Natural and artificial weathering of uncoated and coated DMDHEU-modified sugi wood (*Cryptomeria japonica* D. Don) showed lower weight losses and less cracking than did the unmodified wood (Sudiyanni et al., 1996).

Although modification of the Scots pine wood with commercially available DMDHEU increased the hydrophobicity of the wood surface, it had no adverse effect on the wetting of the wood surface by the waterborne coating. Moreover, the modified surface exhibited much better wetting by exterior commercial waterborne coatings on modified substrates than on unmodified substrates (Tomažič, 2006, Petrič et al., 2007). Penetration of the coatings into DMDHEU-modified wood was deeper and consequently the dried coatings on DMDHEU modified wood exhibited increased adhesion. Coatings on DMDHEU modified wood showed increased performance after natural and artificial exposure in comparison with coatings on unmodified wood and therefore longer maintenance intervals of coatings could be expected on DMDHEU modified wood (Tomažič, 2006). However, water vapour permeability of the system DMDHEU modified wood – coatings was higher than in case of coatings on unmodified wood. It could be due to increased hygroscopicity due to remaining of the catalyst or due to unreacted free hydroxyl groups (Tomažič, 2006).

The results obtained after 18 months of natural weathering in Central Germany showed that the modification of Scots pine sapwood with modified 1,3-dimethylol-4,5-dihydroxyethyleneurea (mDMDHEU, received from BASF AG) enhanced the service life of wood used outdoors. Modified uncoated panels compared to unmodified exhibited reduced discoloration mainly caused by staining fungi. However, mDMDHEU treated panels couldn’t prevent fungal staining of wood, but did reduce colonization. Panels modified with mDMDHEU were also less deformed regarding to cupping and developed smaller cracks and reduced surface roughness and waviness compared to unmodified panels. Both acrylic and oil coatings displayed less discoloration and cracking on the mDMDHEU modified panels after 18 months of natural weathering compared to unmodified panels (Xie et al., 2008).

Colour measurements during 24 months of outdoor exposure of Scots pine sapwood (*Pinus sylvestris*) and beech wood (*Fagus sylvatica*) showed discoloration and lignin degradation of DMDHEU-modified wood (Pfeffer et al., 2011). FTIR spectroscopy revealed lignin degradation during initial exposure time (3-6 months). The surface discoloration was a combination of fungal growth and photo degradation of lignin. The fungal infestation was slowed down while lignin degradation was not, indicating that lignin degradation did not influence the initial fungal infestation of the modified wood surfaces. The DMDHEU modification also reduced the speed of liquid water uptake caused by the inclusion of the chemical in the ray cells, the mayor penetration pathways for water in unmodified wood (Pfeffer et al., 2011). However, the modified specimens exhibited cracks during and after outdoor exposure. The radial penetration of fungal hyphae was reduced in DMDHEU-modified wood which might be caused by blocking of the penetration pathways due to the inclusion of a chemical in the ray cells (Xie et al., 2008).

Conclusions

The test results of the weathering resistance of modified wood depend on many factors such as wood species, modification processes and parameters, type and conditions during outdoor or laboratory exposure. Therefore, the comparison of the results is very difficult. Based on the studied literature it can be summarized and concluded as follows:

- Weathering resistance of modified wood does not change largely when compared to unmodified wood, making a surface treatment advisable for protection and aesthetic appeal of wood. Commercially modified wood producers in their brochures recommend surface treatment materials for protection and retaining the original colour of modified wood without silver-gray patina.

- Thermally modified wood exposed to weathering conditions resulted in the formation of small cracks on the surface of uncoated wood and turned grey in colour. Unpigmented or low build stain did not protect the wood surface, but solvent-borne alkyds and water-borne acrylic paints exhibited better performance than unmodified wood. Pigmented film-forming coating for decking showed to have a short life span during the natural exposure and required regular maintenance but oil based finishes were a better option despite the fact that the colour would not be maintained.

- Acetylated wood is also like any natural wood species susceptible to weathering in outdoor conditions. It only shows the initial stability against UV radiation and thereafter begins to fade and grey as other wood species. Acetylation of wood was shown to have positive effects on performance of coatings. It has been shown in several studies that acetylated wood is vulnerable to mould and blue stain fungi.

- Furfurylated wood decks after three years of outdoor exposure exhibited extensive greying effects and showed no signs of black staining or mould decay. Checking or small surface cracks also occurred. The original colour can be maintained using UV protection oils and water-based acrylic paints.

- DMDHEU-modified uncoated panels compared to unmodified exhibited reduced discoloration mainly caused by staining fungi. Panels were also less deformed regarding cupping and developed smaller cracks and reduced surface roughness and waviness compared to unmodified panels. Colour measurements during 24 months of outdoor exposure of DMDHEU-modified wood showed discoloration and lignin degradation, but both acrylic and oil coatings displayed less discoloration and cracking on the DMDHEU- modified panels after 18 months of natural weathering compared to unmodified panels.

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Subcritical Water Extraction Laboratory Plant Design and Application

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Abstract: The demand for different green extraction techniques, which provide shortened extraction time and reduced organic solvent consumption, constantly increase. Subcritical water is a green, cheap and non-toxic processing medium, which makes treatments inexpensive, ecofriendly, more selective and less time consuming. Furthermore, lower viscosity and higher values of diffusion coefficient and thermal conductivity at subcritical temperatures improve mass and heat transfer rates. All these properties make subcritical water a satisfactory replacement for organic solvents in extraction processes.

The subcritical water extraction (SWE) technology continuously increases its application in different fields. Thus, the aim of this work was to give an overview of two types of the SWE design: dynamic (continuous flow) and static (batch) systems. The design and development of one SWE static system used for laboratory procedures is given in detail. Some applications together with the optimal extraction parameters of this SWE technology are also shown.

Keywords: subcritical water extraction, plant design, green technology, application

Introduction

The green processes represents an attractive topic in the past few decades. One of environmentally friendly technologies is subcritical water extraction (SWE) with many advantages compared to conventional techniques which is confirmed in our recently published review articles (Cvjetko Bubalo et al., 2015; Cvjetko Bubalo et al., 2018). The use of these new green processes opens the possibility to achieve better product qualities and/or even to allow the development of completely new products for the use in the food, beverage, cosmetic and pharmaceutical industries as a natural ingredient. Water is probably the best-known and most widely used solvent. When water is used as a solvent, the SWE technology could also be designated as pressurized hot water extraction (PHWE), superheated liquid extraction (SHLE), pressurized liquid extraction (PLE), accelerated solvent extraction (ASE), superheated water extraction (SHWE) or hot water extraction (HWE) (Plaza, Turner, 2015).

Subcritical water extraction

Subcritical water is water at temperatures above its normal boiling point (100°C) and below its critical point (374°C) at a pressure at which it remains in the liquid state. It represents a cheap, safe and non-toxic processing fluid (Ramos et al., 2002). At these conditions, water becomes less polar and therefore it is a suitable replacement for organic solvents. At a temperature above 374 °C and a pressure above 220 bar, water is considered to be in the supercritical state. Water properties in normal conditions, subcritical/near critical state and supercritical state are presented in Table 1 in which it can be seen that with a change of extraction temperature and pressure main water properties change.

Table 1 – Properties of water at different conditions and in different state (Brunner, 2014)

Property	Water at normal conditions	Near-critical water	Supercritical water
T (°C)	25	350	400
P (bar)	1	250	500
ρ (kg m^{-3})	997.45	625.45	577.79
ε (–)	78.5	14.86	12.16
pKw (–)	14.0	11.5	11.5

At ambient conditions water is considered an extremely polar solvent, and its polarity is characterized by a dielectric constant of around 80. In this state, water is suitable for the extraction of highly polar compounds. But, at a temperature between 100 and 374°C, and under a high and sufficient pressure to keep water in the liquid state, the polarity of water considerably decreases and it becomes suitable for the extraction of both, polar and non-polar compounds. This is caused by a dramatical drop of the dielectric constant with increasing temperature. At elevated temperatures in the subcritical state, surface tension, water viscosity and density, aside from polarity, are significantly lowered too. At elevated temperatures the surface tension of water decreases; this enables enhanced water wetting of the extracting material and the dissolution of targeted compounds in the solvent much faster. Decreased water viscosity enhances its penetration inside the extracting material and thus improves the diffusion rate. The improved diffusion rate enables accelerated extraction as well (Plaza, Turner, 2015).

The advantages of the SWE could be summarized in the following tasks (Cvjetko Bubalo et al., 2018):

- SWE use water as an extraction solvent, which is safe, non-toxic, non-flammable and environmentally friendly;
- Water is easily available and cheap.
- Obtained extracts are safe, without a trace of any toxic solvents;
- SWE is characterized by higher diffusion into the plant matrix and increased mass-transfer properties in comparison to other extraction techniques;
- SWE can be applied for extraction of low-polar as well as non-polar compounds;
- Application of a low cost and easily available extraction solvent and short extraction times minimize the cost of the extraction process.

Drawbacks of SWE (Cvjetko Bubalo et al., 2018):

- High investments costs;
- At elevated temperatures, the risk of unwanted reactions (caramelization, Maillard reactions) increases and toxic compounds can be formed;
- At elevated temperatures possible degradation of temperature sensitive compounds can be expected.

These unique properties of subcritical water, as well as the fact that water as a solvent is easily available, safe, cost-effective, non-toxic, non-flammable, and environmentally friendly, lead to a number of studies on the possibility of the SWE application for the extraction of various compounds, bioactive and many others. The SWE was firstly used in 1994 for extracting polar and non-polar compounds from soils. Since that time, the SWE has been used mainly as an extractant of compounds such as PAHs, PCBs, pesticides and polychlorinated benzofurans from environmental solid samples (Hyotylainen et al., 2000; McGowin et al., 2001). It is also an efficient method for the extraction of antioxidants (phenols and flavonoids), essential oils, fatty acids, oils, carotenoids, sugars, mannitol, pectin, resorcinol, etc. Some of these applications are given in Table 2.

Table 2 – Some applications of the SWE in the last 5 years

Material for extraction/ resource	Targeted compound	SWE operating conditions	Reference
Pistachio (*Pistacia vera* L.) hulls	Polyphenols; gallic acid; pentagalloyl glucose; quercetin; anacardic acid	**Investigated range:** Temperature: 110–190 °C Flow rate: 4 mL/min Pressure: 69 bar **Optimal conditions/highest recovery:** Total gallotannin yields:150-170°C Flavonols: 110-150°C	Erşan et al. (2018)
Red ginseng	Ginsenoside Total phenols	**Investigated range:** Temperature: 150-200 °C Extraction time: 5-30 min **Optimal conditions/highest recovery:** 200°C, 20 min	Lee et al. (2018)
Wood	Hemicellulose	**Investigated range:** Temperature: 160°C Pressure: 9 bar Extraction time: 5-80 min **Optimal conditions/highest recovery:** 80 min	Gallina et al. (2018)
Black mulberry (*Morus nigra* L.)	Gallic acid, protocatechuic acid, catechin, chlorogenic acid, caffeic acid, β-resorcylic acid, p-coumaric acid, naringin, rutin	**Investigated range:** Temperature: 60–200 °C Pressure: 10 bar Extraction time: 30 min **Optimal conditions/highest recovery:** 160°C	Nastić et al. (2018)
Wild geranium (*Geranium macrorrhizum* L.)	Gallic acid, protocatechuic acid, catechin, chlorogenic acid, vanillic acid, p-coumaric acid, ferulic acid	**Investigated range:** Temperature: 60–200 °C Pressure: 10 bar Extraction time: 30 min **Optimal conditions/highest recovery:** 160°C	Nastić et al. (2018)
Comfrey (*Symphytum officinale* L.)	Gallic acid, protocatechuic acid, caffeic acid, β-resorcylic acid, p-coumaric acid, ferulic acid, sinapic acid, naringin, rutin, cinnamic acid, naringenin	**Investigated range:** Temperature: 60–200 °C Pressure: 10 bar Extraction time: 30 min **Optimal conditions/highest recovery:** 160°C	Nastić et al. (2018)
Wild garlic (*Allium ursinum* L.)	Total phenols and total flavonoids	**Investigated range:** Temperature: 120-200 °C Extraction time: 10-30 min Added acidifier, HCl: 0-1.5% **Optimal conditions/highest recovery:** 180.92 °C, 10 min, added acidifier 1.09%	Tomsik et al. (2017)

Material for extraction/ resource	**Targeted compound**	**SWE operating conditions**	**Reference**
Uva ursi herbal dust	Total phenols and total flavonoids	**Investigated range:** Temperature: 120–220 °C Extraction time: 10–30 min Pressure: 30 bar Added acidifier, HCl: 0-1.5% **Optimal conditions/highest recovery:** 151.2 °C, 10 min, 1.5% HCl	Naffati et al. (2017)
White grape pomace	Total phenols	**Investigated range:** Temperature: 170–210°C Extraction time: 30 min Pressure: 100 bar **Optimal conditions/highest recovery:** 210°C, 100 bar, 30 min	Pedras et al. (2017)
Winter savory (*Satureja montana* L.)	Total phenols and total flavonoids	**Investigated range:** Temperature: 79.15-220.5 °C Extraction time: 5.9-34.1 min Pressure: 30 bar **Optimal conditions/highest recovery:** 220°C, 20.8 min, 30 bar	Vladic et al. (2017)
Ginger (*Zingiber officinale*)	Gingerol	**Investigated range:** Temperature: 130-140 °C Extraction time: 10-40 min Pressure: 2 bar **Optimal conditions/highest recovery:** 130°C, 20 min, 2 bar	Yulianto et al. (2017)
Mandarin (*Citrus unshiu* Markovich) peel	Flavonoids (Narirutin, Hesperidin, Naringin, Naringenin)	**Investigated range:** Temperature: 110–190 °C Extraction time: 5–15 min **Optimal conditions/highest recovery:** 130°C, 15 min	Ko et al. (2016)
Tumeric rhizomes (*Curcuma longa* L)	Curcumin	**Investigated range:** Temperature: 120-160°C Extraction time: 6-22 min Particle size: 0.6-2 mm Pressure: 10 bar **Optimal conditions/highest recovery:** 140°C, 10 bar, 14 min, 0.71 mm	Kiama-halleh et al. (2016)
Spent coffee grounds (*Coffea arabica* L.)	Total phenols	**Investigated range:** Temperature: 110-190 °C Extraction time: 15-75 min Pressure: 50 **Optimal conditions/highest recovery:** 177 °C, 55 min, 50 bar	Xu et al. (2015)

Material for extraction/ resource	Targeted compound	SWE operating conditions	Reference
Black tea	Myrcetine and Quercetin* Kampherol**	**Investigated range:** Temperature: 110-200°C Extraction time: 5-15 min Pressure: 101 bar **Optimal conditions/highest recovery:** 170°C, 15 min, 101 bar* 200°C, 15 min, 101 bar**	Cheigh et al. (2015)
Ginseng leaf	Myrcetine and Quercetin* Kampherol**	**Investigated range:** Temperature: 110-200°C Extraction time: 5-15 min Pressure: 101 bar **Optimal conditions/highest recovery:** 170°C, 10 min, 101 bar* 200°C, 15 min, 101 bar**	Cheigh et al. (2015)
Citrus peel	Pectin	**Investigated range:** Temperature: 100-140 ºC Extraction time: 5 min **Optimal conditions/highest recovery:** 120 °C, 5 min	Wang et al. (2014)
Apple pomace	Pectin	**Investigated range:** Temperature: 130-170 ºC Extraction time: 5 min **Optimal conditions/highest recovery:** 150 °C, 5 min	Wang et al. (2014)

Process parameters of the SWE

The main factors affecting the extraction efficiency during the SWE include extraction temperature, time, and solute characteristics. Temperature represents an extremely important parameter due to the fact that at different temperatures different components are formed. A higher temperature of the water leads to the improved wetting of the sample. Further, increasing the temperature also favors mass-transfer kinetics, and results in faster diffusivity. When the temperature increases during the SWE, the strong solute-matrix interactions caused by van der Waals forces, hydrogen bonding, and dipole attractions of the solute molecules and active sites on the matrix can be disrupted, and hydrogen bonding is weakened with increasing temperature. Thermal energy can overcome the cohesive (solute-solute) and adhesive (solute-matrix) interactions by decreasing the activation energy required for desorption (Richter et al., 1996). In addition, the viscosity and surface tension of subcritical water decrease at higher temperatures, hence promoting better penetration of water into the matrix particles to enhance extraction. There are three main drawbacks in using elevated temperatures in the SWE: decreasing selectivity of the extraction, degradation of some analytes, and other chemical reactions in the sample matrix.

Extraction time is notably influenced by temperature and the nature of the sample matrix and solutes. In many works as published in reviews of Plaza and Turner (2015) and Okiyama et al. (2017), a higher antioxidant capacity was observed in the extracts obtained at temperatures of over 175 °C and at longer extraction times, compared to the extracts obtained at lower temperatures and shorter extraction times. The most active antioxidants from rosemary, including carnosol, rosmanol, carnosic acid, methyl carnosate and some flavonoids, were recovered in the extracts using SWE with high antioxidant activity (Ibáñez et al., 2003).

Pressure has very little influence on the properties of water, as long as the water remains in the liquid state. However, a specific minimum pressure is required to maintain the water in the liquid state at the extraction temperature. Pressures elevated from 1 to 10 MPa at treatment temperatures ranging from 100 to 300□ are generally used to maintain water in the liquid state during subcritical water treatment (Wagner, Pruß, 2002).

The particle size of the sample influences the extraction kinetics since a smaller particle size leads to increasing the contact surface between the sample and the extractant.

Solvent-solid ratio is an important parameter in the SWE. It is important that the solvent-solid ratio is as small as possible but at the same time big enough to provide the highest possible extraction yield (Ravber et al., 2015).

All these parameters are important when analyzing the SWE, so the optimization of this process is desirable.

Design of the SWE system

There are two types of equipment for the SWE: dynamic (continuous flow) systems (Fig. 1a) and static (batch) systems (Fig. 1b). The main parts of the dynamic SWE are pump (6.), extractor (4.) and pressure restrictor valves (2.). The pump delivers water through the heating coil to the extraction vessel. On that way water is preheated on the temperature of extraction. The water passes through the extractor. After the extractor the water passes through the cooling coil and can be collected. The pressure of the system is very finely controlled by the air driven liquid pump with a pressure range from 0.2 MPa to 20 MPa. Heating is very finely controlled

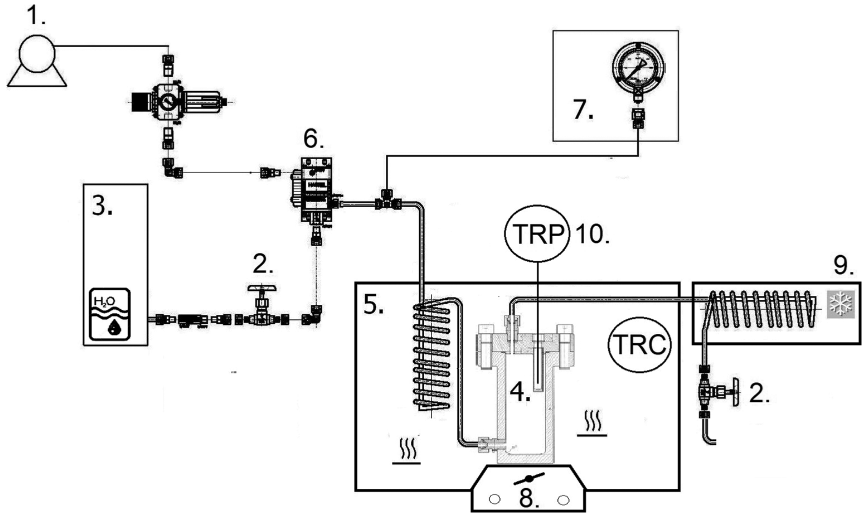

Fig. 1a – The main parts of a dynamic SWE system 1. Compressor, 2. Valves, 3. Water tank, 4. Extractor, 5. Oven, 6. Pump, 7. Manometer, 8. Magnetic stirrer (Optional), 9. Cooling coil (bath), 10. TRP and TRC

by the TRC oven. To prevent sample flow, loss and potential clogging of tubes, the extractor vessel should have sintered stainless steel filters at least at the exit of water from the extractor. Dynamic and static SWE are very similar regarding oven, tubing and valves.

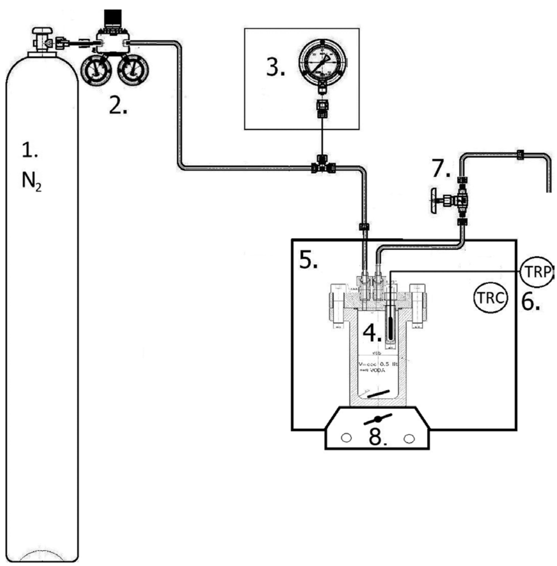

Fig. 1b – The main parts of a static SWE system (Faculty of Food Technology of Osijek): 1. N_2 tank (150/40), 2. Pressure reducing valve (200/50), 3. Manometer, 4. Extractor, 5. Oven, 6. TRC and TRP, 7. Valve, 8. Magnetic stirrer

In contrast to the dynamic SWE the static SWE doesn't have a pump and is pressurized trough N_2 to prevent sample oxidation. The retention time of subcritical water in the dynamic SWE is shorter than in the static SWE resulting in a lower degradation of the thermolabile components which is more preferably. The only disadvantage of the dynamic SWE is that it is more expensive than the static SWE.

At the Faculty of Food technology Osijek the authors of this paper designed and built one plant for the high pressure extraction process using supercritical CO_2 (Jokić et al., 2015; Horvat et al., 2017); so the next step was to design of a new subcritical water extractor.

Handmade subcritical water extraction (HM-SWE) system

The schematic diagram of the newly constructed apparatus for the SWE at the Faculty of Food Technology Osijek is presented in Figure 1b. This is a static SWE system.

Materials used for the HM-SWE system

Materials used for the construction of the HM-SWE system were stainless steel AISI 304. All additional connection tubing parts were also of the same material grade. The extraction vessels were properly tested with a safety factor of 1.5. The extraction vessel was tested at a working pressure of 30 MPa.

Construction of the HM-SWE system

The construction and assembling of the HM-SWE system was performed by Đuro Đaković Aparati d.o.o. (Slavonski Brod, Croatia) which provided material durability tests and pressure test for vessels. Working pressure calculations for the extractor and seamless tubes are given in Eq. (1):

$$P = \frac{2 \cdot S \cdot T}{(O.D. - 2 \cdot T) \cdot SF}$$

where:

P – fluid pressure (MPa)
T – wall thickness (extractor and seamless tube) (m)
O.D. – outer diameter (m)
SF – safety factor (usually 1.5)
S – yield tensile strength of material

Extraction vessel, manometers, pipes and magnetic stirrer

The extraction vessel was made from stainless steel bar (AISI 304) O.D. 90 mm and with a height of 230 mm. A stainless steel rod was drilled (center hole) with a Ø 65 mm bore for 155 mm, so the extractor volume is ca. 500 mL. The extraction vessel is closed with a flange type (Ø 154 mm) closure using eight M16 screws. Sealing is provided with a high temperature O-ring Viton type. In the center of the flange closure there are two quick connectors sealed also with Viton O-rings and one place for a PT temperature probe. High-pressure valves are used to control intake pressure of N2. High pressure pipes AISI 316Ti 6x1mm are used to connect the extraction vessel, gas cylinder and control manometer. The control manometer used is WIKA 0-25MPa with 0.5 MPa division.

The pressure and inert state during the extraction time is provided with N_2 from a cylinder and the desired pressure is achieved using a pressure reducing valve (20/5 MPa).

The magnetic stirrer is placed below the extractor vessel to obtain adequate stirring of water and material.

Conclusions

The SWE emerged in the last few decades as a promising green technology due to its unique properties and a wide variety of possible applications in processing food and natural products. The handmade static system proposed in this paper offers a cost effective solution for small scale research SWE systems. By presenting uniform and simple guidelines for the construction of a laboratory SWE system an adequate scale-up from laboratory to industrial design purposes becomes a simple task.

Acknowledgements

This work has been supported in part by the Croatian Science Foundation under the project "Application of innovative techniques of the extraction of bioactive components from by-products of plant origin" (UIP-2017-05-9909).

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Urban Mining – a New Concept

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Abstract: Population growth, increased standard of living and accelerated industrial growth have led to the increased need for all types of raw materials and energy, but have also caused increasing quantities of waste. This is why recently, in establishing new development strategies, raw material management and waste management policies have been combined at all levels. Urban mining is also a new concept for the use of mineral and other raw materials, as well as the energy potential present in waste, landfills and other anthropogenic sources. Although exploration, extraction and processing of mineral raw materials from such secondary sources are based on similar methods and procedures as in traditional exploitation from natural deposits, still adaptations, innovations and new technological solutions are needed. This paper provides a detailed review over the management of mineral raw materials and the associated waste management in both the European Union and Croatia.

Keywords: urban mining, mineral resource management, landfills, waste management

Introduction

Population growth and increasing standard of living have led to an increased demand for all types of raw materials and energy. Also, industrial growth causes more and more waste to be generated. Therefore, there is a clear need for strategic planning that will combine raw material management and waste management at all levels. In this paper a detailed review is provided over the management of mineral raw materials (mineral resources) and the associated waste management.

Generally speaking, as the need for raw materials is growing, so the efforts to recycle waste should also be increased, since estimates point to the fact that the increased need for resources cannot be met exclusively from primary sources in the long run. Urban mining is a new concept that can make a significant contribution to this goal; it can be simply defined as recycling of raw materials and/or energy from secondary (anthropogenic) sources: products, buildings or waste, by which a more rational use of primary sources, i.e. natural mineral deposits (in case of mineral raw materials) is secured.

Contemporary waste management concepts are based on a hierarchy in which every form of recycling is preferred, with the aim of disposing of as little waste as possible. Increased recycling brings many benefits, such as: reducing primary raw material needs, re-using valuable materials instead of turning them into waste, reducing energy consumption and greenhouse gas emissions, as well as other negative environmental impacts.

This paper presents the main strategic guidelines within the European Union related to waste management and mineral resource management. It also gives an overview of the applicability of these strategic goals to Croatian economy, as well as the measures and activities that should be undertaken to achieve them.

Waste management

In general, it can be said that the awareness about the importance of waste and its management underwent frequent changes in the last century. From regarding waste as a civilizational problem, a new paradigm emerged in which waste is considered a resource. In this development, the most significant step towards a new model can be defined by the waste hierarchy as shown in Fig. 1. In this hierarchy prevention refers to measures that are aimed at avoiding the generation of waste or its reduction during production. The new waste management hierarchy prefers re-use and recycling, including composting and energy recovery from waste. Waste disposal is the least desirable option. Despite the fact that the general awareness of the need to change the policy of waste management is present and even officially proclaimed in national policies, there are still large differences in its application. In some EU countries, about 80% of waste is recycled, whereas in other countries large quantities of waste are still landfilled without reuse of raw materials.

EU Member States are required to implement strategic documents related to mineral raw materials and waste management, and the goals and necessary measures are described in the document entitled "*Roadmap to a Resource Efficient Europe*" (EC, 2011). This document states that during the 20th century the consumption of fossil fuels increased by 12 times, whereas the consumption of various natural re-

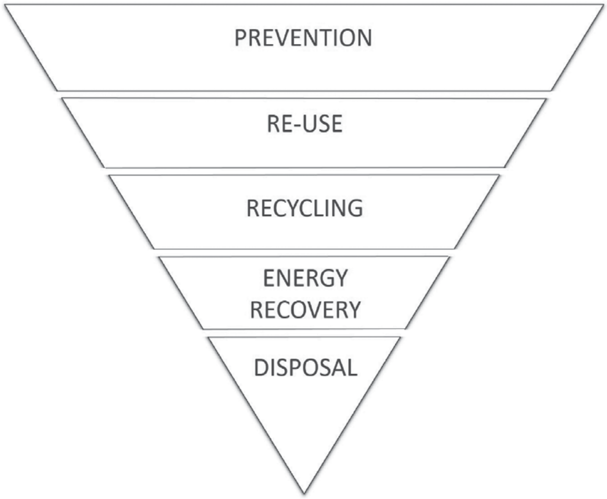

Fig. 1 – Waste hierarchy (EU Directive 2008/98/EC)

sources increased by 34 times. Annually in Europe about 16 tons of materials are spent per person, of which 6 tons are converted into waste, and 3 tons end up in landfills. If such trends persist, natural resources will soon be exhausted, according to some predictions already in the middle of the 21st century. Therefore, efficient resource use is promoted and recommendations are made on how to ensure economic development with the smallest possible use of raw materials from primary sources and least waste production. This document also defines certain goals to be achieved by 2020. Some EU countries are already quite close to achieving these goals, but there are also countries that will need to make significant efforts to reach the same goals within the prescribed deadline.

Today there is a lot of talk about "green economy" and "zero waste societies". In an ideal situation, all metals/mineral raw materials should be recycled and the rest of the waste subjected to biodegradation processes. In this case the disposal and incineration of waste would be completely excluded (ISWA, 2011). In reality, all forms of waste management (disposal/incineration/recycling) are still present to a greater or lesser extent, as can be clearly presented in the Venn diagram (Figure 2). The least desirable option is represented by the lower left corner of the triangle, representing countries where all or almost all waste is landfilled. The most desirable option is at the top, when all waste is recycled ("*zero waste society*"). In most countries, there is also the third option of waste incineration, as shown at the right top. Taking into account the ratios of different waste treatments in a given country, the situation in the indicated diagram is shown by a dot within the triangle. If waste management trends are observed over a longer period of time, it is possible to spot the strategic determinants of a particular country, i.e. which course a country is taking to the ideal zero waste society. In general, the vector is usually directed from the lower left corner to the centre of the diagram, where the current European average is also visible. More advanced countries are already close to the optimum at the top of the triangle. The least desirable option is presented in red in the diagram, representing countries where landfilling waste is still dominant. Yellow represents the so-called transitional countries, where all three waste management options (disposal/ incineration/recycling) are present. The green area is the long-term goal - with emphasis on recycling, energy recovery from waste and depositing minimum quantities of waste. The average EU status is shown by blue dots of the diagram for the period from 1994 to 2014 (Pomberger et al. 2017, Eurostat, 2017). However, some EU countries are still in the least desirable red-marked zone, and a part of them is already in the most desirable green-marked zone, while most of the countries are in the yellow-marked transitional zone. The state of waste management in Croatia is shown according to available data (Eurostat, 2017) with red symbols. It can be noted that waste disposal and recycling are quite equally represented in Croatia, while energy recovery from waste and waste incineration are minimal. The

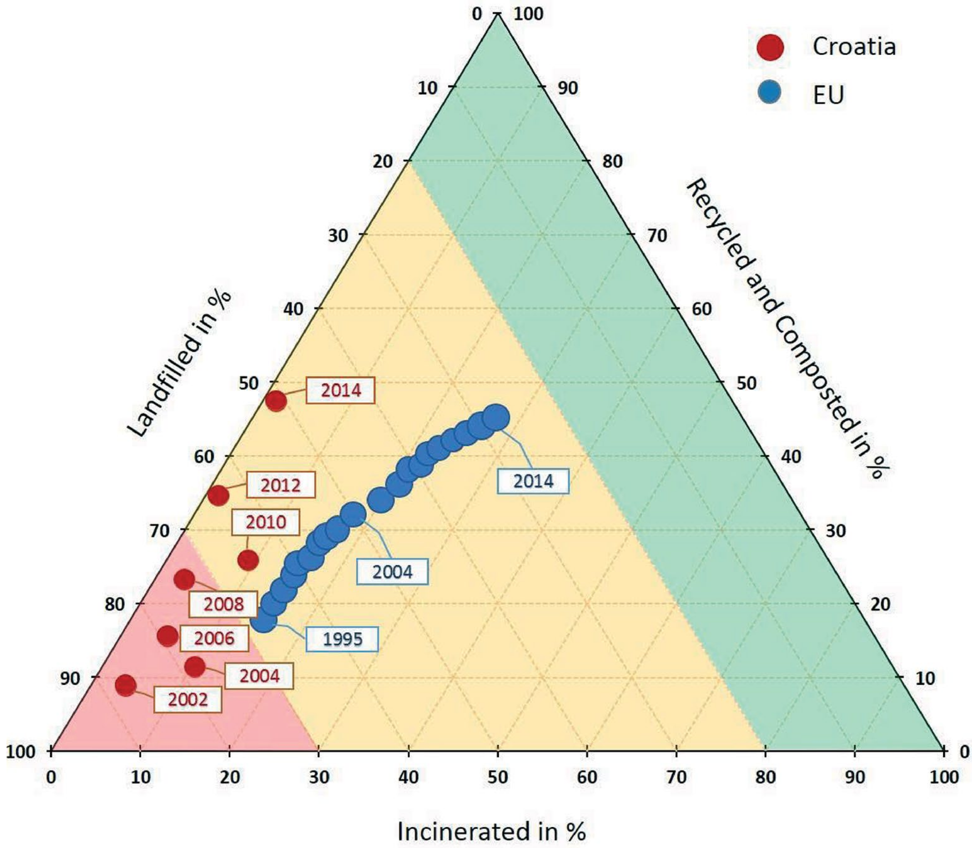

Fig. 2 – Waste management in the EU and in Croatia

mentioned diagram shows that the line of Croatia differs from the European average, since waste is mostly disposed of or recycled, and that incineration and energy recovery from waste are minimal. In the EU much larger quantities of waste are incinerated and recovered for energy. Thus, it follows that Croatia belongs to the countries that have not yet used all the options for recycling/recovery, and that in the future the waste management policy is likely to change and adapt to general trends in the European Union.

Management of mineral raw materials

According to the Mining Act of the Republic of Croatia mineral resources are "all organic and inorganic mineral raw materials found in solid, liquid or gaseous state in original deposits, alluviums, tailing dumps, melting slags, or natural solutions (Official Gazette "Narodne novine", 2013). Mineral raw materials include: "energy mineral raw materials (hydrocarbons, fossil fuels), mineral raw materials for industrial processing, mineral raw materials for production of construction materials, dimension stone, metal ores (Official Gazette "Narodne novine", 2013).

Mineral raw material management strategies can be based on primary sources, i.e. the mineral resources of a country, or on secondary sources obtained by recycling. Economic growth is not achievable without mineral resources, so many European countries that have a shortage of mineral resources rely on imports from the global market, in combination with implementing measures for the efficient use and recycling of mineral raw materials.

At world level, the need for mineral raw materials is drastically increasing. In addition, regional share in production is significantly altered. The global trend is that the share of production is continually increasing in Asia, and at the same time decreasing in Europe and North America. This can lead to shortages of certain mineral raw materials (which are difficult to substitute only by recycling) and/or a significant increase in prices. The results of recent surveys on the availability and supply risk of minerals/metals that are important for the economic development of EU countries are shown in Fig. 3. The figure shows that mineral raw materials can be classified into three groups (ISWA, 2011):

1. Mineral raw materials of low economic value and with low supply risk (marked in green). These materials do not have a significant impact on industrial development.

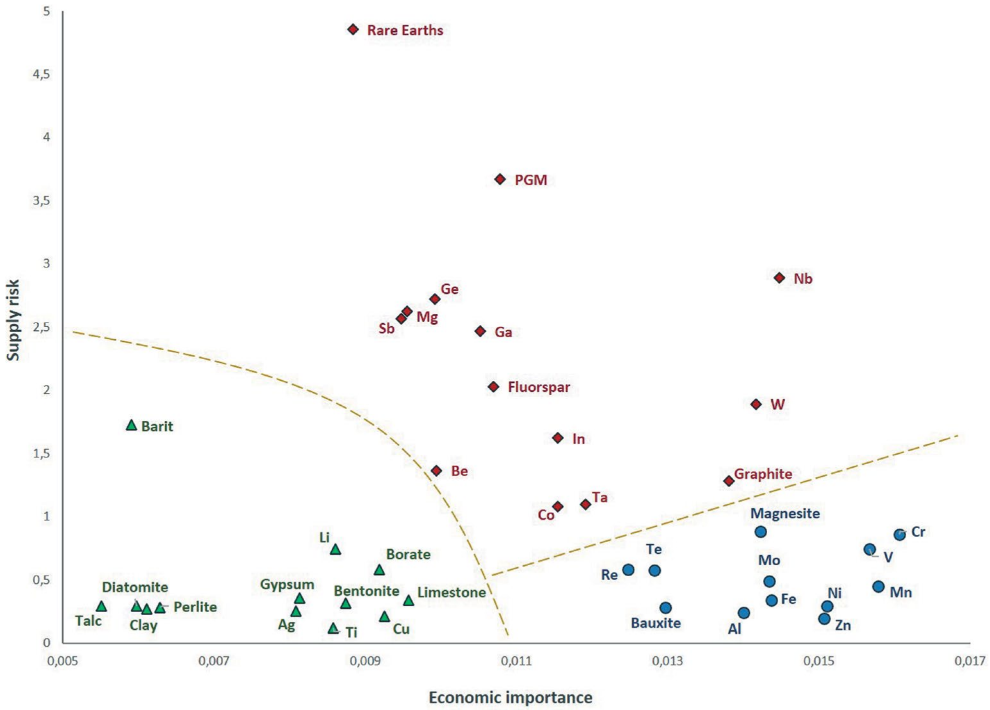

Fig. 3 – Mineral raw materials: economic importance and supply risk (ISWA, 2011)

2. Mineral raw materials of relatively high economic value but with low supply risk (marked in blue). There are mainly sufficient quantities of these materials, or they can be easily replaced with other materials, so that they also have no significant effect on industrial development.

3. Mineral raw materials of high economic value and with high supply risk (marked in red). There are about 14 materials that are considered critical for further industrial development.

Certain mineral raw materials from the last critical group are produced in only a few countries of the world (about 90% of rare earths and antimony, and about 75% of germanium and tungsten are produced in China, about 90% of niobium in Brazil and 77% of platinum in South Africa).

In Croatia mainly hydrocarbons and non-metallic mineral raw materials are exploited (Vrkljan, 2017). These are mainly mineral raw materials for industrial processing, mineral raw materials for production of construction materials and dimension stone (group 1 in Fig. 3). Croatia does not possess any reserves of metal mineral raw materials or raw materials belonging to the group of critical minerals (groups 2 and 3 in Fig. 3). This also means that for its sustainable development Croatia will lack mineral raw materials, which it will have to acquire on the global market, and at least partially secure from secondary sources by applying the concept of urban mining.

Urban mining

In the past several decades waste management strategies have been based on circular economy principles, replacing the previous linear economy principles. In the traditional approach to the extraction of mineral raw materials from natural deposits, in the exploitation phase mining waste (topsoil, overburden and waste rock) and in the processing phase tailings were created. In this process waste rock was usually inert for the environment, representing a problem mainly due to its large quantity and visual effects on the landscape. Tailings often belong to the category of hazardous waste and pose a threat to all components of the environment.

With the shift to circular economy, and due to the increase in the required quantities of mineral raw materials and the awareness of their limited supply in natural deposits, a completely new concept emerged called urban mining (Cossu et al., 2012a). Urban mining includes activities and technologies developed with the intent to recycle mineral raw materials and energy from so-called anthropogenic sources (products, buildings, landfills). Figure 4 shows the link between classical and urban mining and waste management. Also, Table 1 lists some waste streams (such as electronic waste, end-of-life vehicles, construction waste etc.) and landfill sites in general, useful components present in waste and ways that they can be reused, as well as certain problems that could arise in the process or need to be solved in the future. Thus for example, quantities of waste of electrical and electronic equipment (WEEE) are constantly increasing, and in that waste stream there are some valuable mineral raw materials (rare-earth elements, precious metals and metals). Some of the mentioned mineral raw materials that can be recycled from WEEE- belong exactly to the group of critical mineral raw materials (see Fig. 3), which are low in supply in natural deposits, are available on a limited number of locations and are difficult to obtain, or are obtainable at very high prices on the global market. Similar conclusions can be drawn for other waste streams shown in Table 1, which suggests that urban mining as a new concept will definitely evolve in the future. This is certainly a major challenge for a large number of professionals involved in solving complex engineering, safety and environmental problems encountered when exploring, extracting and processing useful raw materials from "urban mines".

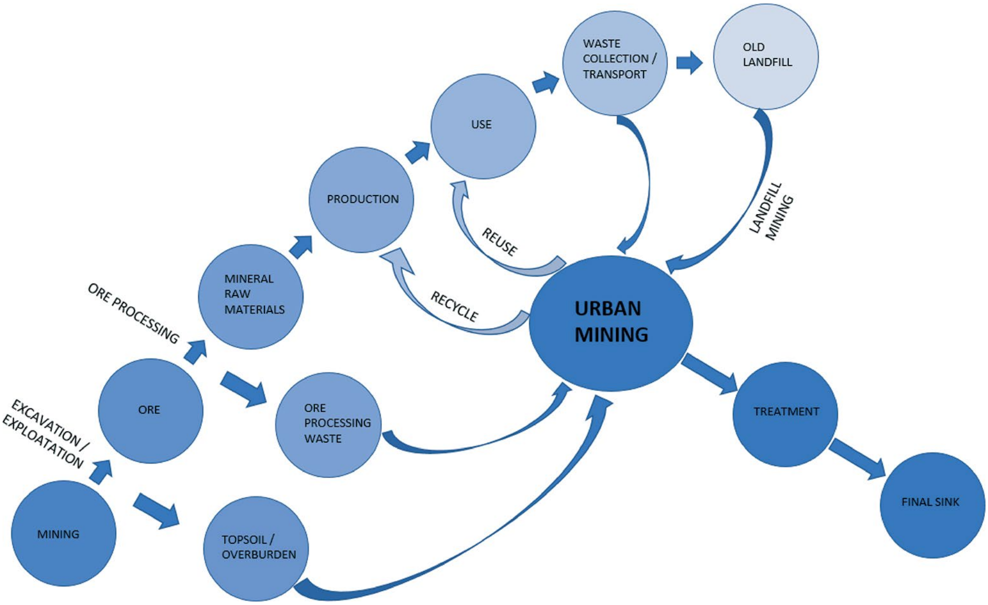

Fig. 4 – Correlation between waste management and mineral raw materials management (Cossu et al. 2012a, ISWA, 2014)

Today the demands for mineral raw materials by far exceed the possibilities of obtaining them from secondary sources i.e. recycling (Serranti et al., 2012). Nonetheless, this fact does not diminish the importance of the further development of recycling technology, since using secondary sources reduces the total quantity of mineral raw materials that need to be obtained from primary sources. The decision on whether it is profitable to recycle a certain raw material or not, or which is the best applicable recycling technology, should be made by applying LCA (Life Cycle Assessment). By such assessment waste management (through waste prevention and reuse/recycling/energy recovery from waste) is directly linked to mineral raw materials management. Certain experience with such a unique approach already exists (Franke et al. 2015). Accordingly, it is necessary to evaluate the available reserves of mineral raw materials (primary sources) at national level and then evaluate the needs and criticality of supply of certain mineral raw materials, depending on industrial development, energy consumption and standard of living of the population, as well as identify and evaluate the availability of secondary raw materials from anthropogenic (secondary) sources. By comparing the available reserves from primary and secondary sources with the needs that provide the desired development of society, conclusions can be reached as to whether the reserves of certain mineral raw materials are sufficient, or whether they will have to be obtained on the global market.

Table 1 – Urban resources for reuse of secondary mineral raw materials (adopted from Cossu et al. 2012a)

Waste stream/ Source of waste	Recovered materials	Products/ Applications	Possible problems
WEEE	Rare-earth elements (samarium, europium, yttrium, gadolinium, dysprosium, etc.)	Cathode ray-tube glass Electronic equipment	Hard to recycle Hazardous metals
	Metals and metalloids (copper, aluminium, iron, steel, lead, cadmium, tellurium)	Electronic equipment Semi-conductors	Implementation problems in the "waste chain" (devices remain in the household even after they are no longer used, there is no organized separate collection, etc.) Incomplete toxicological data
	Precious metals (gold, silver, platinum, palladium, iridium, ruthenium, indium)	Electronic equipment	High energy consumption at recycling Non-metallic and non-combustible slag Emission from thermal processes Economic viability only in large-scale recycling Multicomponent metal mixtures Precious metals are often coated with plastic or ceramic materials, high losses in the recycling process
	Cathode ray-tube glass	Ceramic products (bricks, tiles, stoneware) Lead alloys	Contains heavy metals, hazardous waste, limitations of recycling in the glass industry Requires special technology for separating lead-free and lead glass
End-of-life vehicles (ELV)	Metals (aluminium, copper, brass, iron, zinc)	Metal components, alloys Zinc coatings	Depends to a great extent on the secondary market Difficult recycling of materials
Construction and demolition waste (C&D)	Concrete	Road filling, railway subgrade, concrete production Piles Quartz sand	Regulations, dust and CO_2 emission (processing and transport)
	Asphalt	Asphalt	Heterogeneous and variable composition
	Bricks	Road filling, railway subgrade, concrete production	

Waste stream/ Source of waste	Recovered materials	Products/ Applications	Possible problems
Combustion residuals	Bottom ashes (inert) Bottom ashes (metals)	Geotechnical materials, aggregates, fillers Concrete Secondary raw materials: titanium, copper, zinc	Limit values in leaching tests A need to improve the technical and environmental characteristics; different properties compared to conventional materials; The impact on the environment associated with the use of ashes; Lack of regulations The need for chemical and eco-toxicological analyses Insufficiently explored
	Fly ash	Preparation of mortar/cement	Seasonal production (heating season) Need for electrodialysis in order to decrease leaching of Ba, Cr, Pb, Zn, Na and Cl
	Slag (industrial incineration)	Filling material Reactive media in wastewater treatment Landfills cover	Potential pollution during the construction phase Insufficiently explored Heavy metals plant uptake
Waste from road sweeping	Inert materials (sand, gravel, fine gravel)	Concrete aggregate	A substantial quantity of water is required for washing/cleaning of the material
Sludge (industrial and sewage sludge)	Phosphorus (wastewater sludge) Inert material (sewage sludge)	Mineral fertilizer Concrete	Contains heavy metals Sludge content decreases compressive strength
Landfills	Ferrous metals	Reuse in metallurgy	
	Fine fraction	Landfill cover	Quality could be questionable due to heavy metals leaching
	Inert materials (non-ferrous metals, glass, stones)	Recycled glass Geotechnical materials, aggregates, filler	Not always in compliance with recycling standards Limit values in leaching tests

Landfill mining

Landfill mining (LFM) stands for the excavation of waste (or its useful components) from old (closed) landfills (ISWA, 2013).

Landfill mining was first introduced in Israel in 1953 as a way to obtain fertilizers for orchards (Krook et al., 2012). In the 1990s, however, it was more intensely used in the USA, Europe and Asia. LFM was then used for the required expansion of existing landfills and lack of space due to public opposition to the construction of new landfills, as well as the growth of urban areas. The interest in LFM has diminished at the beginning of the 21st century, since the method did not prove successful in obtaining quality and economically viable materials through recycling processes. The method has since been applied in cases related to soil cleaning, urban space demands, and energy recovery from waste or increasing the capacity of existing landfills, i.e. when LFM is linked to additional needs and therefore economically justified at certain locations.

In the near future, landfills could be used for the management of all types of raw materials, including mineral raw materials (ISWA, 2014) in three ways, as follows:

- strategic storage (materials that currently cannot be recycled due to financial or technological reasons; separate disposal of waste components is preferred)
- as mines for secondary resources (of non-recyclable raw materials) and
- as permanent repositories i.e. sink of hazardous substances (if it can be ensured that they do not pose a threat to the environment and human health in the long run).

LFM represents a complex intervention on landfills, consisting of extracting and processing waste through material and energy recovery and/or site redevelopment. The rest of the waste that cannot be recycled is again disposed of in a controlled manner (Cossu and Raga, 2012b). Usually, such activities are carried out for one of the following reasons:

- Recovery of resources - for example recycling of metals or plastic, energy recovery from waste
- Recovery of the landfill volume through recycling and extending the lifetime of the landfill
- Remediation of contaminated sites of old landfills through excavation and processing of waste
- Reclamation of land enabling site redevelopment.

On the other hand, LFM is also associated with potential technical problems if the old landfills contain large amounts of biodegradable waste or high levels of leachate. In such circumstances, the use of mechanization and digging can be very difficult due to the mechanical instability of wet waste and the potential emissions of biogas components (some of which are hazardous, flammable or explosive, such as methane). It is clear, therefore, that the decision to launch mining activities on landfills will depend on a detailed analysis of economic, social and environmental impacts.

As already mentioned, LFM is a complex engineering procedure that encompasses the following phases:

- Preliminary works
- Waste extraction
- Waste processing
- Site remediation
- Site redevelopment.

In the preliminary phase, in addition to the usual activities of preparation and investigation, it is possible to find hazardous substances in the waste, which can jeopardize the initiation of further processes, or cause further increase in price of waste processing. After extraction, waste must be processed in accordance with the end user's requirements, or in case of energy recovery from waste, it must be prepared by grinding, removal of metal, drying and the like. In the final stage and depending on the future use of the landfill area, investigations are carried out on the site and air, soil and water quality is analysed in order to plan appropriate remediation and site redevelopment.

Based on the above, it can be concluded that these projects require detailed preparation and implementation of various preliminary works for the purpose of determining:

- the morphological and structural characteristics of the landfill
- the composition of disposed waste and the fractions that can be extracted
- biogas and leachate properties
- measures required to protect workers' health and safety
- technical requirements regarding excavation and separation of waste components
- economic justification of the procedure.

Landfills contain numerous materials that can become secondary raw materials. A number of factors affect the composition of waste in a given landfill, primarily the way waste collection is organized. One way is to separate waste into recyclable components (e.g. paper, aluminium cans, iron and steel, glass, plastic packaging) when collecting waste and put them into separate containers. Another way is to separate "wet" waste (organic waste, waste from green spaces etc.) from "dry" waste (all "non-compostable" waste). Municipal waste can be collected without separation (called mixed waste). The composition of waste is also dependent on demographic indicators, habits of the population, economic activities and many other indicators, so it is clear that the composition of waste will vary from site to site. Taking into account the demands of secondary raw material customers (quality of secondary raw materials), it is also obvious that there is no "universal" waste processing procedure. The technological waste processing scheme may vary to a certain extent depending on the above-mentioned specifics and the required quality of secondary raw materials. Despite the mentioned differences and due to the cited factors, in waste processing almost identical methods are used as in mining: crushing, grinding, screening, separation (magnetic, gravity, dense medium separation, etc.). The three main processes - crushing, screening and separation - are carried out in the stated order (Figure 5), regardless of the type of waste.

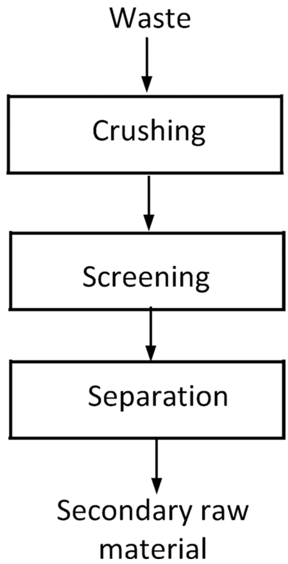

Fig. 5 – Waste processing

In the grinding process from larger pieces of waste smaller pieces are formed, whereby the bond between the various types of material is broken, i.e. there is a release of one from the other (liberation is achieved). Achieving an appropriate degree of liberation is crucial for later successful separation. Crushing is carried out in various types of crushers (jaw crusher, impact crusher, hammer crusher, crushing rolls, blade crusher etc.), which are selected depending on the characteristics of the waste to be crushed.

After crushing screening is carried out, i.e. grain groups of approximately the same size are separated (so called "classes"), whereby the grain size must be adjusted to the separator, in which separation is then performed. Waste classification is usually carried out by sieving, using different types of screens (vibrating screen, trommel screen, gyratory screen, flip flop screen etc.); the process may be "dry" or "wet" (with addition of water), depending on waste characteristics. Sometimes the crusher and the screen work in a closed circle, i.e. the material is cyclically crushed and sieved until it is small enough to be accepted by a particular separator. In this respect, crushing and screening are preparatory procedures for the separation process, since it is impossible to carry out the separation without liberation, while screening (sieving) ensures the grain size at which the separation will be effective.

The third procedure that is used to obtain secondary raw material from waste processing is separation. There are several different separation methods, and which one (or more) of them will be used depends on the characteristics of the waste to be processed. In order to achieve separation, there must be a difference in some of the physical properties on which a particular separation method is based. One of the methods is gravitational concentration based on the difference in the density of individual waste components to be separated and it may be carried out in water or air as a medium. If it is carried out in a heavy medium, then it is called dense medium separation (DMS). These types of separation can be carried out for separating any type of waste in which there is a sufficient difference in density, and whether this difference is sufficient is determined by the concentration criterion. Magnetic separation separates materials based on the difference in magneticity (magnetic permeability and magnetic susceptibility) and is used to extract iron and steel from waste. In waste recycling eddy current separation is also used relatively often, to separate non-ferrous metals (mainly aluminium). Electrostatic separation uses the force of electric fields and separates conductors from non-conductors based on the differences in electrical conductivity. Froth flotation is based on the difference in surface properties (different wettability of surface material) and it separates materials into hydrophobic and hydrophilic, where surface features can be influenced by adding flotation reagents. Optical sorting is used to separate waste based on visual differences (e.g. colour, shine). The hand picking should also be mentioned, which is commonly used as a control method after mechanical sorting, which is not fully effective.

The assessment of cost effectiveness of LFM is also a complex task, where in addition to economic indicators all environmental indicators need to be considered. Initial investment in extensive research, excavation and processing of waste must be correlated with the assessment of the possibility of remediation and conversion of the landfill site, as well as potential long-term earnings. At the same time, it is necessary to reconcile the demands of different professions and regulations in the field of mining, construction, environmental protection etc.

In conclusion, LFM is a new concept that has been carried out on a limited number of locations. At this point in time it is impossible to claim that it can be successfully applied to each landfill and at any location. To facilitate the usage of raw materials from landfills, further research is required, which today is mainly focused on defining the methods for selecting the most appropriate old landfills potentially usable for LFM, developing innovative recycling solutions, applying LCA etc. Should urban and landfill mining prove to be cost-effective, safe and environment-friendly activities that will provide diverse resources needed for the development of society, after the intensive research phase the implementation phase will follow, which will require intensive co-operation between different sectors and stakeholders, and the adaptation of regulations.

Conclusion

In developed societies today, there are more and more discussions about sustainable development, protection of natural resources, circular economy, ecological design, ecological printing, zero-waste society etc. Such modern endeavours and concepts are in line with the concept of urban and landfill mining. The reason for such a paradigm shift lies in the increased awareness of the growing need for space, energy and raw materials, some of which, such as mineral raw materials, are non-renewable. This also leads to the need to link strategic documents in the field of raw material management and waste management. Croatia has limited quantities of some mineral raw materials, but also lacks some of them (e.g. metals and so-called critical minerals), that are necessary for the development of advanced technologies. For this reason, Croatia belongs to the group of countries that can obtain these mineral raw materials either on the global market or from secondary sources, where this potential is yet to be assessed.

For the sustainable development of societies and sustainable resource management, different interests and demands have to be harmonized. Apart from the necessary development of new technologies in the field of engineering, economic, political, ethical, social and environmental aspects must be taken into account in order to ensure the safe and cost-effective introduction of urban and landfill mining into strategic documents. This also opens up opportunities for cooperation between a large number of professions, as well as for developmental research and innovation. In such world-wide trends Croatia should also get involved.

Acknowledgements

The publication of this paper was supported from the funds of the project "Improvement the Engineering Properties of Soil Using Recycled Plastic" by the Development Fund of the University of Zagreb.

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New Method for Performing Vibratory Stimulation and Detection of Early Cortical Response

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Abstract: Deep sense capability is one of very important indicators of numerous pathologies in medicine, and one of the indicators of deep sense is the sense of vibration. One of the methods for testing the sense of vibration is vibratory evoked potentials, which present the response of the nervous system to vibratory stimulus. Currently used vibratory stimulation has a small clinical value because obtained results do not incorporate quantifiable information about the entire afferent activity of vibratory sensory pathway (VSP), and response appears around 50 ms, providing no information about early cortical activity.

The aim of this research was to develop a method of vibratory stimulation that would provide information about the functional integrity of the whole VSP.

The impossibility of monitoring the function of the whole VSP is related to changes in stimulation parameters between successive stimuli and because of that the basic premise of evoked potentials (equal parameters for every stimulus) is disrupted. A vibratory stimulator with controllable pressure of vibratory applicator was constructed in order to provide equal parameters for every stimulus to obtain quantifiable information about the entire VSP. Optimum parameters of stimulation were chosen (stimulus frequency of 120 Hz, stimulus duration of 50 ms, and wrist as the site of stimulation).

Keywords: deep sense, vibratory sensory pathway, vibratory stimulation, evoked potentials, vibratory stimulator

Introduction

Deep sense capability is one of very important indicators of numerous pathologies in medicine, and because of that it is of great bearing on the determination of exact quantitative parameters related to deep sense. One of the indicators of deep sense is the sense of vibration. It occurs as a response of the nervous system to the vibration stimulus. Major receptors responsible for the sense of vibration are mechanoreceptors (Merkel's receptors, Meissner and Pacinian corpuscles) and each type of mechanoreceptors is most sensitive to a particular frequency range (Guyton, 1999). Merkel's corpuscles are the most sensitive to low range frequencies, Meissner's corpuscles to medium range frequencies and Pacinian corpuscles to high range frequencies (Bensmaïa, 2005, Gilman, 2002). The most appropriate frequency range for vibratory stimulation is around 100 Hz, because in this range both Meissner and Pacinian corpuscles are most sensitive.

Evoked potentials are the neurophysiological method that has been in use for many years and it provides information about the functionality of specific parts of the nervous system. This technique registers electrical activity of the brain that occurs as a response to specific stimuli [9]. Vibratory stimulation activates vibratory receptors and elicited electrical response could be registered along vibratory sensory pathways and on the sensory cortex.

The currently used vibratory stimulation has a small clinical value because the obtained results do not incorporate quantifiable information about the entire afferent activity of vibratory sensory pathways, from receptors in the skin to the sensory cortex. Elicited responses appear around 50 ms and they are the reflection of late cortical integration, but with little diagnostic relevance.

As opposed to that, the electrical stimulation of the somatosensory pathways, anatomically and physiologically almost identical to the VSP, obtains complete information on the functionality of the pathway and provides information about the response of pre cortical structures and also cortical response, so it could be assumed that the problem with the stimulation of the vibratory sensory pathways lies in an inadequate stimulation of the vibratory sensory receptors.

Therefore, there is a need to establish a method that could provide quantified information about the functionality of vibratory sensory pathways. The aim of our study was to develop a method of vibratory stimulation that would provide quantified information and facilitate the implementation of an improved method in daily clinical routine.

The most commonly used method for testing the sense of vibration is an examination with a vibratory fork. In this method, a vibratory fork is reclined to a patient's body, usually at the wrist, and the patient expresses his/her subjective sense of vibrations. The disadvantage of this method is a lack of objectivity and dependence on the patient's subjective perception and cooperation. The use of this method is impossible with patients in a coma, patients that are unable to communicate or with small children (Krbot, 2011).

In addition to classical tuning fork that vibrates with a single frequency, there is also a quantitative tuning fork, Rydel-Seiffer tuning fork, which has the ability to change the frequency from 64 Hz to 128 Hz (Lai S, 2014, Martina, 1998, Pestronk, 2004). Both types of tuning forks only provide information about subjective ability to sense the vibration, which is insufficient for quantified diagnostics. The quantitative tuning fork has advantages over classic ones in the objectivity of the information gathered, but this method is still subject to the subjective impact of the single person and does not provide quantified information.

Sense of vibration could also be examined with quantitative sensory testing (QST). The method is based on the examination of the sense of heat and vibration on skin, but usually it provides only information about participants' threshold. It is dependent on participants' cooperation and the interpretation of results differs between research groups (Chong, 2004, Siao, 2003, Zaslansky, 1998).

Also, devices like Vibratron (Physitemp Instruments, Clifton, NY) are used for examination of vibratory threshold. Device consists of one control unit and two vibratory units that produce vibration of different frequencies.

All described methods do not have standardized parameters, and standardized parameters are important for longitudinal follow up of disease progression and for comparison of results achieved between different research groups (Burns, 2002). Any of these methods do not provide quantified and comparable information about the functional integrity of vibratory sensory pathways.

In order to provide proper information about vibratory sensory pathways, neurophysiological methods with quantified vibratory stimulation (vibratory stimulator) were used (Goldber, 1979). Constant voltage was used for stimuli with constant amplitude, and in this setup, there was control about the amount of energy delivered to receptors. The amount of energy delivered to receptors is not an appropriate measurement, because there is no control over the energy received by them.

Experiments conducted in this area used different parameters of stimulation (duration, frequency, place of stimulation), but they did not achieve early evoked response (Hämäläinen, 1990, Münte, 1996, Snyder, 1992, Tobimatsu, 1999, Tobimatsu, 2000). Münte and his group stimulated extensor carpi radialis on both hands with different frequencies of stimulation (40 Hz, 80 Hz, 160 Hz), and the first registered neurophysiological component was P50 (positive component that appeared 50 ms after the stimulus) (Münte, 16). Similar results were achieved by Hämäläinen who stimulated the middle finger of the hand with a low frequency (24 Hz) and high frequency (240 Hz) stimulus, but the earliest registered component appeared 45 ms after the stimulus over the contralateral primary sensory cortex (Hämäläinen, 1990). No early cortical activity was detected.

Evoked potentials

Evoked potentials provide insight into the function of different parts of the nervous system and the brain. The application of the evoked potentials method is widely accepted, from different fields of medicine (clinical neurophysiology, intraoperative neurosurgical and surgical monitoring) to neuroscience, with particular emphasis on the field of cognitive neuroscience.

The method is completely non-invasive and it has excellent temporal resolution (around 1 ms), and because of that it is suitable for testing the functional state of a particular sensory or motor pathway.

The advantage of evoked potentials is the complete independence of the cultural and educational influence (Lai CL, 2010), which is of great importance for cognitive testing where the objective assessment of skills is necessary. Also, participants could not affect the results of evoked potentials, because in specific situations it is possible to obtain an electrophysiological response even when the participant does not pay attention to the presented stimulus (Luck, 2005).

The method is based on the electrical activity that occurs as a response of the nervous system and the brain to specific stimuli. Participants are exposed to different stimuli and the response of the nervous system to specific stimuli is registered, and further processed through averaging an adequate number of responses to the identical stimulus (Išgum, 2009). Identical stimuli would provide an identical response of the nervous system, and the average of the specific numbers of successive responses would be identical to a single response only if all the successive stimuli have identical characteristics.

The results of the evoked potentials method are presented in the form of specific components. The latency (time of appearance) and the amplitude of the component provide information about the characteristics of the evoked response

Theoretical background for construction of vibratory stimulator

The currently used vibratory stimulation technique in the evoked potentials method has a small clinical value because it does not provide quantitative information about the whole vibratory sensory pathway, which is reflected in the absence of the early components of the evoked response.

The aim of this research was to establish an objective method for the examination of functional integrity of the whole vibratory sensory pathways, from receptors in the skin to primary sensory cortex in the brain.

The electrical stimulation of somatosensory pathways activates all neuronal fibres in a stimulated nerve and provides complete information about the functional integrity of these pathways, from the earliest response to the results of the late cortical integration. Neuronal fibres that transmit information from the vibratory receptors have the identical anatomical path as the somatosensory pathways, but their evoked response consists only of late cortical components. That leads to the assumption that, due to the anatomically preserved transmission path, the problem with the activation of vibratory sensory pathways with vibratory stimulation is related to an inadequate stimulation of vibratory receptors.

In the evoked potentials method stimuli should be identical in order to generate identical and repeatable responses. According to literature, vibratory receptors generate action potentials synchronized to vibratory stimulation, and it is questionable why evoked activity could not be detectable through the entire vibratory sensory pathway (Rugiero, 2010). Vibratory sensitive mechanoreceptors respond to vibratory stimulation in correlation to stimulation parameters and because of that identical stimulus should evoke identical response of the nervous system (Loewenstein, 1996, Rugiero, 2010). It can be concluded that the problem with the registration of evoked activity through the entire vibratory sensory pathways is caused by the fact that successive stimuli do not have identical parameters and because of that action potentials with different characteristics are generated. Inadequate activation of mechanoreceptors causes asynchronous propagation of action potentials through the pathways and disables registration of peripheral components and early components of cortical response. The results of previous studies with vibratory stimulation showed late components as a manifestation of late cortical integration of asynchronous input to primary sensory cortex (Hämäläinen, 1990, Münte, 1996).

Currently used vibratory stimulators have constant displacement of vibratory applied part, which generates identical amplitude of for every stimulus. It means that constant amount of energy is transferred to tissue (Goldber, 1979), but it does not define the amount of energy received by tissue because the geometrical relationship between the vibratory applicator and the tissue is variant. Therefore, although the amount of energy transferred to tissue is always the same; the delivered amount of energy depends on the mutual relationship between the tissue and the applicator.

There is no stable geometrical relationship between vibratory applicator and stimulation site because of inevitable macro and micro movements of the vibratory stimulator relative to the participant (movements of participants, breathing, etc.), and because of that constant amplitude generates vibratory stimuli with different parameters. This means that successive stimuli are not quantitative repeatable and have different parameters, and without an identical stimulus there is no possibility of evoking identical repeatable response, which is necessary for averaging and noise suppression applied in the evoked potentials method.

Pacinian corpuscle is a mechanoreceptor sensitive to changes at the beginning and end of stimulus, which is specific for vibratory stimulus (Guyton, 1999). It generates an action potential dependent on stimulus characteristics and it is necessary that characteristics of pressure applied to corpuscle are identical for every stimulus. In order to achieve this, it was necessary to construct vibratory stimulator that would generate successive vibratory stimulus with identical pressure of vibratory applicator.

According to these conclusions, a specially designed vibratory stimulator was constructed. It has the ability to retain constant pressure of vibratory stimulus instead of constant amplitude, and because of that, it generates identical stimuli with well-defined parameters necessary to monitor the functional integrity of the whole vibratory sensory pathways.

The working principle of vibratory stimulator is shown in Fig. 1. The initial signal for vibratory stimulator consists of two components: the initial pressure of vibratory applicator and the amplitude of vibratory stimuli. The pressure sensor is in con-

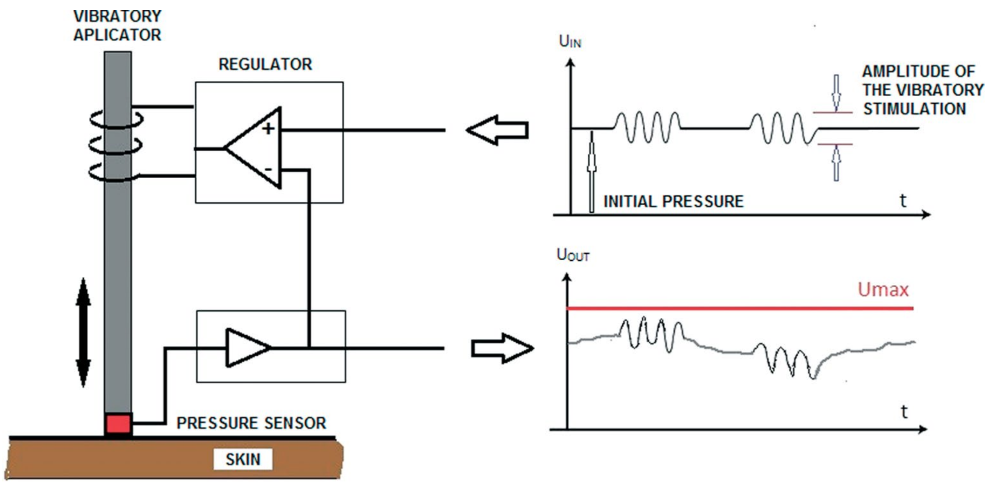

Fig. 1 – The working principle of the vibratory stimulator

tact with the skin and sends feedback about the vibratory applicator pressure in the controller. If there is a change in the pressure, then negative feedback regulates the displacement of the vibratory applicator in order to achieve controllable pressure through the entire stimulation.

The constructed vibratory stimulator has well defined parameters of stimulation. Two control waveforms can be selected (sine and triangle), stimulation frequency is adjustable in the range from 30 to 300 Hz, stimulus duration from 10 to 500 ms, and interstimulus interval from 100 to 2000 ms. Also, different intensities of the pressure can be chosen. There are separate controls over intensity of initial constant pressure and superimposed variable pressure. Stimulation frequency is chosen according to physical characteristics of vibratory receptors and according to relevant literature, target frequency is around 100 Hz (Fattorini, 2006). Stimulus duration also has a significant impact on evoked neurophysiological response, and because of that, the aim of this research is to find suitable parameters of stimulation in order to achieve repeatable and reliable responses.

Materials and methods

In this study 38 participants were included, 15 females, mean age 39.8 years (18-72 years). Measurements were performed in the Laboratory for Cognitive and Experimental Neurophysiology, Department of Neurology, University Hospital Center Zagreb. The Ethical Committee of the University Hospital Center Zagreb approved the study. Before starting, the experiment was explained in detail to every participant. All participants signed an informed consent.

During the experiment participants were placed in a sound insulated chamber. They sat in a comfortable armchair and were instructed to relax and minimize blinking in order to reduce artifacts. Vertical oculogram was recorded with bipolar channel, one electrode situated below the right eye and referred to reference electrode at Cz position in order to detect vertical ocular movements for a more precise treatment of ocular artifacts.

32 electrodes were used for recordings and the main goal was to examine parameters of stimulation necessary to achieve repeatable evoked response (stimulation frequency, duration, interstimulus interval, and place of stimulation). A specially designed cap (actiCap) with 32 electrodes positioned according to International 10-20 system was used [BrainProducts GmbH, Germany]. The cap is made of active electrodes, based on high-quality Ag/AgCl sensors with integrated noise subtraction circuits for lower noise levels. Activity was recorded with monopolar channels

referred to average value of voltage for all electrodes. Before the measurement, areas under each electrode were cleaned with abrasive paste in order to reduce impedance, and conductive paste was applied to each area in order to achieve adequate conductivity for recording very small signals (order of magnitude ~μV).

For the known comparison, somatosensory evoked potentials (SSEP) with current stimulation were recorded for every participant. SSEP is a well-established diagnostic method used in daily clinical routine. For the current stimulation, constant current stimulator [Twister, Germany] was used. The registration of evoked responses was performed with the same electrodes as for vibratory stimulation. Monopolar square wave electrical pulses, duration of 200 μs and stimulation rate of 5 pps were used for electrical stimulation. Stimulation intensity was dependent of the threshold of the direct muscle response for every participant.

Based on many years of experience working with various modalities of vibratory stimulation, for all measurements in this study the constant pressure presented over the measuring system as the effect of the weight of 270 grams was selected.

Each of the measurement conditions was tested by 200 stimuli, which was sufficient to achieve repeatable and reliable response.

Recordings were performed with BrainAmp amplifier and recording software Brain Vision Recorder [BrainProducts GmbH, Germany]. Recorded signals were filtered with band pass filter from 0.5 Hz to 250 Hz. The sampling frequency was 5000 Hz. Data analysis was performed with Brain Vision Analyzer Software [BrainProducts GmbH, Germany].

Results and discussion

The examination was performed with four different frequencies of stimulation (30 Hz, 120 Hz, 200 Hz, and 300 Hz). The main components are N1 and P1, as shown in Fig. 2. N1 component appears around 20 ms and P1 component appears around 30 ms.

The neurophysiological response evoked with a frequency of 120 Hz provides results most comparable with the activity evoked with current stimulation, somatosensory evoked potentials (SSEP). A frequency of 120 Hz is in concordance with the data from the relevant literature (Fattorini, 2006, Gilman, 2002). Meissner and Pacinian corpuscles, mechanoreceptors sensitive to vibratory stimulation, overlap their area of sensitivity around the frequency of 100 Hz. Stimulation with a fre-

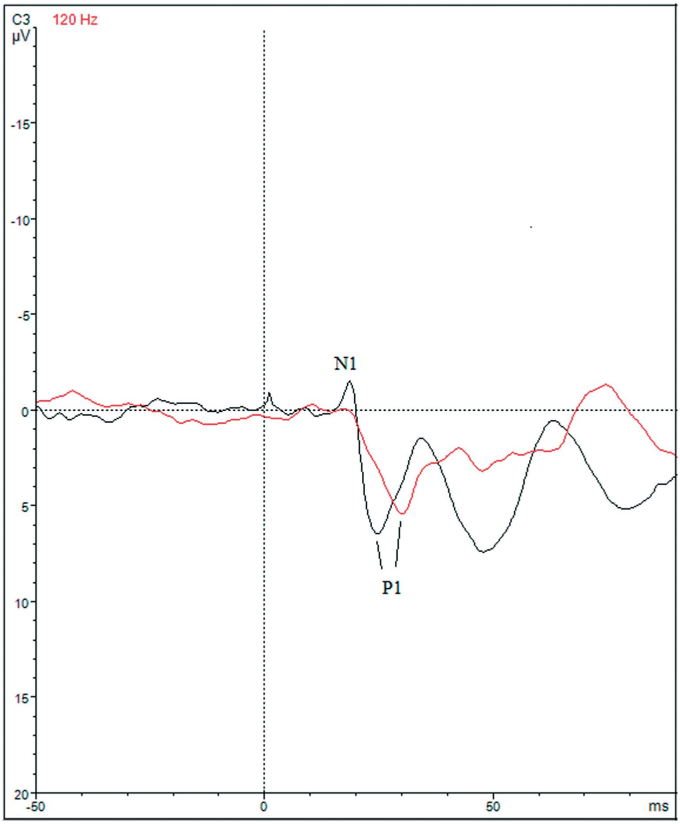

Fig. 2 – Evoked response – stimulation frequency 120 Hz, comparison of SSEP response (black) and vibratory stimulation response (red)

quency around 120 Hz is appropriate for vibratory stimulation because it activates a larger number of mechanoreceptors and this is why the frequency of 120 Hz was chosen as a stimulation frequency for further measurements.

The registered components (N1 and P1) present early cortical response, which is in concordance with the results of SSEP. Also, the achieved components appeared around 20 ms, which is much earlier than the components observed in studies with other vibratory stimulator (around 50 ms) (Hämäläinen, 1990, Münte, 1996). Identical parameters of successive stimuli enable repeatable and identical evoked response, which allows the detection of early cortical response.

The second important parameter is stimulus duration. Measurements were performed with a stimulus duration of 10 ms and with 50 ms. The results obtained with both durations had the morphology of main components similar to the morphology of SSEP, and for both durations, the complete evoked response was obtained.

The spatiotemporal distribution of evoked response indicates that responses evoked with a duration of 50 ms have higher intensity. A longer duration of stimulation provides longer exposure of the primary sensory cortex to sense of vibration which ensures a stronger activation of the primary sensory cortex, and because of that the intensity of evoked activity is higher. The duration of 50 ms reached desired evoked response and because of the minimal required duration of the experiment longer durations of stimulation were not tested.

The third important information is information about the place of stimulation. According to the well know somatotopic organization in humans (homunculus), sensory cortex area for the hand has a wider surface then sensory areas for other body parts. It can be easily detected with non-invasive, surface electrodes, and it has clear lateralization (contralateral side of the cortex). Therefore, the hand was chosen as the stimulation position. Measurements were performed on three different positions: the finger (first distal joint of the middle finger), the wrist and the elbow. Responses evoked with stimulation of the wrist or the elbow were in concordance with the results evoked with SSEP, while stimulation of the finger evoked responses with recognizable morphology, but longer latency. This presentation of the results was expected, because latency of the response is related to the distance of the place of stimulation from the sensory cortical area (the length of the activated peripheral pathway). Pacinian corpuscles, mechanoreceptors sensitive to the sense of vibration, had small spatial density (Gilman, 2002) and because of that bigger surface should be stimulated in order to achieve better activation. Stimulation of the finger evokes lower quality response in comparison with responses evoked at wrist or elbow, due to the small surface available for stimulation. Stimulation of the elbow evokes response in only 50% of participants, while evoked response of wrist stimulation is recognizable and repeatable for every participant, due to the activation of a higher number of Pacinian corpuscles for wrist stimulation. According to the presented facts and results, the wrist was chosen for the place of stimulation.

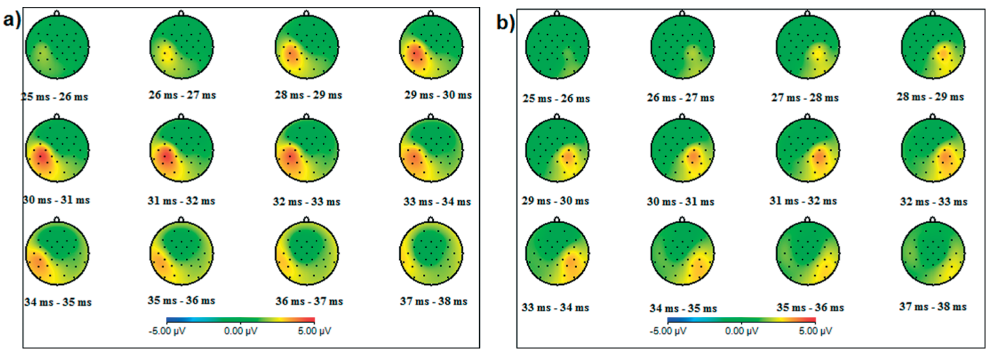

Fig. 3 – Vibratory evoked response: a) stimulation of the right hand; b) stimulation of the left hand

The evoked response achieved with vibratory stimulation meets expected anatomical requirements; stimulation of the right/left hand activates the adequate sensory cortical area on the contralateral hemisphere (as presented in Fig. 3).

The reproducibility of the evoked response was achieved for a single participant, but also for a group of participants, which provides evidence that evoked response is not created only by chance, it is a real neurophysiological response of vibratory sensory pathways to vibratory stimulation.

Conclusion

The results presented in this research provide information about the parameters necessary to achieve reliable and repeatable neurophysiological response to vibratory stimulation (frequency of stimulation, duration of stimulation, place of stimulation). Evoked response can be described with well-defined parameters (latency, amplitude and localization of the main components) which enable longitudinal monitoring of a single participant, but also a comparison of results between groups of participants. This is the main advantage of this method, because it allows the presentation of the functional state of vibratory sensory pathways in the form of quantified information. Also, the achieved results include early components which provide information about early cortical activity necessary for the functional examination of the entire vibratory sensory pathway. Further measurements on the population with different types of pathologies related to the vibratory sensory system are necessary in order to present the diagnostic value of the method.

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Data Science for Genome Based Optimization in Agriculture: EU Research Data Alliance and Biopotential of Croatia Cultivars

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Abstract: The development of high-throughput sequencing methodologies resulted in omic big data sets in biotechnology (pharmaceuticals, agriculture, and food technology) reflecting information on biological potential of large number of varieties of worldwide importance. Omic databases specific to Croatian cultivars, autochthonic plants and animal varieties are also being developed. Comparative advantages and opportunities for the improvement of Croatian cultivars and species can be advanced by inclusion and systemic comparative analysis within EU project RDA (Research Data Alliance) for open data access to H2020 research projects. The bottleneck for the application and discovery of optimal biopotential from big data is the use of advanced machine learning (ML) algorithms supported by thorough validation criteria. The ML algorithms (elastic nets, boosted decision tree forests, and deep learning are applied here for Diversity Array Technology (DArT) genotypization for production of *Triticum aestivum* (wheat bread making cultivars).

Keywords: Research Data Alliance, Boosted decision trees, Elastic nets, DArT genotypization, *Triticum aestivum*

Introduction

The world is facing a number of interrelated global factors which present a risk for its sustainability. Two of the factors are exponentially growing population, presently estimated at seven billion and predicted to ten billion in 2050, and the global climate warming with an estimated average temperature rise of 2.5 ^{0}C . These global risks directly affect food production which is the main economic and political stability factor. The key underlying factor is availability of water needed for agriculture which is the primary input to food chain. Food production must be adapted to global warming, lack of water for agriculture and animal protein productions, and increased levels of soil and water pollution. Croatia also faces the same problems related to climate changes affecting agricultural production and over a long period of time increased temperatures and extended periods of drought weather (Fig. 1). These challenges must be addressed with potentials of molecular based life sciences entering a new era of data science with big data (petabyte) of sequencing data and advances in new machine learning algorithms based on the broad availability of computer clusters (Hadoop) with Tensor low (TPU) processing computer architecture. Croatia needs to explore these advanced technologies and develop new potentials of autochthonic plant and animal varieties for higher yield and quality (wheat, corn, olive, pork, tangerines, fish farming, marasca cherries, etc.). It is especially interesting to explore the biopotential (bioprospecting) Croatian Adriatic Sea and rare autochthonic plants for pharmaceutical production.

Fig. 1 – Distribution of global aridity land, A: 2011, B: prediction 2050, (Dai. A., 2011, J. Farrant, 2016)

High-throughput sequencing technology has brought life science into a "big data" era with an unrivalled explosion of genomics, transcriptomics, proteomics, and metabolomics. The falling cost (<$1,000 per genome) and increasing speed (<1 day per genome) of high throughput sequencing lead to the snowballing data at petabyte level. However, it is still difficult to transfigure such "Big Data" to valuable biological insights into regulation of metabolic pathway activities. The gap between omics data and cell phenotypes is one of the biggest challenges for achieving "Data-to-Insight". In recent years, a rapid development of artificial intelligence, especially deep learning, provides novel options to overcome this challenge.

The key factor to cope with challenges by harnessing global biological potentials is large scale open data integration. For Croatia data science projects are an important integration into EU project Research Data Alliance (RDA). It is an open access structured database divided into working groups. The working groups IG Agricultural data and WG Wheat data Interop (Hologne O., 2017) are applicable for improvement of Croatian cultivars. The RDA main objectives are: coordination of worldwide research effort to build research infrastructure for wheat genomics, physiology, breeding, and computer science experts in data science and bioinformatics.

Materials and Methods

Molecular markers are technologies which represent invaluable research tool for understanding the genetic control of various traits. They have frequently been utilised in quantitative trait loci (QTL) mapping studies, and applied in breeding programmes through marker-assisted selection. In Croatia there are two scientific institutions, Agricultural Institute of Osijek and Centre of Excellence for Biodiversity and Molecular Plant Breeding in Zagreb, leading in research to improve existing cultivars and by bioprospecting to harness Croatia biopotential. The application of molecular markers resulted in genome associated wide studies (GWAS) as a part of big data science in agriculture. Diversity Array Technology (DaRT) (Jaccoud D, et al., 2001) is commonly molecular marker technology applied in molecular agriculture studies. Due to global aspects of these studies open access databases (RDA) with experimental data accessible for analysis were created. Here are the applied data available from International Maize and Wheat Improvement Centre (CIMMTY, 2017). A similar study for Croatian selected winter wheat cultivars is available (Novoselović D, et al, 2016). The dimension of the applied big data set is 1276x599x8 (DaRT markers x number of wheat breeding lines x number of phenotypes) containing in total about 6 million data points.

The objective of this study is to apply different algorithms of big data analytics to develop predictive models for each of wheat phenotypes, to determine individual DaRT marker importance, and by use of computer simulation assist breeding programs for optimization of new varieties with improved phenotype properties. The applied methodologies are elastic nets (Efron and Hastie, 2016), neural networks (Chollet and Allaire, 2018), and decision trees (Kurtanjek, 2016, 2017). Algorithms for data science available in R are applied (R Core Team, 2018). The main keys of the applied algorithms are feature (DaRT) space regularization and extensive (multifold) bootstrap validation. The elastic nets are linear regression models with use of combined L_1 and L_2 penalty functions to reduce the dimension of the model linear parameter space by systemic testing. The standard linear model, with x denoting DaRT markers is given by

$$\hat{y} = \sum_{i=0}^{i=N} \beta_i \cdot x^{i-1} + E \tag{1}$$

with the objective function

$$F_{object}(\beta) = SSE(y - \hat{y}) + \lambda_1 \cdot L_1 + \lambda_2 \cdot L_2 \tag{2}$$

Neural networks and decision trees are the principal nonlinear models applied in big data science. Deep learning neural networks harness potential of multilayer structure and big data for regularization of inference prediction space,

$$\hat{y} = NN(x) + E \tag{3}$$

while decision trees apply averaging of large random ensemble decisions

$$\hat{y} = \frac{1}{N} \cdot \sum_{i=1}^{i=N} DT_i(x) \; + E \tag{4}$$

Elucidation of decision rules is improved by regularization accounting for ensemble dimension N_T, size of the trees N and purity of the tree leafs

$$\min F_{object.}(X, DTF, \omega) = SSE(y, \hat{y}) + \phi(DTF, \omega) \tag{5}$$

$$\phi(DTF, \omega) = \gamma \cdot N_T + \frac{1}{2} \cdot \lambda \cdot \sum_{i}^{N_T} \omega_i^2 \tag{6}$$

Bootstrapping and optimization based analytical evaluation of gradients are the most important powers of the boosted decision tree forests.

Results and Discussion

DArT profiles of samples (breeding lines) are binary records (0 and 1) corresponding to the presence of marker diversity (SNP and/or methylation) referenced to a standard. A sample of such a record of 1,279 markers is shown in Fig. 2. Most of the profiles are mutually poorly correlated, with the average absolute value of R = 0.1. However, there is a significant correlation between subsets of the profiles and particular phenotype properties. The dimensions of the DArT subspaces determined by the elastic nets for the phenotypes protein content and area grain yield (t/ha) are presented in Fig. 3.

The corresponding sub-dimensions are in the ranges 82-215 and 60-150. Relatively large dimensions of the phenotype subspaces are reflections of complexity of gene

Fig. 2 – A sample distribution of DArT 1279 markers of a single wheat breeding line accession. Markers with diversities are depicted as white lines.

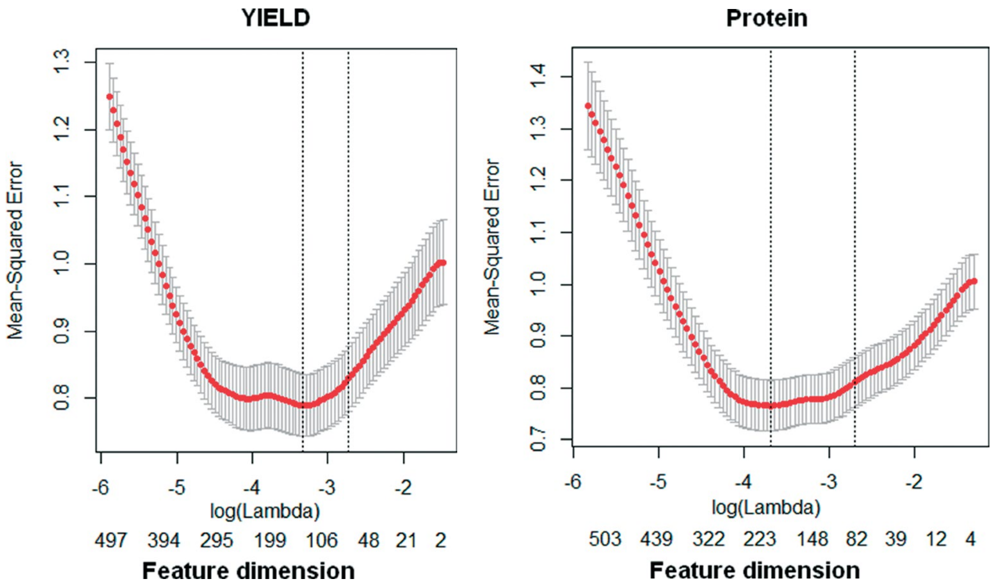

Fig. 3 – Validations of dimensions DArT feature spaces by elastic nets.

interactions responsible for individual property. The obtained correlation coefficients for the elastic net models for the prediction of protein content and yield are R=0.8 and R=0.72 respectively. The unexplained variance by the elastic nets is due to nonlinear interactions (gene level synergism). Considerable improvements for phenotype predictions, accounting for epigenesis, are obtained by multilayer nonlinear interactions, embedded into decision trees and/or deep learning models. Pre-

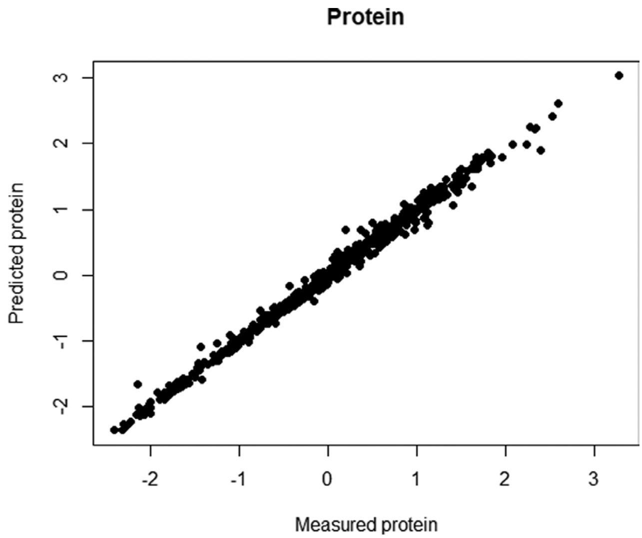

Fig. 4 – Correlation line between DecisionGS model for wheat protein predictions and experimental data.

diction accuracy is increased to 92 % of accounted variance (determination factor). High accuracy of decision trees model (decision tree genetic selection algorithm, abbreviated as DecisionGS) for protein content is depicted in Fig. 4. High accuracy for specific wheat property prediction models enables their application for computer simulation and optimization of breeding process. A simulation program for random exchange of gene (DArT) exchange between parent breeding lines and corresponding prediction of progeny phenotype was developed.

Fig. 5 shows an example of simulated breeding and optimization of protein production by area. As the first parent is selected the wheat breeding line with high protein content but low productivity, and as the second parent the line with low protein content but high yield. DArT correlation between the parents is R = 0.84. 100 randomly generated progenies with corresponding distribution of the optimization objective to gain maximum of protein production per unit are simulated. The median of the distribution is about 5 % higher compared to each of the parent breeding pool. The optimal progeny is shown in Fig. 5 with 15 % increase in the protein yield per area.

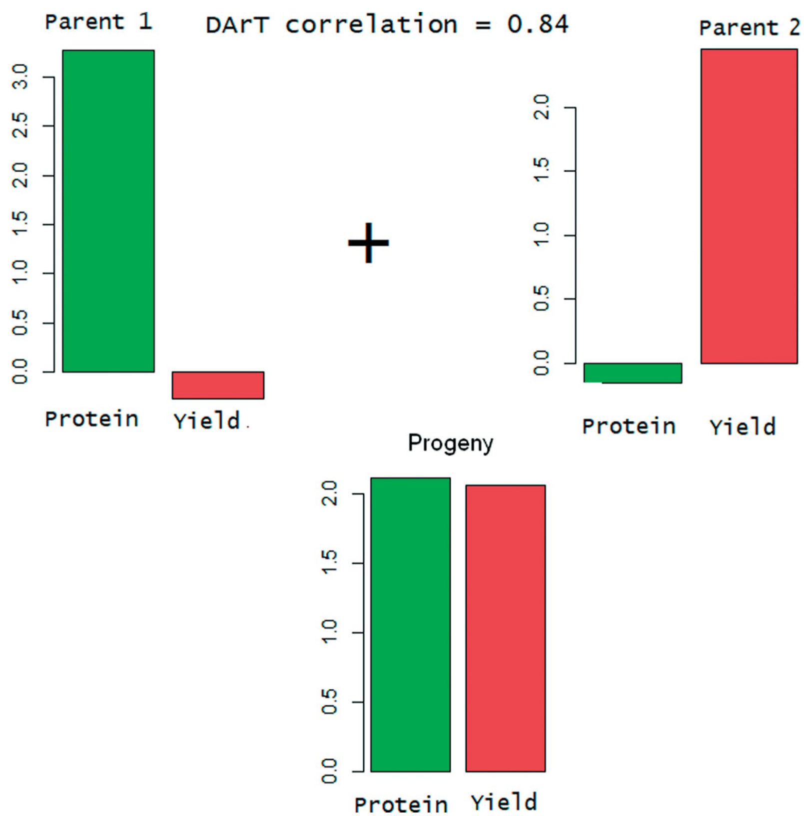

Fig. 5 – Prediction of wheat breeding progeny with optimal protein content and grain yield per area (t/ha).

Conclusions

The application of data science and big data omics studies of the Croatian biopotential are the strategic technologies needed to adapt to global risks due to population increase and global warming. The objectives should be an increase in the national production and food quality with emphasis on specific biopotential of plant and animal varieties in Croatia.

The application of the advanced models and algorithms from data science is essential to harness knowledge for the optimization of production from omic big data sets. The integration and open access of big data, such as the project EU Research Data Alliance, is the key factor for excellence in science projects.

The optimization of wheat production based on computer assisted genomic simulation of breeding improvement is being developed here. A big data set is applied from international science cooperation projects on DArT genotypization to derive elastic nets and boosted decision trees models for prediction of specific wheat phenotypes. The derived DecisionGS model predicts protein content and yield with an accuracy of 92 %. The high accuracy of the model enabled the simulation and optimization of a breeding program resulting in 15 % increase of protein production per area.

Acknowledgements

I would like to thank to Valentina Španić and Daniela Horvat, the members of Agriculture Institute, Osijek, Croatia, for cooperation and valuable assistance.

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Numerical Analysis of Heterogeneous Engineering Materials

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Abstract: A heterogeneous material such as nodular cast iron is widely used as a material of engineering structural components. The realistic description of its deformation responses demands an accurate modelling at both macroscopic and microscopic scales. In this paper a two-scale computational approach employing the homogenization scheme based on the small strain nonlocal continuum theory is presented. Discretization at both scales is performed by means of the C^1 continuity finite element developed by using the strain gradient theory. After the scale transition procedure and the homogenization approach at the microlevel, the constitutive relations are computed at each material point at the macroscale predicting the structural deformation response. All algorithms derived were embedded into the finite element program ABAQUS. The performance and accuracy of the proposed approach was verified in an example, where the microstructure of a nodular cast iron is modelled by an academic representative volume element.

Keywords: heterogeneous materials, second-order homogenization, C^1 finite element, nonlocal continuum theory

1. Introduction

Many engineering materials have a heterogeneous structure, and they are often referred to as multi-phase materials, composite or heterogeneous materials. From an engineering point of view, multi-phase materials are desirable because they can be tailor-made to take advantage of particular properties of each constituent. Besides rock, concrete, wood, fibre-reinforced composites and other similar materials, metals such as nodular cast iron are widely used as a material for structural components in mechanical engineering. The nodular cast iron consists of graphite spheroids or nodules, positioned in an either ferritic or pearlitic matrix, providing large fatigue strength. The size, shape, spatial distribution, volume fraction and the properties of the constituents making up the microstructure have a significant impact on the behaviour of material properties observed at the macroscale.

Modelling of the mechanical behaviour of heterogeneous materials represents an essential issue in engineering. In recent years the investigation of the relations between mechanical properties of material and its microstructure became very attractive topic, considering that almost all materials are heterogeneous at lower scales. Depending on the material microstructure, size effects can be observed, resulting in different mechanical behaviours (Fleck and Hutchinson, 1993, 2001). Unfortunately, the classical continuum theory cannot capture such effects, since it does not contain an internal length scale. As a remedy, extension towards the higher-order continuum theory has been proposed. The first significant work in extension to the higher-order continuum theory originates from Cosserat brothers (Cosserat and Cosserat, 1909), which gave a first systematic review of a three-dimensional solid. Unfortunately, the potential of this generalization was not recognized until the early sixties of the last century. Important developments in higher-order theories were achieved during the 1960's (Mindlin and Tiersten, 1962; Koiter, 1963; Toupin, 1964). Pioneering achievements in this full second-gradient theory were established in (Mindlin, 1965) with introduction of the double stress tensor as the work conjugate to second derivative of the displacement field. Also, there are approaches introducing a material with the microstructure (Germain, 1973), where each point has its own degrees of freedom. In the last few decades advantages of the higher- order theories have been recognized as a valuable tool for modelling of material elastoplasticity derived within the gradient dependent plasticity as well as for the damage modelling (de Borst, Pamin and Geers, 1999; Putar *et al.*, 2017). Due to higher-order gradients available, the description of the localization phenomena and material softening is possible without loss of ellipticity of governing equations. Furthermore, with introduction of an intrinsic length scale, the size effects, which can be very often observed in experimental investigations, can be efficiently described by means of numerical algorithms. For more details on the review of gradient continua, see (Zhu, Zbib and Aifantis, 1997; Maugin and Metrikine, 2010).

For the solution of practical problems analytical solutions for the higher-order continua may be obtained only for a few very simple problems. Consequently, finding solution to the problem using the numerical analysis, for example, the finite element method is necessary. The higher- order displacement gradients invoked in the virtual work statement lead to a higher-order differential equation. Numerical solution of this governing equation requires a higher interpolation scheme, where C^1 continuity must be ensured. In the finite element framework this brings necessity for a higher-order finite element formulation supporting additional degrees of freedom (Argyris, Fried and Scharpf, 1968). On the other hand, structural complexity of the element also increases (Clough and Tocher, 1965). Increased complexity of the finite element formulation as well as inconvenient numerical implementation are the main reasons that these elements are not too attractive for practical use. Therefore, many efforts have been undertaken trying to simulate gradient problems compensating requirement for C^1 interpolations. In this field many methods have been developed, for example, the implicit methods (Askes, Bennett and Aifantis, 2007), the mixed formulations where kinematic relation between displacements and displacement derivatives is enforced by Lagrange multipliers (Amanatidou and Aravas, 2002), or by penalty functions (Zervos, Papanicolopulos and Vardoulakis, 2009) and the micromorphic continuum formulations with Lagrange multipliers (Shu, King and Fleck, 1999) or penalty parameters (Britta Hirschberger, Kuhl and Steinmann, 2007). Unfortunately, alternative approaches suffer from drawbacks, resulting in locking and unphysical results. A comprehensive state-of-the-art of C^1 continuous finite element formulations is given in (Fischer, Steinmann and Willner, 2011).

To accurately predict the mechanical response of the evolving microstructure, the multiscale approach is required, integrating physical understanding of material behaviour at various physical scales. A rapid increase in computational power boosted by innovative solutions in numerical modelling has enabled detailed quantification of the mechanical response of materials across multiple scales for nonlinear processes. Using the multiscale setting we are able to develop constitutive models applicable at engineering scales using detailed information obtained from finer scales through application of newly developed class of computational homogenization methods.

The overall concept of the computational homogenization was developed in (Suquet, 1985) and its main attention is determination of the effective properties of heterogeneous media. The computational homogenization allows the incorporation of the microstructure into a standard continuum model turning standard boundary value problem into a nested boundary value problem, containing the macroscale and the microscale level. In such a scheme an explicit macroscopic material model is not available. Instead, it is provided by the locally attached microscopic boundary value problem driven by macroscopic quantities. However, a finer scale geometry (microstructure) is often unknown, so statistical assumptions have to be made. Macroscopic properties are determined by the homogenization process acting on the effective, homogenized sample of material called statistically Representative Volume Element (RVE), see for example (Stroeven, Askes and Sluys, 2004; Gitman, Gitman and Askes, 2006). The resulting effective material is supposed to represent all macroscopic properties of the microheterogeneous structure and enables to restrict the computational effort to the smallest, still representative, material sample. Firstly developed concepts of computational homogenization techniques are built within the standard local continuum mechanics, where the behaviour of the material point depends only on the first gradient of the displacement field, referred to as the first-order homogenization. Unfortunately, the first-order micro-macro computational approaches, as well as the conventional homogenization methods, have some major disadvantages. As first, even though the first-order homogenization technique accounts for an influence of the heterogeneous microstructure by explicit modelling of the microconstituents, it cannot take into account the absolute size of the microstructure. Consequently, geometrical size effects cannot be accounted for. On the other hand, from the mathematical point of view the first-order approach relies on the intrinsic assumption of uniformity of the macroscopic stress and strain fields appointed to RVE. Due to uniformity assumption the first-order homogenization is not appropriate for problems dealing with high gradients, where the macroscopic fields can vary rapidly. To overcome these shortcomings, the second-order computational homogenization procedure, as extension of the classical computational homogenization was proposed (Sluis *et al.*, 1999). To derive the second-order homogenization, the nonlocal continuum theory satisfying C^1 continuity has to be used at the macroscale. In this way the first and the second gradient of the displacement field at the macrolevel are prescribed through the essential boundary conditions on the RVE. At the microscale, RVE is still treated as an ordinary continuum, described by the standard continuum theory using well known constitutive equations. From the solution of the RVE boundary value problem, the stress, double stress tensor and constitutive matrices giving the higher-order continuum constitutive behaviour are extracted from the homogenization procedure. Even though the second-order computational homogenization approach has many advantages, the scale transition of variables between two different continuum approaches suffers from several drawbacks, as revealed in (Luscher, McDowell and Bronkhorst, 2010).

Hence, a new multiscale algorithm based on the nonlocal second-order computational homogenization was presented in this contribution. In comparison to available multiscale approaches employing the second-order computational homogenization, the proposed algorithm preserves the nonlocal theory at both the macrolevel and the microlevel. The modified strain gradient elasticity theory (Ru and Aifantis, 1993), assuming the linear elastic material behaviour and small strain, has been adopted. The discretization at both scales was performed by the C^1 continuity plane strain triangular finite element derived in (Lesičar, Tonković and Sorić, 2014). A consistent nonlocal homogenization scheme was proposed. The derived scale transition methodology, as well as homogenization procedure were embedded into the finite element program ABAQUS by means of FORTRAN subroutines. The performance and accuracy of the proposed approach was verified on an example dealing with the elastic three-point bending test. The microstructural RVE describes a nodular cast iron structure in an academic way.

The paper is organized as follows. In Section 2 the nodular cast iron representing a heterogeneous material is described in more detail. Section 3 deals with the numerical modelling of the heterogeneous material. Therein the basic relation of the non-local continuum and the finite element derivation are presented. In Section 4 the two-scale transition together with the homogenization approach and numerical implementation are described. The numerical example is presented in Section 5. In the last Section 6 concluding remarks are given.

2. Heterogeneous materials in engineering applications

One of highly heterogeneous material which has a wide application in industrial structural components is nodular cast iron. The determination of its mechanical properties was in the focus of a considerable amount of research during the past several decades. This section provides an overview of the authors' studies that are performed in order to investigate the influence of the microstructure on the mechanical behaviour of the nodular cast iron. It is an iron - carbon alloy which has mechanical properties similar to steel. However, in comparison to steel, nodular cast iron reduces production cost and weight of structural components. In addition, it has superior castability and machinability. For these reasons, it is widely used in energy equipment and transportation and nuclear industries, such as wind turbine components, vehicle industry, shipbuilding, pipes or nuclear storage, transportation casks and many other cyclically loaded structures (Minnebo, Nilsson and Blagoeva, 2007; Shirani and Härkegård, 2011; Šamec, Potrč and Šraml, 2011).

Nodular cast iron consists of graphite spheroids or nodules, dispersed in an either ferritic or pearlitic metal matrix. In general, the ductile iron with the ferritic matrix exhibits lower yield and tensile strength, but higher elongation and toughness. The pearlitic matrix has the opposite effect on the mechanical properties. A matrix with both ferritic and pearlitic phases with intermediate mechanical properties is often found in practice. Besides the matrix microstructure, the fatigue strength of nodular cast iron is influenced by the graphite morphology (size, shape and distribution of graphite nodules) (Hübner *et al.*, 2007; Costa, Machado and Silva, 2008, 2010).

The results of experimental studies on the mechanical behaviour of ductile nodular cast iron EN-GJS-400-18-LT depending on the material microstructure are well elaborated in the previous publications of the authors' research team (Čanžar, P., Tonković, Z., Bakić, A., Kodvanj, 2011; Čanžar, Tonković and Kodvanj, 2012; Čanžar, P. and Tonković, 2014). In this section, a short description of the test procedure is given, and some selected test results are presented. The cyclic deformation and fatigue behaviour of four types of cast iron produced by different technologies are considered. The investigated material was provided by the company MIV Varaždin of Croatia. Herein, some results for two types of the cast iron produced by flotret (Type 200) and inmould (Type 400) techniques are presented. The graphite morphology of the casting types is shown in Fig. 1, while the microstructural data are presented in Table 1. As may be seen, both materials have a predominantly ferritic matrix, where the perlite content is not more than 7%. Furthermore, material type 200 produced by the flotret process has significantly larger nodules with low density distribution than type 400 of nodular cast iron. Besides, the material type 200 has graphite nodules with the lowest circularity (irregularly shaped nodules). On the other hand, material type 400 produced by the inmould process has smaller ferrite grains and smaller nodules, more spherical and regular in shape than those in material type 200.

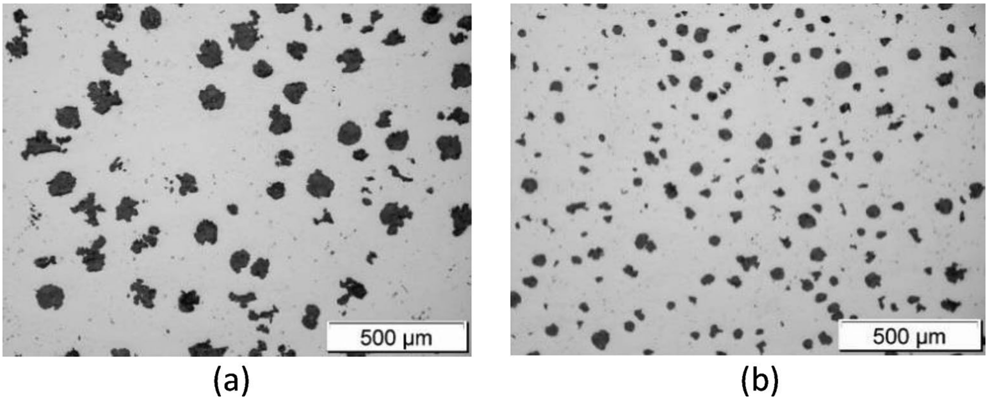

Fig. 1 – The microstructure of nodular cast iron: (a) type 200 and (b) type 400 (Čanžar, 2012; Čanžar, Tonković and Kodvanj, 2012)

Table 1 – Metallographic characteristics of nodular cast iron (Čanžar, 2012; Čanžar, Tonković and Kodvanj, 2012)

Material type	Graphite nodules			Pearlite	
	Number (mm^2)	Average size (μm^2)	Circularity	Area (μm^2)	%
200	57	1,416.80	0.57	49,925.41	4.99
400	81	837.09	0.66	69,726.31	6.97

Monotonic tensile, cyclic and fatigue tests were performed on the servo-hydraulic fatigue testing machines Walter Bai LFV 50-HH, MESSPHYSIK BETA 50-5 and INSTRON 8801 with a load capacity of ±50 kN. Monotonic tensile tests are carried out on flat specimens (Krstulović-Opara *et al.*, 2015). The loading process was acquired by the infrared (IR) thermography and the 3D Digital Image Correlation (DIC). In Fig. 2 the loading sequence images obtained for 10 mm/s loading velocity are presented. The images in Figs. 2(a), obtained by the 3D DIC show the von

Mises equivalent strain distribution. The infrared thermal images in Figs. 2(b) present the thermal distribution proving that generated heat is a consequence of plastic deformation. As presented in (Krstulović-Opara *et al.*, 2015), the generated heat acquired by the IR camera is equivalent to equivalent plastic strain distribution acquired by the 3D DIC (Fig. 2). Therefore, the optical techniques showed to be a powerful tool for the development and calibration of constitutive models from full-field measurements of displacements and strains. The mechanical properties of the nodular cast iron Type 200 obtained from the monotonic tensile test are as follows: yield strength of 256.5 MPa, tensile strength of 417.2 MPa, modulus of 182.4 GPa and elongation of 23.5%, respectively. The nodular cast iron type 400 has very similar monotonic tensile properties.

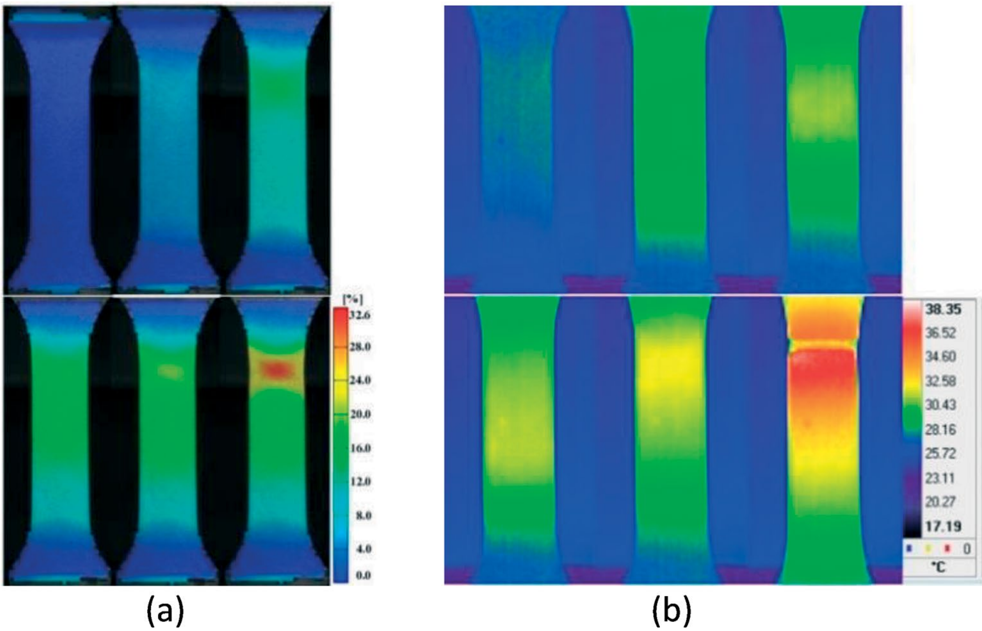

Fig. 2 – Displacement controlled tension test at 0.1 mm/s; (a) von Mises strain (3D DIC), (b) temperature distribution (IR) (Krstulović-Opara *et al.*, 2015)

Fig. 3 shows representative stress–strain hysteresis loops obtained from symmetrical tests ($\Delta\varepsilon/2=\pm1.2\%$) on a cylindrical specimen prepared according to ASTM E606 standard. It can be observed that the ductile nodular cast iron EN-GJS-400-18-LT exhibit significant cyclic hardening. Both types of material have a similar hardening rate and the major difference between them is in achieving maximum stress in first and all subsequent half-cycles as well as in achieving the first yielding point.

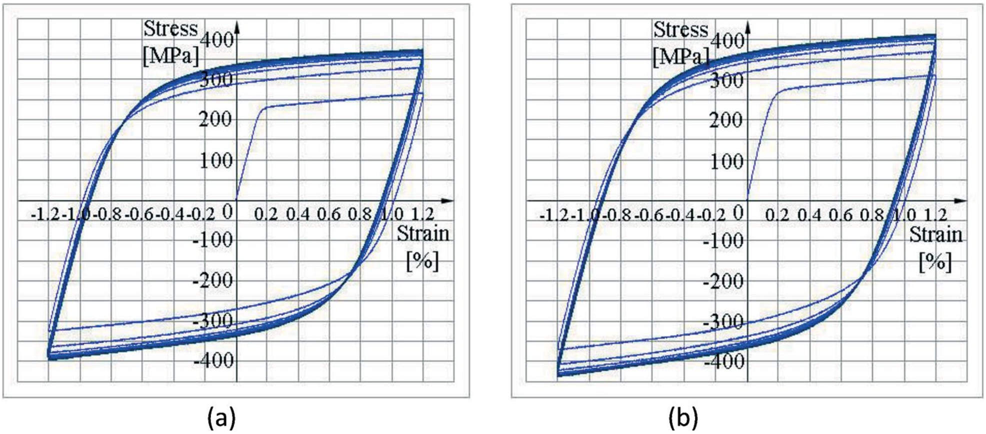

Fig. 3 – Stress–strain hysteresis loops for: (a) type 200 and (b) type 400 of the nodular cast iron (Čanžar, 2012; Čanžar, Tonković and Kodvanj, 2012)

The next part is concerned with the fatigue crack initiation and propagation testing on a compact tension (CT) specimen prepared according to ASTM E647 standard. Fig. 4 shows the cracked specimen with exposed nodular cast iron microstructure. As can be seen, the direction of crack growth is towards the graphite nodule which acts as a barrier for further crack propagation. The big advantage of nodular graphite are its round edges (despite the sharp edges of lamellar graphite) that not only reduces the risk of crack initiation, but also acts as a crack arrester and increases the crack propagation resistance. As it is described in (Ochi *et al.*, 2001), the fatigue cracks propagate in a zig–zag manner in the ferrite matrix but linearly in the pearlite matrix, because the difference in crack sensitivity depends on matrix strength and also because the ferrite grain boundary prevents crack propagation. In addition, fatigue cracks always start at the interface between the graphite nodule and the surrounding ferrite matrix, while graphite nodules remain generally unbroken (Bubenko, Konečná and Nicoletto, 2009).

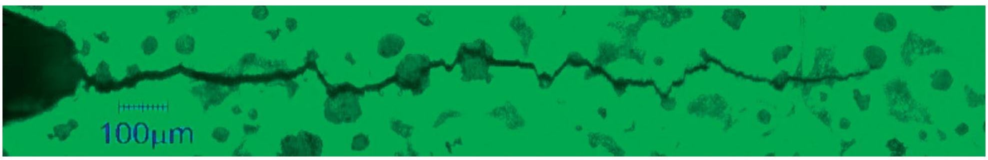

Fig. 4 – Microstructural crack exposure (Čanžar, 2012; Čanžar, Tonković and Kodvanj, 2012)

Fig. 5 illustrates the variation of the crack length (a) versus the number of cycles (N) for different load ratios (R). Herein, the test load is applied in sinusoidal form with the frequency of 10Hz, defined by the maximum load of 12kN and the load ratio R. The two different loading regimes (R=0.1 and R=0.5) for both material

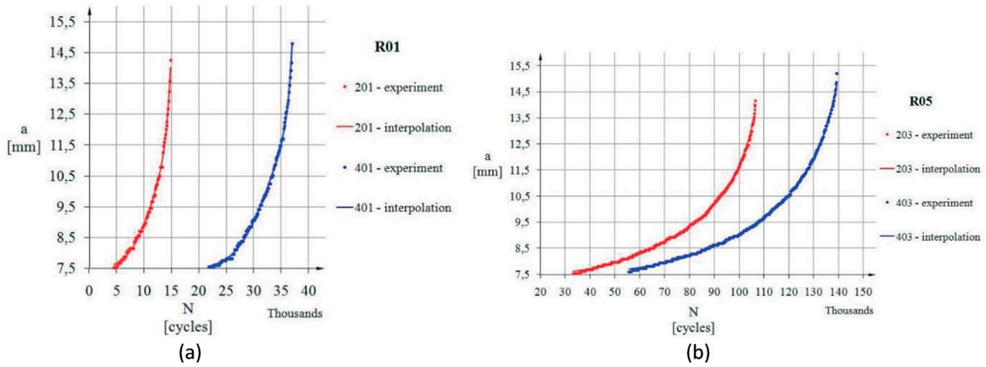

Fig. 5 – Number of cycles vs. crack length for: a) R=0.1 and b) R=0.5 load ratio (Čanžar, P., Tonković, Z., Bakić, A., Kodvanj, 2011)

types are performed. During the crack propagation tests, the crack length is measured in real time by an optical measuring system Aramis 4M using a novel technique proposed in (Čanžar, 2012; Čanžar, Tonković and Kodvanj, 2012). As expected, it has been observed that the number of cycles to failure increased with increase in load ratio. For the most rigorous load ratio R=0.1, there is the most pronounced difference in material types considering crack propagation. As described in (Čanžar, Tonković and Kodvanj, 2012), material type 200, produced by the flotret process, shows the least crack resistance. On the contrary, material type 400, produced by the inmould technique, lasts approximately 2.5 times longer till the final specimen fracture. The results show that the materials with a large number of smaller as well as with more regularly shaped graphite nodules and small ferrite grains (material types 300 and 400) have larger resistance to crack initiation and propagation resulting in higher fatigue life. A larger number of more regular and smaller nodules contributes more to higher fatigue resistance than a small number of large irregularly shaped graphite nodules that act as an internal notch in the ferritic matrix (material type 200). These results are consistent with those reported in (Iacoviello *et al.*, 2008; Xue, Bayraktar and Bathias, 2008; Hütter, Zybell and Kuna, 2015).

It can be concluded from the presented results that the size, shape and distribution of the graphite nodules have no significant influence on cyclic hardening of the ductile nodular cast iron EN-GJS-400-18-LT but they play a great role in the crack initiation and propagation process (Čanžar, 2012; Čanžar, Tonković and Kodvanj, 2012). This provided a motivation for research work in the field of deformation process modelling of heterogeneous materials using two-scale formulations (“macro-micro”) based on the concepts of computational homogenization and RVE.

3. Numerical modelling of heterogeneous material

3.1 Basic relations of the nonlocal continuum

In addition to the strain tensor $\boldsymbol{\varepsilon}$ which is defined as a symmetric gradient of the displacement field $\mathbf{u}$ in the classical small strain continuum theory, the second-order strain $\boldsymbol{\eta}$ is introduced into the nonlocal continuum theory. $\boldsymbol{\eta}$ is the third-order tensor, representing the gradient of $\boldsymbol{\varepsilon}$

$$\boldsymbol{\eta} = \nabla \otimes \boldsymbol{\varepsilon} . \tag{1}$$

The variation of the strain energy density function is expressed as

$$\delta W = \frac{\partial W}{\partial \boldsymbol{\varepsilon}} : \delta \boldsymbol{\varepsilon} + \frac{\partial W}{\partial \boldsymbol{\eta}} : \delta \boldsymbol{\eta} = \boldsymbol{\sigma} : \delta \boldsymbol{\varepsilon} + \boldsymbol{\mu} : \delta \boldsymbol{\eta}. \tag{2}$$

In Eq. (2), $\boldsymbol{\sigma}$ and $\boldsymbol{\mu}$ represent the Cauchy and the double stress tensors, respectively, which are work conjugates to the strain and the second-order strain. Using straightforward mathematical manipulations, as explained in (Lesičar, Tonković and Sorić, 2014), relation (2) can be modified to

$$\delta W = \nabla \cdot (\boldsymbol{\sigma} \cdot \delta \mathbf{u}) - (\nabla \cdot \boldsymbol{\sigma}) \cdot \delta \mathbf{u} + \nabla \cdot \left[\boldsymbol{\mu} : (\nabla \otimes (\delta \mathbf{u})) \right] - \nabla \cdot (\delta \mathbf{u} \cdot (\nabla \cdot \boldsymbol{\mu})) + (\nabla \cdot (\nabla \cdot \boldsymbol{\mu})) \cdot \delta \mathbf{u}. \tag{3}$$

From Eq. (3) the internal work variation can be defined in the integral form over the body surface A as

$$\begin{aligned}\delta W^{\text{int}} = & \int_A \left[\mathbf{n} \cdot (\boldsymbol{\sigma} - (\nabla \cdot \boldsymbol{\mu})) \cdot \delta \mathbf{u} \right] \mathrm{d}A + \int_A \left[(\nabla^A \cdot \mathbf{n}) \otimes \mathbf{n} \cdot (\mathbf{n} \cdot \boldsymbol{\mu}) \cdot \delta \mathbf{u} \right] \mathrm{d}A - \\ & \int_A \left[\nabla^A \cdot (\mathbf{n} \cdot \boldsymbol{\mu}) \cdot \delta \mathbf{u} \right] \mathrm{d}A - \int_V \left[\nabla \cdot (\boldsymbol{\sigma} - (\nabla \cdot \boldsymbol{\mu})) \cdot \delta \mathbf{u} \right] \mathrm{d}V + \int_A \left[(\mathbf{n} \cdot \boldsymbol{\mu} \cdot \mathbf{n}) \cdot (D \otimes (\delta \mathbf{u})) \right] \mathrm{d}A,\end{aligned} \tag{4}$$

where the body forces are neglected. In Eq. (4), $\mathbf{n}$ represents unit outward normal, while ∇^A and D denote surface and normal gradient operators, respectively. The variation of the external work is written in the form

$$\delta W^{\text{ext}} = \int_A (\mathbf{t} \cdot \delta \mathbf{u}) \mathrm{d}A + \int_A \left[\boldsymbol{\tau} \cdot (D \otimes (\delta \mathbf{u})) \right] \mathrm{d}A . \tag{5}$$

In Eq. (5), $\mathbf{t}$ and $\boldsymbol{\tau}$ are the surface traction and the double surface traction, respectively defined as

$$\mathbf{t} = \mathbf{n} \cdot (\boldsymbol{\sigma} - (\nabla \cdot \boldsymbol{\mu})) + (\nabla^A \cdot \mathbf{n}) \otimes \mathbf{n} \cdot (\mathbf{n} \cdot \boldsymbol{\mu}) - \nabla^A \cdot (\mathbf{n} \cdot \boldsymbol{\mu}), \tag{6}$$

$$\boldsymbol{\tau} = \mathbf{n} \cdot \boldsymbol{\mu} \cdot \mathbf{n} . \tag{7}$$

The principle of virtual work is expressed by the relation

$$\delta W^{\text{int}} = \delta W^{\text{ext}} \tag{8}$$

which yields the equilibrium equation

$$\nabla \cdot \left(\boldsymbol{\sigma} - \left(\nabla \cdot \boldsymbol{\mu} \right) \right) = \mathbf{0} \,. \tag{9}$$

For more details on the derivation of the aforementioned relations, please refer to (Lesičar, Tonković and Sorić, 2012). Also, the presented relations can be easily extended to the large strain assumption, as derived in (Lesičar, Sorić and Tonković, 2016).

3.2 Finite element derivation

Within this research, the displacement-based C^1 continuous triangular finite element is derived and implemented into the FE software ABAQUS (ABAQUS, 2014). The C^1 continuity means that displacements and displacements derivatives within the element are continuous functions. The element is derived and adjusted for the application in the multiscale procedure. The proposed strain gradient triangular finite element is shown in Fig. 6.

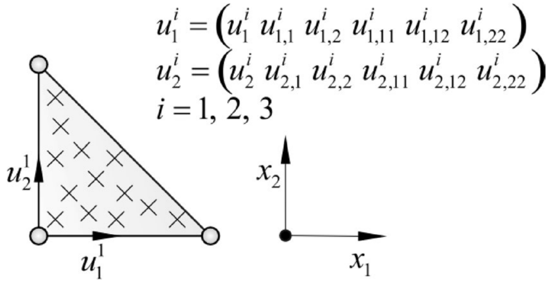

Fig. 6 – C^1 triangular finite element

The element consists of three nodes and twelve degrees of freedom (DOF) per node. The nodal degrees of freedom are two displacements and their first and second order derivatives with respect to the Cartesian coordinates. The element displacement field is approximated by the condensed fifth-order polynomial defined by 18 nodal values (Lesičar, Tonković and Sorić, 2012). The weak form of Eq. (9) expressed through the principle of virtual work may be presented as

$$\int_A \left(\boldsymbol{\sigma} : \delta\boldsymbol{\varepsilon} + \boldsymbol{\mu} \,\vdots\, \delta\boldsymbol{\eta} \right) \mathrm{d}A = \int_s \left(\mathbf{t} \cdot \delta\mathbf{u} \right) \mathrm{d}s + \int_s \left[\mathbf{T} : \left(\nabla \otimes \left(\delta\mathbf{u} \right) \right) \right] \mathrm{d}s \,, \tag{10}$$

where s represents the closed boundary line of the surface area A. Also, in the second integral term on the right side of (10), the double traction tensor $\mathbf{T} = \boldsymbol{\tau} \otimes \mathbf{n}$ is introduced. Due to the C^1 continuous interpolations adopted in the element formulation, only displacement field needs to be discretized, while the remaining gradient terms can be easily computed through the shape function derivatives. The displacement field $\mathbf{u}$ inside an element may be expressed by the well-known relation as

$$\mathbf{u} = \mathbf{N}\mathbf{v}\,. \tag{11}$$

In Eq. (11), $\mathbf{N}$ is the shape functions matrix, and $\mathbf{v}$ is the vector of the nodal degrees of freedom. The strain $\boldsymbol{\varepsilon}$ and the higher-order displacement gradient $\boldsymbol{\eta}$ are obtained by the shape function derivatives using the following relations

$$\boldsymbol{\varepsilon} = \begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ 2\varepsilon_{12} \end{bmatrix} = \mathbf{B}_{\varepsilon}\mathbf{v}\,, \tag{12}$$

$$\boldsymbol{\eta} = \begin{bmatrix} \eta_{111} \\ \eta_{222} \\ \eta_{221} \\ \eta_{112} \\ 2\eta_{121} \\ 2\eta_{212} \end{bmatrix} = \begin{bmatrix} u_{1,11} \\ u_{2,22} \\ u_{1,22} \\ u_{2,11} \\ 2u_{1,21} \\ 2u_{2,12} \end{bmatrix} = \mathbf{B}_{\eta}\mathbf{v}\,, \tag{13}$$

where $\mathbf{B}_{\varepsilon}$ and $\mathbf{B}_{\eta}$ are the matrices containing appropriate interpolation polynomials derivatives. Since in a general case, the material and geometrical nonlinearities may be involved, relation (10) should be solved in an incrementally-iterative procedure via iterative corrections. Therefore, the constitutive updates of the stress and double stress are computed by the linearized incremental constitutive relations

$$\Delta\boldsymbol{\sigma} = \mathbf{C}_{\sigma\varepsilon} : \Delta\boldsymbol{\varepsilon} + \mathbf{C}_{\sigma\eta} : \Delta\boldsymbol{\eta}\,, \tag{14}$$

$$\Delta\boldsymbol{\mu} = \mathbf{C}_{\mu\varepsilon} : \Delta\boldsymbol{\varepsilon} + \mathbf{C}_{\mu\eta} : \Delta\boldsymbol{\eta}\,. \tag{15}$$

Herein $\mathbf{C}_{\sigma\varepsilon}$, $\mathbf{C}_{\sigma\eta}$, $\mathbf{C}_{\mu\varepsilon}$ and $\mathbf{C}_{\mu\eta}$ are the consistent material tangent stiffness matrices providing correlations among corresponding stress and strain variables. Using the standard finite element mathematical procedures, the usual linearized finite element equation is obtained

$$\mathbf{K}\mathbf{v} = \mathbf{F}_{\mathrm{e}} - \mathbf{F}_{\mathrm{i}}\,. \tag{16}$$

More details about derivation of the finite element and element matrices used in Eq. (16) can be found in the authors' publication (Lesičar, Tonković and Sorić, 2014) for the small strain case, as well as in (Lesičar, Sorić and Tonković, 2016) for the large strain assumption. However, in the present contribution, a special case of the strain gradient theory was adopted (Aifantis, 1999). Accordingly, the modified constitutive relations are used, where the stress tensors are defined as

$$\Delta\boldsymbol{\sigma} = \mathbf{C} : \Delta\boldsymbol{\varepsilon}\,, \tag{17}$$

$$\Delta\boldsymbol{\mu}_{x_1} = l^2 \left(\mathbf{C} : \Delta\boldsymbol{\varepsilon}_{x_1} \right), \tag{18}$$

$$\Delta\boldsymbol{\mu}_{x_2} = l^2 \left(\mathbf{C} : \Delta\boldsymbol{\varepsilon}_{x_2} \right). \tag{19}$$

In the constitutive relations (18) and (19), $\boldsymbol{\varepsilon}_{x_1}$ and $\boldsymbol{\varepsilon}_{x_2}$ represent strain gradients with respect to the Cartesian coordinates x_1 and x_2, while $\boldsymbol{\mu}_{x_1}$ and $\boldsymbol{\mu}_{x_2}$ are their work conjugates. As can be seen, they are multiplied by the material dependent microstructural parameter l. For more details, see (Akarapu and Zbib, 2006).

4. Two scale transitions and homogenization

All materials can be considered as heterogeneous at various scales of observation. Material heterogeneities are interesting ultimately through their influence on non-uniform response and microstructure evolution. Using the multiscale setting, the constitutive models applicable at engineering scales can be developed using detailed information obtained from finer scales through application of newly developed class of computational homogenization methods. The computational homogenization allows incorporation of the microstructure into a standard continuum model turning standard boundary value problem into a nested boundary value problem, containing both the macroscale and the microscale level. The macroscopic properties are determined by the homogenization process acting on the effective, homogenized sample of material called RVE. The resulting effective material is supposed to represent all macroscopic properties of the microheterogeneous structure and enables to restrict the computational effort to the smallest, still representative, material sample. In the presented scheme, the microstructure is described by the strain gradient elasticity theory assuming linear elastic material behaviour and small strains. In the following the subscript "m" is appointed to microlevel variables and the subscript "M" represents macrolevel quantities.

4.1 Macro to micro scale transition

The starting point in the macro-to-micro transition is a Taylor series expansion of the RVE displacement field depending on the macroscale displacement gradients (Geers and Kouznetsova, 2010) expressed as

$$\mathbf{u}_{\mathrm{m}} = \boldsymbol{\varepsilon}_{\mathrm{M}} \cdot \mathbf{x} + \frac{1}{2}\left[\mathbf{x} \cdot \left(\nabla \otimes \boldsymbol{\varepsilon}_{\mathrm{M}}\right) \cdot \mathbf{x}\right] + \mathbf{r} \, . \tag{20}$$

In Eq. (20), **r** represents the microfluctuation displacement field. The microfluctuations are short-wavelength displacements representing a contribution of the microconstituents to the macrolevel displacement field. Since in the multiscale scheme the microstructure is explicitly modelled, the contribution of the microfluctuations should be accounted for. As known in the homogenization theory, the volume average of the microscale quantities must be equal to their macroscale conjugates at a material point. Enforcing this principle between the macrolevel and microlevel strains, and the second-order strains as well, the following microfluctuation constraints arise

$$\frac{1}{V}\int_{V}\left(\nabla_{\mathrm{m}} \otimes \mathbf{r}\right)\mathrm{d}V = \frac{1}{V}\int_{\Gamma}\left(\mathbf{n} \otimes \mathbf{r}\right)\mathrm{d}\Gamma = \mathbf{0} \, , \tag{21}$$

$$\frac{1}{V}\int_{V}\left(\nabla_{\mathrm{m}} \otimes \left(\nabla_{\mathrm{m}} \otimes \mathbf{r}\right)\right)\mathrm{d}V = \frac{1}{V}\int_{\Gamma}\left(\mathbf{n} \otimes \left(\nabla_{\mathrm{m}} \otimes \mathbf{r}\right)\right)\mathrm{d}\Gamma = \mathbf{0} \, , \tag{22}$$

where *G* represents the RVE boundary, as shown in Fig. 7. Enforcement of the constraints (21) and (22) is easily achieved by means of the appropriate boundary conditions used on the RVE. In this research the gradient displacement- and gradient generalized periodic boundary conditions will be utilized. Since in the case of gradient displacement boundary conditions the microfluctuation field on the RVE boundaries is suppressed, (21) and (22) are satisfied without any actions. In the case of periodicity assumption, see (Geers and Kouznetsova, 2010), it is easy to prove that (21) and (22) are fulfilled. In the finite element context, Eq. (20) should be rewritten in matrix form to express the nodal degrees of freedom of an *i*th node along the RVE boundaries, which gives the following identity

$$\mathbf{u}_{i} = \mathbf{D}_{i}^{T}\boldsymbol{\varepsilon}_{\mathrm{M}} + \left(\mathbf{H}_{1}^{T}\right)_{i}\left(\boldsymbol{\varepsilon}_{,1}\right)_{\mathrm{M}} + \left(\mathbf{H}_{2}^{T}\right)_{i}\left(\boldsymbol{\varepsilon}_{,2}\right)_{\mathrm{M}} \, . \tag{23}$$

In Eq. (23), the macrolevel strains and strain gradients have the form according to the gradient theory adopted in the homogenization scheme. **D**, $\mathbf{H}_1$ and $\mathbf{H}_2$ are the coordinate matrices which transform strains into finite element nodal degrees of freedom (Lesičar and Tonković, 2015).

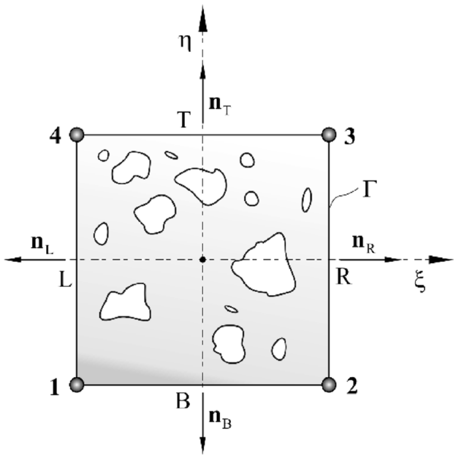

Fig. 7 – Representative Volume Element

Based on (20) and (23), the microfluctuation constraints (21) and (22) can be rearranged to

$$\int_{\Gamma} \mathbf{u}_{\Gamma}\, d\Gamma = \left(\int_{\Gamma} D_{\Gamma}^{T}\, d\Gamma \right) \boldsymbol{\varepsilon}_{M} + \left(\int_{\Gamma} \left(\mathbf{H}_{1}^{T} \right)_{\Gamma} d\Gamma \right) \left(\boldsymbol{\varepsilon}_{,1} \right)_{M} + \left(\int_{\Gamma} \left(\mathbf{H}_{2}^{T} \right)_{\Gamma} d\Gamma \right) \left(\boldsymbol{\varepsilon}_{,2} \right)_{M} . \quad (24)$$

By imposition of (23) and (24) on the RVE, the boundary value problem of the RVE is fully settled. A corresponding solution can be found by any appropriate technique, mostly the finite element method.

4.2 Micro to macro scale transition

After resolving the microlevel boundary value problem, the stress tensors and the constitutive behaviour are required for the macroscale computation. In the scale transition, the energy equivalence principle is fulfilled through the Hill-Mandel condition

$$\frac{1}{V} \int_{V} \left(\boldsymbol{\sigma}_{m} : \delta\boldsymbol{\varepsilon}_{m} + \boldsymbol{\mu}_{m} : \left(\nabla_{m} \otimes \delta\boldsymbol{\varepsilon}_{m} \right) \right) dV = \boldsymbol{\sigma}_{M} : \delta\boldsymbol{\varepsilon}_{M} + \boldsymbol{\mu}_{M} : \left(\nabla \otimes \delta\boldsymbol{\varepsilon}_{M} \right) . \quad (25)$$

Obviously, for further derivation, relation (20) can be inserted into Eq. (25). After a lengthy procedure, which is explained in (Lesičar, Tonković and Sorić, 2017), one can obtain homogenized stress tensors relations

$$\boldsymbol{\sigma}_{M} = \frac{1}{V} \int_{V} \boldsymbol{\sigma}_{m}\, dV , \quad (26)$$

$$\boldsymbol{\mu}_{M} = \frac{1}{V} \int_{V} \left(\boldsymbol{\mu}_{m} + \boldsymbol{\sigma}_{m} \otimes \mathbf{x} \right) dV . \quad (27)$$

To complete the whole micro-macro procedure, the macroscopic constitutive behaviour is necessary. Since the heterogeneous materials are considered, the constitutive relations are much more complex compared to the usual forms used for homogeneous materials. Due to the irregular microstructure which is accounted for, the stresses depend not only on their energy conjugate strains, but also on the other displacement gradients appearing in the numerical model. Hence, to account the contribution of the heterogeneous microstructure on the macroscale, the generalized constitutive relations are derived in which every stress tensor is expressed in terms of the macrolevel displacement gradient tensors, as

$$\begin{aligned} \Delta\boldsymbol{\sigma}_{\mathrm{M}} &= \mathbf{C}_{\sigma\varepsilon} : \Delta\boldsymbol{\varepsilon}_{\mathrm{M}} + \mathbf{C}_{\sigma\varepsilon_{x_1}} : \Delta\left(\boldsymbol{\varepsilon},_1\right)_{\mathrm{M}} + \mathbf{C}_{\sigma\varepsilon_{x_2}} : \Delta\left(\boldsymbol{\varepsilon},_2\right)_{\mathrm{M}} , \\ \Delta\left(\boldsymbol{\mu}_{x_1}\right)_{\mathrm{M}} &= \mathbf{C}_{\mu_{x_1}\varepsilon} : \Delta\boldsymbol{\varepsilon}_{\mathrm{M}} + \mathbf{C}_{\mu_{x_1}\varepsilon_{x_1}} : \Delta\left(\boldsymbol{\varepsilon},_1\right)_{\mathrm{M}} + \mathbf{C}_{\mu_{x_1}\varepsilon_{x_2}} : \Delta\left(\boldsymbol{\varepsilon},_2\right)_{\mathrm{M}} , \\ \Delta\left(\boldsymbol{\mu}_{x_2}\right)_{\mathrm{M}} &= \mathbf{C}_{\mu_{x_2}\varepsilon} : \Delta\boldsymbol{\varepsilon}_{\mathrm{M}} + \mathbf{C}_{\mu_{x_2}\varepsilon_{x_1}} : \Delta\left(\boldsymbol{\varepsilon},_1\right)_{\mathrm{M}} + \mathbf{C}_{\mu_{x_2}\varepsilon_{x_2}} : \Delta\left(\boldsymbol{\varepsilon},_2\right)_{\mathrm{M}} . \end{aligned} \tag{28}$$

Accordingly, the nine constitutive operators are required. They are derived by the static condensation procedure of the global RVE stiffness, as explained in (Lesičar, Tonković and Sorić, 2017). The homogenized constitutive matrices are expressed through the condensed RVE stiffness $\tilde{\mathbf{K}}_{\mathrm{bb}}$ and the coordinate matrices as

$$\begin{aligned} \mathbf{C}_{\sigma\varepsilon} &= \frac{1}{V}\mathbf{D}\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{D}^T, & \mathbf{C}_{\sigma\varepsilon_{x_1}} &= \frac{1}{V}\mathbf{D}\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{H}_1^T, & \mathbf{C}_{\sigma\varepsilon_{x_2}} &= \frac{1}{V}\mathbf{D}\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{H}_2^T, \\ \mathbf{C}_{\mu_{x_1}\varepsilon} &= \frac{1}{V}\mathbf{H}_1\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{D}^T, & \mathbf{C}_{\mu_{x_1}\varepsilon_{x_1}} &= \frac{1}{V}\mathbf{H}_1\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{H}_1^T, & \mathbf{C}_{\mu_{x_1}\varepsilon_{x_2}} &= \frac{1}{V}\mathbf{H}_1\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{H}_2^T, \\ \mathbf{C}_{\mu_{x_2}\varepsilon} &= \frac{1}{V}\mathbf{H}_2\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{D}^T, & \mathbf{C}_{\mu_{x_2}\varepsilon_{x_1}} &= \frac{1}{V}\mathbf{H}_2\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{H}_1^T, & \mathbf{C}_{\mu_{x_2}\varepsilon_{x_2}} &= \frac{1}{V}\mathbf{H}_2\tilde{\mathbf{K}}_{\mathrm{bb}}\mathbf{H}_2^T. \end{aligned} \tag{29}$$

4.3 Numerical implementation

The multiscale procedure comprising the presented nonlocal homogenization scheme was implemented in the commercial software ABAQUS, as shown in Fig. 8. The C^1 finite element formulation is used for discretization at both the macroscale and the microscale. Since the C^1 finite elements are not supported by the Abaqus finite element library, the element developed was implemented by means of the user subroutine UEL. Even though the same finite element is used at both scales, there are some differences in their formulation. As mentioned before, at the macrolevel the global nonlinear finite element equation is solved. In each material point of the macrolevel element, the displacement gradient increments $\Delta\boldsymbol{\varepsilon}_{\mathrm{M}}$, $\Delta(\boldsymbol{\varepsilon},_1)_{\mathrm{M}}$ and $\Delta(\boldsymbol{\varepsilon},_2)_{\mathrm{M}}$ are computed and updated. Afterwards, they are prescribed on the RVE boundaries in the form of the RVE boundary conditions based on relation (23). At the microlevel, the boundary value problem is solved, where the homoge-

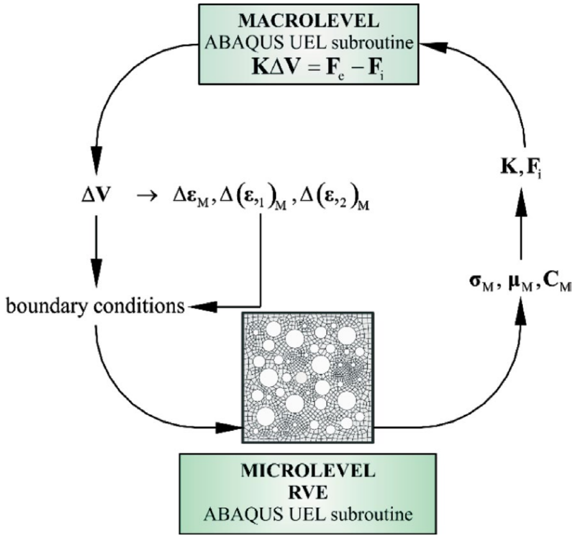

Fig. 8 – Micro-macro multiscale algorithm

nization procedure is conducted by means of Eqs. (26), (27) and (29). After solving the RVE boundary value problem using the derived homogenization strategy, the results are transferred back to the macrolevel material point. The presented computational procedure must be carried out at every finite element integration point. For more details about implementation, see (Lesičar, Tonković and Sorić, 2017).

5. Numerical example

The presented procedure is verified on a problem of three-point bending test of the notched specimen. The deformed discretized model with boundary conditions is presented in Fig. 9. The dimensions of the test specimen are 100 × 20 × 10 mm with a notch root radius of 0.08 mm according to standard ASTM E1820. The support-span is 79 mm.

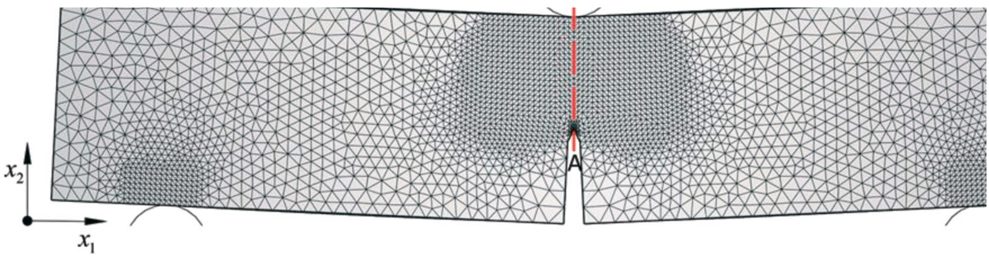

Fig. 9 – Three-point bending test specimen

The boundary conditions are suited as the simulation of a real experimental setup. The support span is modelled as two support rollers with a diameter of 8 mm. The force of 10 kN was applied over the loading roller. The rollers are modelled as rigid bodies. The finer mesh is used in the vicinity of the notch (Fig. 10) and near the roller contact regions, where the high stress gradient is expected. Since at the moment the authors do not possess necessary data of the RVE representing the nodular cast iron, the material considered is an academic example of the linear elastic steel with 13% randomly distributed porosities. However, this academic material is the closest representation of real nodular iron. The Young's modulus is taken as 210 GPa, which describes the ferritic matrix and the Poisson's ratio is set to 0.3. The porosities represent graphite nodules, which are not explicitly modelled here due to their negligible stiffness in comparison to the matrix material. The material microstructure is represented by the RVE1 of the side length L = 0.2 mm discretized by 790 finite elements as shown in Fig. 11. On the RVE, the gradient generalized periodic boundary conditions were used.

The constant discretization mesh was kept along the red line A-A displayed in Fig. 9. The analysis of this problem was conducted in an adaptive manner. The material constitutive matrices are computed by the homogenization prior to the analysis. For the linear elastic problem considered here the homogenized stress tensors values can be obtained by the analytical expression in a standard manner. For the generalized constitutive behaviour due to the analysis of the heterogeneous material the stress tensors are then calculated according to relations (28). The adaptivity mentioned here means that a few elements in front of the notch inside the red line in Fig. 10 are computed in the multiscale setting attaching the RVE1 to their material points in order to track the microstructural effects in front of the notch.

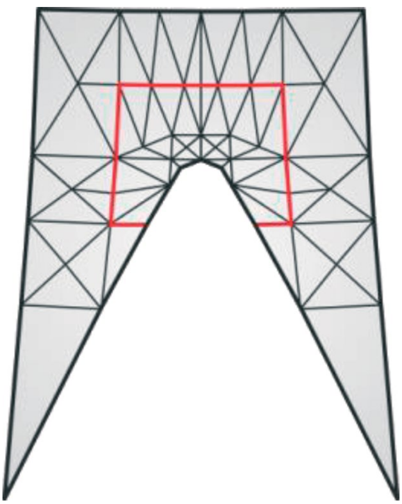

Fig. 10 – Mesh around notch root

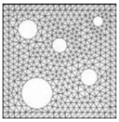

Fig. 11 – RVE1

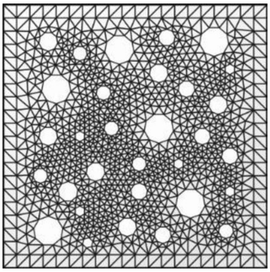

Fig. 12 – RVE2

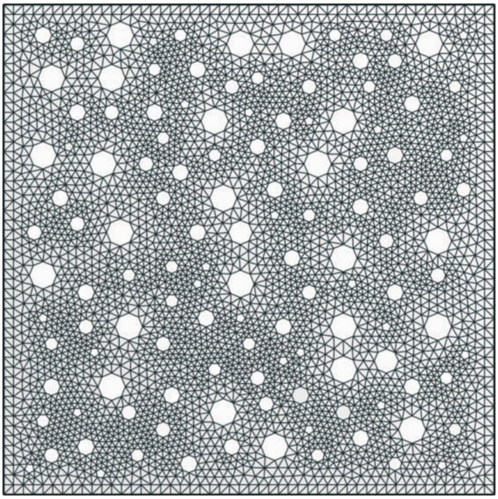

Fig. 13 – RVE3

In order to prove that the microstructure presented in Fig. 11 is truly representative, two larger RVEs, the RVE2 with side length L = 0.5mm and the RVE3 with side length L = 1mm were considered, too. Their geometries are shown in Figs. 12 and 13. However, in the second-order homogenization, the RVE size directly involves managing of the nonlocality effects. Thus, for the comparison of the results all the RVE sizes needed to describe the same nonlocal behaviour were governed by the same nonlocal parameter. To ensure comparability, the appropriate combination of the RVE size and microstructural parameter l was chosen, as briefly discussed in (Lesičar, Tonković and Sorić, 2017). For both larger RVE sizes the same behaviour of the specimen is exhibited, which leads to the conclusion that the microstructural model represented in Fig. 11 can be found as a true RVE. In the following figures the distribution of the relevant displacement gradient in front of the notch along the line A-A of length H = 11mm is presented. For the bending pattern exhibited here the dominant gradients of displacements are $u_{1,1}$ which is in fact the strain ε_{11}, and opens the notch, $u_{1,21}$ describing the trapezoidal deformed shape and $u_{2,11}$ representing curvature. The multiple analyses were conducted for various values of the microstructural parameter l. Figs. 14, 16 and 18 show the distributions of the relevant displacement gradients in front of the notch. In these diagrams the ordinate represents the distance from the notch tip in the vertical direction denoted as H. As expected, the high gradients appear in the vicinity of the notch due to the geometrical discontinuity and on the upper surface of the specimen due to the roller penetration causing crimping of the material. Moving away from the notch tip the peak areas the gradients rapidly drop and disappear in the inner part of the specimen. With an increase in l the general behaviour is preserved, but the stiffness of the material is increased due to a larger nonlocal influence. Detailed insight into the distributions in front of the notch are given in Figs. 15, 17, and 19. It is visible that the stiffer

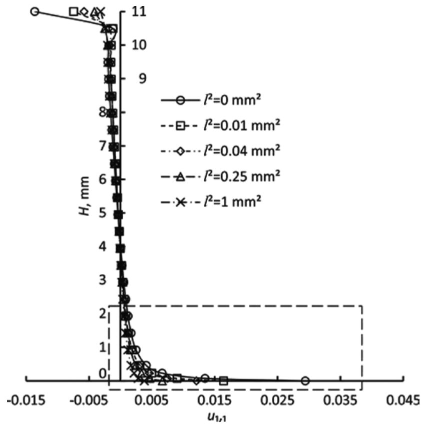

Fig. 14 – Distribution of $u_{1,1}$ in front of the notch

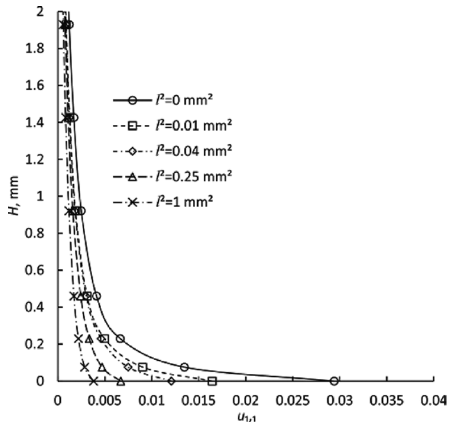

Fig. 15 – Detail of distribution of $u_{1,1}$ in front of the notch

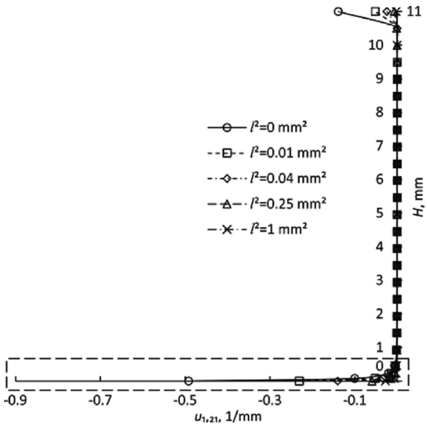

Fig. 16 – Distribution of $u_{1,21}$ in front of the notch

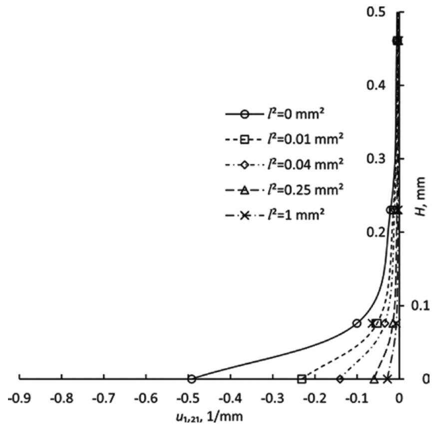

Fig. 17 – Detail of distribution of $u_{1,21}$ in front of the notch

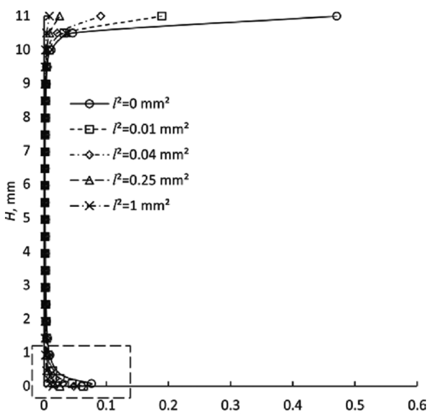

Fig. 18 – Distribution of $u_{2,11}$ in front of the notch

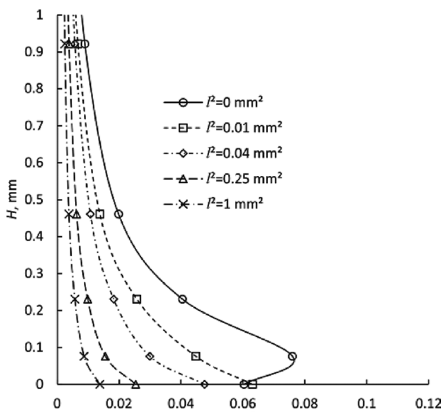

Fig. 19 – Detail of distribution of $u_{2,11}$ in front of the notch

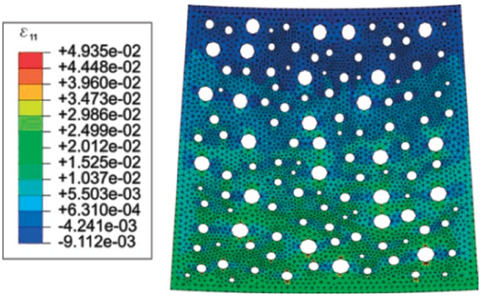

Fig. 20 – Distribution of ε_{11} on RVE3

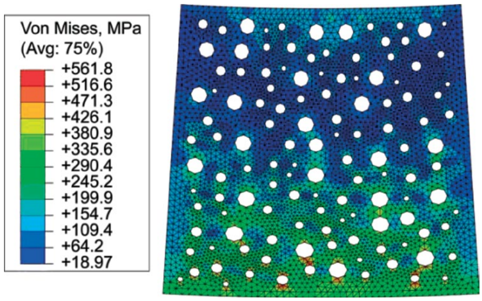

Fig. 21 – Distribution of Von Mises stress on RVE3

response coming with increased l is common to all gradients. Furthermore, Figs. 20 and 21 displays the strain ε_{11} and the Von Mises stress on the RVE3 located at the notch tip for $l^2 = 0$. On this RVE the gradient displacement boundary conditions are utilized. It can be seen that the RVE is elongated as a consequence of ε_{11}. Due to the mixed second-order derivative $u_{1,21}$, the trapezoidal deformation mode is prominent. The curvature, which is the result of $u_{2,11}$ is not expressed in such an extent as the trapezoidal mode, but with a further increase in loading it could be easily distinguished. In Fig. 20 a smooth change of strain from tension to compression is visualized, as expected for the bending problem. The distribution of the equivalent Von Mises stress is visualized in Fig. 21, which is exhibited in accordance to the deformation mode. Also, stress concentrations around pores representing the graphite nodules can be observed. As is known, t stress concentrations serve as initiators of a damage and may cause further softening of materials. In future research, an extension of the material behaviour towards softening will be considered, where the influence of stress concentration on damage initiation and propagation at the microlevel will be studied.

6. Conclusion

The paper presents an approach for numerical modelling of deformation responses of heterogeneous engineering materials. Nodular cast iron, which is widely used in engineering structural components, is described in more detail. It is shown that its heterogeneity described by size, shape and distribution of the graphite nodules has significant influence on load carrying capacity. The numerical analysis requires the consideration at both macro- and microscale which may be performed by means of a multiscale approach.

In this contribution the second-order two-scale computational homogenization scheme employing the strain gradient elasticity theory at the macro- and microlevel is presented. The formulation of the nonlocal theory is embedded into the finite element framework using the C^1 continuity three node triangular plane strain finite element. It is shown that the two-scale formulation applied is mathematically more consistent than the multiscale approach using the nonlocal theory only at the macrolevel, usually used in available literature.

All algorithms developed are implemented in the FE software ABAQUS. To demonstrate the capability of the presented computational procedure, the three-point bending test of the notched specimen was modelled. The microstructure of the nodular cast iron is presented by the academics RVEs. The influence of the RVE size as well as the microstructural parameter on the material behaviour are analysed and discussed. As expected, the realistic deformation responses are computed.

Further research should be directed to the application of the presented algorithm to the more realistic description of nodular cast iron microstructure. In addition, some damage phenomena at the microstructural level should be modelled, which can lead to fracture development at the material point of the macroscale. An accurate and numerically efficient damage and fracture modelling can significantly contribute to the assessment of structural integrity and lifetime prediction as well.

Acknowledgement. This work has been fully supported by Croatian Science Foundation under the project "Multiscale Numerical Modelling of Material Deformation Responses from Macro- to Nanolevel" (2516).

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Scour around the Circular and Square Profile Piers

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Abstract: The study shows the methodology and results of the conducted local erosion research around circular and square profile piers under clear-water conditions. Physical and numerical modelling technique has been used to achieve the primary goal for determining the depth of the erosion pit, comparing with the results obtained through the application of empirical equations suggested by a series of authors.

The shape of the pier cross section (circular and square), number of piers in the flow cross section (1, 2, 3) and the flow depth with the corresponding velocity were varied. The granulation of the applied model sediment is uniform and homogeneous (d=2mm). Basic geometrical features of the physical and numerical model were not changed (except for the piers). Based on physical model measurements and numerical model simulations, maximum erosion depths (scour) were determined. The obtained results were compared mutually and with empirical equation results using the same geometric and hydraulic conditions. Numerical simulations were conducted with the aim of Mike 21fm numerical model based on the finite volume method.

The modelling results indicate a more pronounced erosion around the circular piers. The empirical equation of Melville (1997) gives the values of erosion pit depth closest to the measurement results of the physical model and the results of numerical model simulations. The highest degree of resemblance with the models results was achieved in the case where three piers were embedded. The measurement results of the physical model are more consistent with the results of the empirical equation compared to the results obtained by numerical simulations.

Keywords: local scour, pier, numerical model, physical model

1. Introduction

The most common cause of bridge failure is erosion around their piers and abutments. For the purpose of prevention it is necessary to regularly observe the changes of the bedrock. Therefore, the interaction between the water flow and in-water bridge construction elements during the flood condition should be defined as precisely as possible with the aim of preventing bridge damage and consequent loss of life and property. A reduction of the flow cross section due to natural conditions or bridge piers/abutments implementation in the water stream causes a significant disturbance in the flow field. The velocity and the unit discharge increases causing the added erosion of the bedrock. The evolution of the scour pit around the bridge piers and abutments is a dynamic and time-consuming process, but can be significantly accelerated in a relatively short time during the occurrence of flood waves.

Since 1950 in the United States, 60% of 823 bridges have been partially damaged or destroyed as a result of intensive scouring (Shirola and Holt, 1991). The USA Federal Highway Association has reported that every year about 50 bridges fail in the USA. Brice and Blodgett (1978) state that 50% of the bridge failures in the USA are caused by local erosion. Miller (2003) reported that the breakdowns of bridges in New York and Tennessee resulted in a loss of 18 lives during the period 1987 – 1989. Also seven people were killed because of the bridge failure over the river Arrayo Pasajero in 1995. According to Richardson and Davis (2001), storm Alberto in Georgia was responsible for 130 million dollar damage needed for reparatory and reconstruction of more than 100 bridges. Many bridges were broken or damaged during major floods in Turkey (Yanmaz, 2002). In the United States, the state of river bridges has been continuously monitored since 1991, and it was found that 17,000 were in a critical condition due to local erosion problems (Lagasse et al., 1998). The biggest bridge in Croatia that has failure due to the scouring is "Jakuševac" bridge on the railway Velika Gorica - Sesvete, at the point of bridging the Sava River near Mičevac. The bridge was built in 1968. On March 30, 2009, at 22:30, the stability of the load-bearing structure collapsed during the passage of a freight train.

The stability of the watercourse depends on the sediment transport regime. Riverbed instability is a natural phenomenon resulting from the erosion and sedimentation process that develops gradually at medium flow conditions or evolve rapidly during the flooding regime (Melville and Coleman, 2000). Local erosion is usually divided into: a) clear-water erosion and b) live bed erosion. Therefore, the local erosion equations are categorized in this way.

Clear-water erosion (scour) occurs in case of no sediment removal upstream of the bridge. The degree of erosion depends on the local flow field defined by the cross sectional geometry. Erosion around the bridge piers develops relatively fast in the initial stage under clear-water conditions, and due to an increase in the erosion pit, it reduces stresses and achieves balance and interrupts further development of the erosion pit.

Live bed erosion occurs in the presence of sediment transport upstream from the bridge. This kind of erosion refers to the case of intense erosion pit development in the initial stage, followed by the reduced scouring until the achievement of the equilibrium conditions (sedimentation and erosion of the material in the erosion pit area is equal).

The measurements of the maximum depth of the erosion pit under clear-water condition were initially performed on the physical model. Variations in geometric and hydraulic characteristics are given in table 1 (18 experiments). Thereafter, a numerical model of sediment transport was implemented for the same conditions that were used in the previously performed analyses on the physical model.

The following parameters and conditions were used in the course of the investigation:

- the width of the experimental channel (distance of lateral vertical walls B = 0.8m, constant in all experiments);
- diameter of the uniform model sediment (d = 0.002 m = 2 mm);
- piers cross section and diameter (circular D = 0.1 m, square D = 0.1 m);
- pier configuration along the contraction profile (with 1/2/3 piers);
- inflow depth (h = 0.04 ; 0.05 ; 0.06 m);
- inflow average flow velocity (v = 0.22 ; 0.26 ; 0.29 m/s);
- experiment duration on the physical and numerical model (14,400 s);
- model discharge Q = 0.011 m^3/s.

2. Physical model

The physical model was created in the Hidrotehnic Laboratory of the Faculty of Civil Engineering, University of Zagreb (Figures 1 and 2). The physical model is 2.0 m long and 0.8 m wide. It consists of inflow part where a uniform flow develops, working section with quartz sand of 2 mm diameter where piers are embedded, and outlet zone in which the water depth is regulated. The discharge regulation valve is located on the model entrance and Thomson measurement overflow on the

Fig. 1 – Physical model for local erosion analysis around the pier

model exit section. The needle probes are used to measure water level and erosion pit depth.

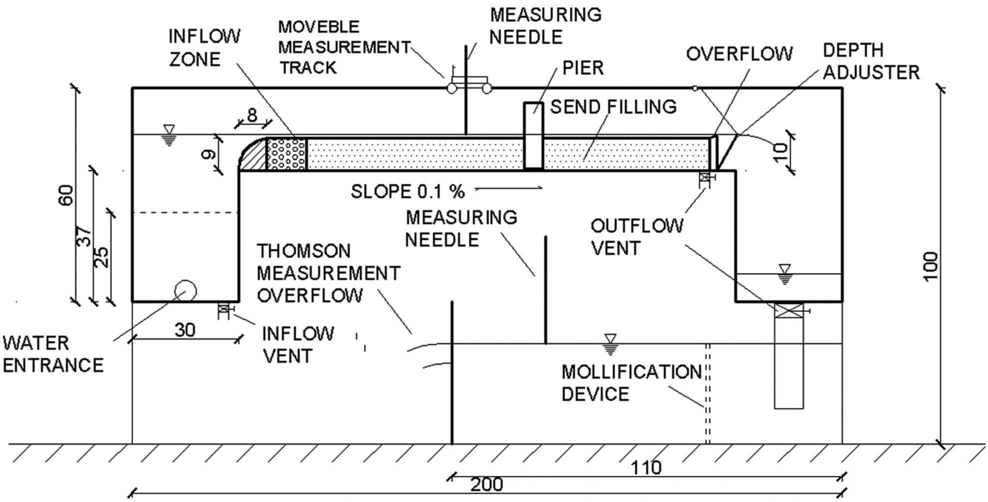

Fig. 2 – Schematic presentation of the physical model and associated measurement equipment for the local erosion analysis around the pier

Table 1 – Nomenclature of experiments on physical and numerical model with basic geometric and hydraulic characteristics (*N* – number of piers in flow profile, *KR* – circular cross section, *KV* – square cross section, *a* – the transversal width of the gap between the outer edges of the piers, $h_{X=1.0}$ – water depth before pier section at the chainage x = 1.0 m, $h_{X=1.7}$ – water depth after pier section at the chainage x = 1.7 m, *V* – average flow velocity before pier section at the chainage x = 1.0 m)

Exp. num.	N	form	a / D (1)	$h_{X = 1.0\,m}$ (m)	$h_{X = 1.7\,m}$ (m)	V (m/s)
1	1	KR		0.063	0.062	0.22
2	1	KR		0.053	0.05	0.26
3	1	KR		0.048	0.042	0.29
4	2	KR	2	0.063	0.062	0.22
5	2	KR	2	0.053	0.05	0.26
6	2	KR	2	0.049	0.042	0.29
7	3	KR	1.25	0.064	0.062	0.22
8	3	KR	1.25	0.054	0.05	0.26
9	3	KR	1.25	0.05	0.042	0.28
10	1	KV		0.063	0.062	0.22
11	1	KV		0.053	0.05	0.26
12	1	KV		0.048	0.042	0.29
13	2	KV	2	0.063	0.062	0.22
14	2	KV	2	0.053	0.05	0.26
15	2	KV	2	0.049	0.042	0.29
16	3	KV	1.25	0.066	0.062	0.21
17	3	KV	1.25	0.056	0.05	0.25
18	3	KV	1.25	0.052	0.042	0.27

3. Numerical model

The numerical model Mike 21fm (www.dhigroup.com) was used. The model solved 2D Navier-Stokes equations for noncompressible fluid using Reynolds's averaging and Boussinesq hydrostatic assumption. For spatial discretisation, the final volume method with continuous and non-overlapping cells was used. The model spatial domain (Figure 3) was discretised in the horizontal direction with structured rectangular mesh at the inflow part of the model (square cells with area $2.5*10^{-3}$ m^2) and unstructured triangular mash elsewhere (triangular cells with average area $1.8*10^{-3}$ m^2 ; $6.0*10^{-4}$ m^2 ; $2.0*10^{-4}$ m^2).

The bottom was adopted as initially horizontal with a constant depth of 0.5 m in the area covered with square cells and with a constant depth of 0.05 m on the remaining part of the model domain (identical to the actual dimensions of the physical model). Along the lateral vertical walls a zero flow velocity condition was imposed (no-flow boundary).

At the left open boundary (the boundary condition of the hydrodynamic part of the model) constant inflow discharge Q = 0.011 m^3/s was used (see Table 1). On the right open boundary constant water surface levels were used, aiming identical water depth at chainage x = 1.7 m as measured on the physical model under the same hydraulic condition (column $h_{X=1.7m}$, see Table 1). The initial conditions for flow velocity components were adopted with 0 m/s in two horizontal directions for all numeric cells. Numerical simulations covered the period of 14,400 s (4 hours).

The closure of the turbulence model relies on Smagorinsky concept (1993), using Smagorinsky coefficient with spatial uniform value 0.2. Roughness was parameterised using Manning coefficient with spatial uniform value 0.015 $m^{1/3}/s$.

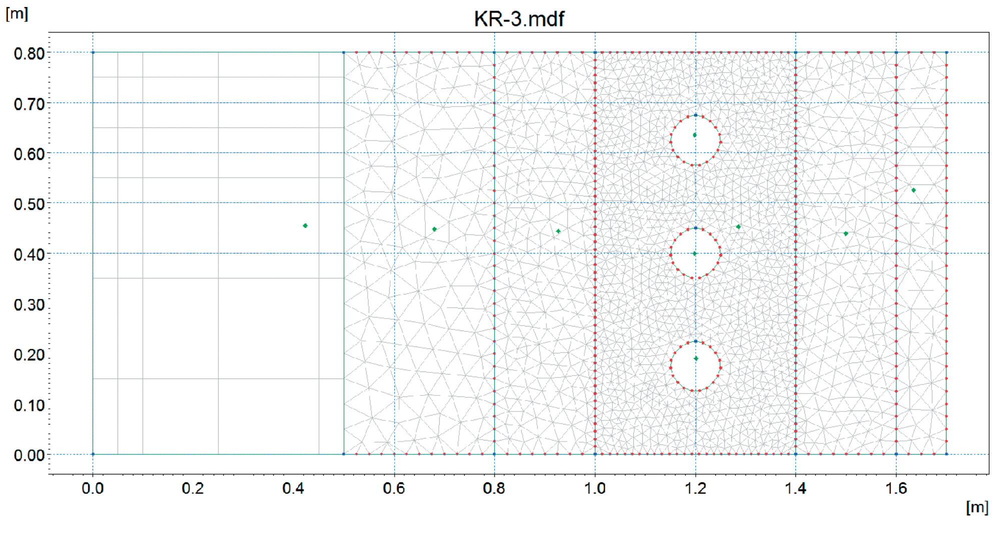

Fig. 4 – Spatial discretisation of the numerical model domain for simulations with three circular piers and diameter of 0.1 m

The integral formulation of continuity and momentum equations for 2D shallow water in the Cartesian coordinate system reads (Sleigh and Gaskel, 1998; Zhao et al., 1998):

$$\frac{\partial \boldsymbol{U}}{\partial t} + \nabla \cdot \mathrm{F}(\mathrm{U}) = \mathrm{S}(\mathrm{U}) \tag{1}$$

$$U=\begin{bmatrix} h \\ hu \\ hv \end{bmatrix} \quad F_x=\begin{bmatrix} hu \\ hu^2+gh/2 \\ huv \end{bmatrix} \quad F_y=\begin{bmatrix} hv \\ hvu \\ hu^2+gh/2 \end{bmatrix} \quad S=\begin{bmatrix} hs \\ gh(S_{0x}-S_{fx}) \\ gh(S_{0y}-S_{fy}) \end{bmatrix} \qquad \text{(2a,b,c,d)}$$

$$S_{fx}=\frac{n^2u\sqrt{u^2+v^2}}{h^{4/3}} \qquad S_{fy}=\frac{n^2v\sqrt{u^2+v^2}}{h^{4/3}} \qquad (3)$$

where: $\boldsymbol{U}$ conservative variable vector; $\boldsymbol{F}$ flux vector function; $\boldsymbol{S}$ source/sink vector; S_{0x} and S_{0y} bottom slope in x and y direction; S_{fx} and S_{fy} energy line slope defined with Manning equation, n Manning coefficient.

Using the Green-Gauss theorem in integration of equation 1 along i-th cell gives:

$$\int_{Ai}\frac{\partial \boldsymbol{U}}{\partial \boldsymbol{t}}d\Omega+\int_{Ai}\boldsymbol{S}(U)d\Omega=-\int_{\Gamma i}(\boldsymbol{F}\cdot n)dS \qquad (4)$$

where: A_i i-th cell area, Ω integration variable defined on A_i, Γ_i wetted perimeter of cell A_i, ds integration variable along wetted perimeter, n vector of outer normal. Horizontal convective members are calculated using Riemann solver with Roe approximation (Roe, 1981; Alcrudo and Garcia-Navarro, 1993; Toro, 1997).

The sediment transport model uses the following set of equations for transport intensity calculation:

$$\Phi_t=\frac{C^2}{2g}\theta^{2.5} \qquad (5)$$

$$\Phi_t=\frac{q_t}{\sqrt{(s-1)gd^3}} \qquad (6)$$

$$\theta=\frac{U_f^2}{(s-1)gd} \qquad (7)$$

where: C Chezy coefficient, q_t total mass flux of sediment, g gravity constant, θ nondimensional bed stress, U_f shear velocity, d grain diameter (adopted $d = 2$ mm); s relative sediment density (adopted 2.65).

The above formulation assumes that nondimensional bottom stress is much larger than the critical Shields parameter for erosion initiation. At the left inflow open boundary of the sediment transport model zero sediment flux condition was used, while on the outflow open boundary zero gradient flux for sediment was used.

4. Empirical equations

The previous research shows that local erosion around bridge piers depends on the bottom material properties (primarily granulation), watercourse configuration, flow characteristics, fluid properties and bridge pier geometry. Most of the parameters are in mutual interaction. For the purposes of estimation of erosion pit depth in clear-water condition ($V / V_c < 1$, V_c critical flow velocity for erosion initiation), empirical equations according to the following authors were extensively used:

$$d_s = 1.4\, D \qquad \text{Breusers (1965)} \qquad (8)$$

$$d_s = 2.42\, D \left(\frac{2V}{V_c} - 1 \right) \left(\frac{V_c^2}{g \cdot D} \right)^{1/3} \qquad \text{Hancu (1971)} \qquad (9)$$

$$d_s = 1.84\, D \left(\frac{h}{D} \right)^{0,3} \qquad \text{Jain (1981)} \qquad (10)$$

$$d_s = 0.46\, K_s\, D \left(\frac{h}{D} \right)^{0,4} \left(\frac{h}{d} \right)^{0,07} h^{-0,32} \qquad \text{Gao (1993)} \qquad (11)$$

$$d_s = K_{yb}\, K_D\, K_s \qquad \text{Melville (1997)} \qquad (12)$$

$$d_s = 0.24 \left(\frac{0,8 \cdot h \cdot V}{\sqrt{d}} \right)^{1/3} - h \qquad \text{Antunes do Carmo (2005)} \qquad (13)$$

where: V_c = 0.0305 $d^{0.5}$ – 0.0065 d^{-1} for 1mm < d_{50} < 100mm (Melville i Coleman, 2000), K_{yb} coefficient for the influence of pier foundation size (K_{yb} = 2.4 D for $D / d < 0.7$; $K_{yb} = 2\,(dD)^{0.5}$ for $0.7 < D / d < 5$; K_{yb} = 4.5 D for $D / d > 5$; Melville i Coleman, 2000), K_D pier – sediment relation coefficient factor (K_D = 0.57 log (2.24 D/d) for $D / d < 25$; K_D = 1 for $D / d > 25$; Melville and Sutherland, 1988), K_S coefficient for the shape of pier cross section (K_S = 1 for circular ; K_S = 1.22 for square pier).

The effect of pier group depends primarily on the distance between the piers and piers layout within the watercourse. If the flow direction is orthogonal to the piers line (α = 90 °) and a/D > 7, all the piers forming the group act as a single pier (separated erosion pits around every individual pier). On the other hand, if a/D < 0.5, one common pit around the pier group will be formed (Salim and Jones, 1999).

5. Measurement and modelling results

Figure 5 shows measured (physical model) and calculated (numerical model) depths of erosion pit for experiment conditions 1-18 (Table 1).

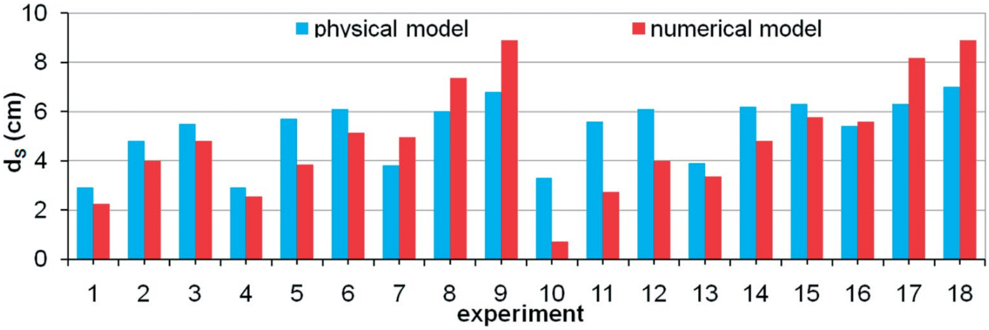

Fig. 5 – Measured (physical model) and calculated (numerical model) depths of erosion pit in experiment conditions 1-18 (table 1)

According to the numerical model results, the average depth of the erosion pit for the circular pier/piers is 2% higher than in the case with the square pier/piers. The measurement results of the physical model show that the depth of the erosion pit for the square pier/piers was on average higher by 15% than for the circular pier/piers. Furthermore, the layout with two circular piers causes an increase in the depth of the erosion pit by an average of 8% (physical and numerical model), while the layout with 3 circular piers results in a higher depth of the erosion pit by an average of 63% (physical and numerical model). When one increases the number of piers, the increase of erosion pit depth is more pronounced. Embedding of two squared piers results with increase of erosion pit depth by 85%, while in the case of three embedded piers the increase of erosion pit depth is almost 3 times (285%). These percentages represent mean values of all measurement results and numerical simulations. The average measured erosion depth in all 18 experiments is 33% higher than the average value obtained by using the numerical model.

Figures 6 and 7 show vertically averaged flow fields obtained by the numerical model for the corresponding conditions shown in Table 1. Figures 8 and 9 show appertaining calculated erosion fields in the model spatial domain.

Figure 10 shows the comparison of the erosion pit depths computed by numerical model and calculated on the basis of the empirical equations 8 – 13. Figure 11 shows the local erosion around two circular and square piers after achieving the equilibrium condition in experiments 6 and 15 on the physical model.

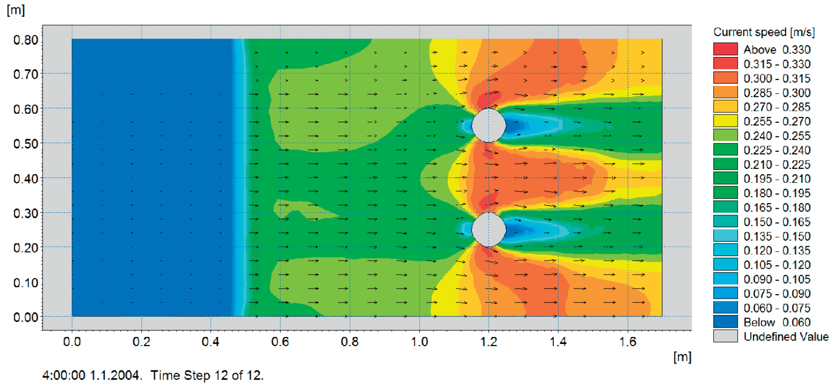

Fig. 6 – Vertically averaged flow field for two circular piers of a diameter D = 0.1 m with a water depth $h_{(X = 1.7m)}$ = 0.06 m used for the outflow open boundary condition

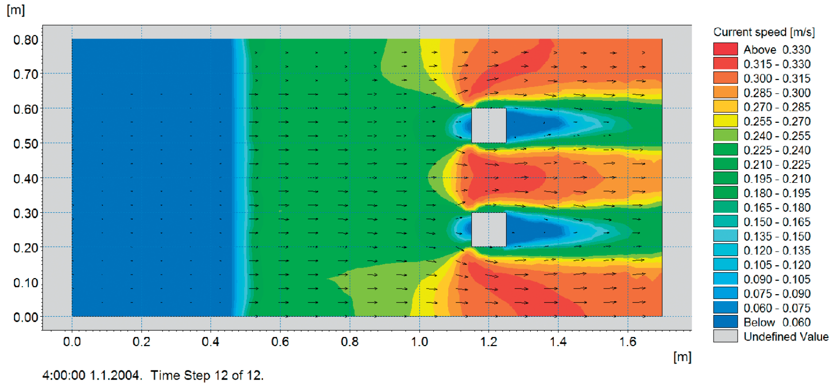

Fig. 7 – Vertically averaged flow field for two square piers of a diameter D = 0.1 m with a water depth $h_{(X = 1.7m)}$ = 0.06 m used for the outflow open boundary condition

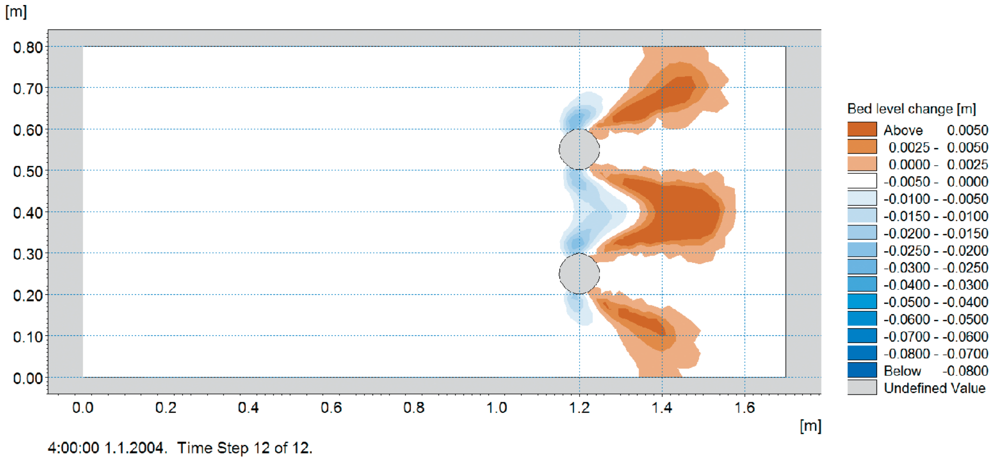

Fig. 8 – Erosion/sedimentation field for two circular piers of a diameter D = 0.1 m with a water depth $h_{(X = 1.7m)}$ = 0.06 m used for the outflow open boundary condition

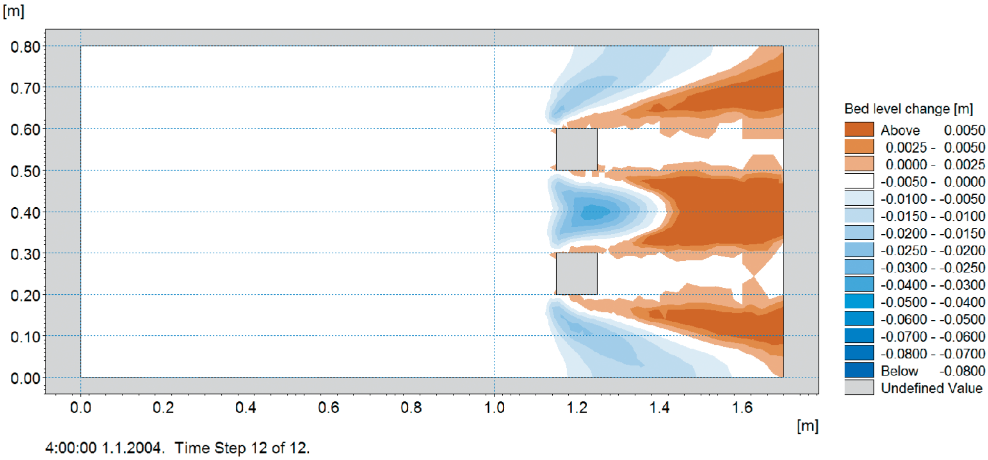

Fig. 9 – Erosion/sedimentation field for two square piers of a diameter D = 0.1 m with a water depth $h_{(X = 1.7m)}$ = 0.06 m used for the outflow open boundary condition

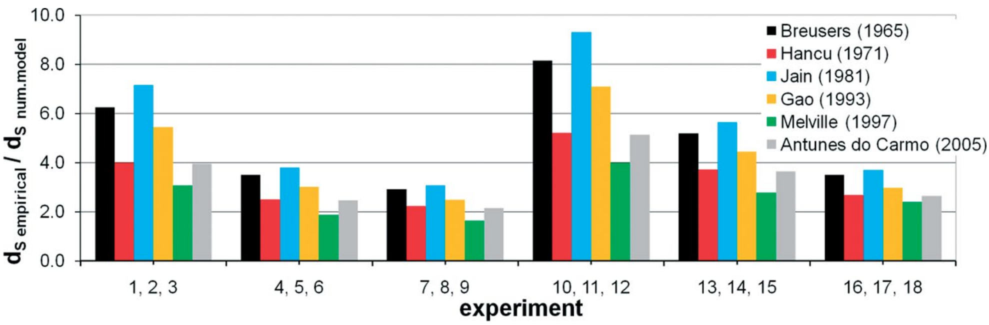

Fig. 10 – Comparison of the erosion pit depths computed by the numerical model and calculated on the basis of empirical equations 8 – 13

Fig. 11 – Local erosion around two circular and square piers after achieving the equilibrium condition in experiments 6 and 15 on the physical model (see Table 1)

Figure 12 shows the comparison of the erosion pit depths measured on the physical model and calculated on the basis of empirical equations 8 – 13.

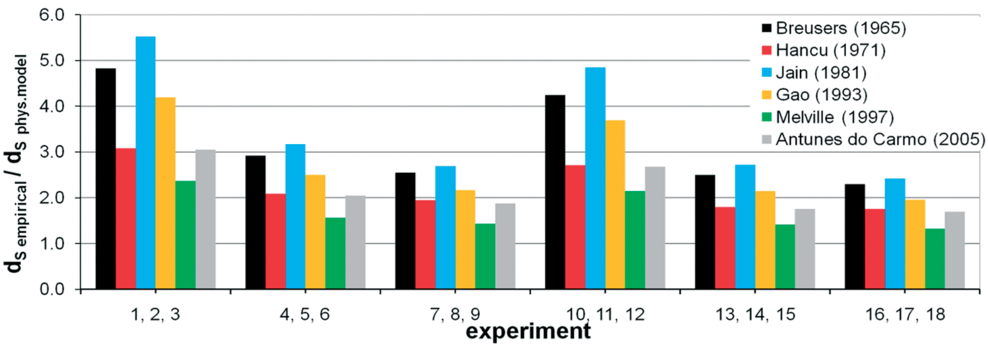

Fig. 12 – Comparison of the erosion pit depths measured on the physical model and calculated on the basis of empirical equations 8 – 13

The results in Fig. 10 indicate that closest results of the erosion pit depth computed by the numerical model and obtained using the empirical equation given by Melville (1997) is in the presence of three piers. On the other hand, in the case of a single pier, the numerical model gives significantly lower values (on average five times lower). Recognizing the absence of the member in the empirical equation that directly represents the influence of the pier group, it can be concluded that the contribution of the pier group is indirectly imposed in the empirical equation.

The results given in Fig. 12 point out that the measurement results of the physical model, the same as the results obtained by numerical simulations, best correspond to the results of Melville (1997) empirical equation. It should be noted that the highest degree of resemblance between the measured and empirical values was achieved in the case of the layout with three piers. In the layout with one pier, the measurement of the physical model gives significantly lower values of erosion depths than the empirical equations (twice lower in the case of square pier and empirical equation according to Melville (1997)). Therefore, it could be concluded that the empirical equations contain an additional security coefficient that covers the stochastic nature of the erosion process in realistic environmental conditions.

6. Conclusion

A study of local erosion around pier/piers of circular and square profiles in clear-water conditions was carried out. The technique of physical and numerical modelling was applied and the depth of the erosion pit was measured and calculated. The measurement results of the physical model and obtained by numerical simulations were compared with the results of empirical equations given by a series of authors. In the scope of investigation some geometric and hydraulic parameters were varied: the shape of the pier cross section (circular and square), the number of piers in the partition profile (1, 2, 3), and the flow depth and flow velocity. The granulation of the applied model sediment is uniform and homogeneous (d = 2 mm).

The measurement results of the physical model and the implementation of numerical model simulations point to a more pronounced erosion around the pier/piers of circular cross section relative to the pier/piers of square cross section. Thus the depth of the erosion pit in the case of circular pier/piers is higher by an average of 5% (for 1, 2 and 3 piers on the physical and numerical model).

It is noted that Melville's (1997) empirical equation takes into account the greatest number of hydraulic and geometric properties of the watercourse and the piers themselves, and that the result of its application is closest to the measurement results of the physical model or the results of numerical simulations. The highest degree of similarity with model results was achieved in the presence of three piers, when the Melville empirical equation (1997) gives only 15% greater depth of the erosion pit than measured on the physical model.

The measurement results of the physical model are more consistent with the results of empirical equation compared to the results obtained by numerical simulations.

The future research should be focused on field work with measurement campaigns undertaken immediately after the occurrence of extreme flooding conditions.

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Investigation of the Impact of the Type of Weave on Shear Properties of Woven Fabrics in Various Directions

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Abstract: Shear behavior is a very important mechanical property of woven fabrics. Shear properties of woven fabrics were tested in various directions because of anisotropy. This research was focused on the experimental study of shear properties of woven fabric for different types of weaves, when shear force acts on specimens that are cut at different angles to the weft direction. Tests were conducted on woven fabric specimens that were fastened in two parallel clamps that were placed in the tensile tester. Three cotton woven fabrics of different types of weave (plain, twill, and sateen) were used. Based on the diagram of the measured values of shear force and corresponding vertical displacement, shear angles and corresponding shear stresses were calculated. The initial shear modulus of woven fabrics was determined experimentally in the laboratory. Based on the experimentally obtained values, the theoretically calculated initial shear modulus of arbitrarily chosen fabric directions was calculated. The results of the conducted research show a very high degree of correlation between experimental and theoretical initial shear moduli only for the orthogonal plain weave fabric which represents a symmetrical weave.

Keywords: anisotropy, initial shear modulus, pure shear, shear angle, shear force, woven fabric, weave

1. Introduction

In practical use, textile fabrics are subjected to a wide range of complex deformations, so the shear properties of woven fabrics are important in many practical applications. During shear deformation, the woven fabric yarns experience a large angular variation between warp and weft yarns. Test methods of shear properties of woven fabrics are listed in the existing literature [1-3]. To understand the mechanisms of woven fabric shear behavior, shear apparatuses which measure woven fabric shear properties are described [4-8]. They indicated that the hysteresis produced during shearing is determined wholly by the frictional restraints arising in the rotation of the yarns from the intersecting points in the woven fabric. In addition, the existing literature proves that the shear mechanism is one of the important properties influencing the draping and pliability of woven fabrics [9].

Shear deformation of woven fabrics also affects their bending and tensile properties in various directions other than just in the warp and weft directions [10]. Kilby introduced the classical elasticity theory with the assumption of a woven fabric regarded as an anisotropic material with two planes of symmetry at right angles to one another [11]. He used a simple grid model for woven fabrics and analyzed the relationship between stress and strain in the plane and noted that there is a connection between the Poisson ratio, shear modulus and modulus of elasticity of the woven fabric. He showed that shear rigidity can be calculated from the tensile properties of the woven fabric at an angle of 45° in relation to the plane of the plate. Grosberg and Park [12] produced a mathematical analysis to determine the initial shear modulus, frictional shear stress, and shear rigidity. At the beginning, researches mainly focused on the shear behavior of woven fabrics in both principal directions because it affects much woven fabric behavior, and later their attention was directed at woven fabric shear properties in various directions. Therefore, the shear properties of woven fabrics should be determined in various directions. This engineering property has been studied by many researchers. Anisotropy is the characteristics of woven fabric that affects its physical and mechanical properties [13]. The determination of shear stresses and strains in various directions involves complex mechanisms that provide information about the shear properties of woven fabrics in various directions where the angles between two sets of yarns change in the intersecting points. Due to the inherent nature of woven fabrics an accurate and reliable determination of shear angle and shear stress is a difficult task.

The aim of this study was to determine the shear angle, shear forces and shear stresses of woven fabric using clamps that were specially designed in the laboratory for measuring shear forces. Shear force acts on woven fabric specimens that are cut at different angles to the weft direction. Also, the influence of anisotropy and type of weave to the initial shear modulus values of a woven fabric was analyzed. The degree of agreement between experimental results and calculated values of the initial shear modulus was determined. The structure of the apparatus and the measurement procedures are introduced and illustrated in this paper. Woven fabric specimens which are fastened in two parallel clamps that are placed in the tensile tester that will be used for the experimental determination of shear properties of the woven fabric.

2. Theory of pure shear

Woven fabrics are elastic orthotropic materials with a very small deformation which are defined as orthotropic plates with two mutually perpendicular planes of elastic symmetry [14]. These planes of elastic symmetry are planes of orthotropy. The x-axis represents the weft direction, and the y-axis represents the warp direction of woven fabric. In the arbitrary cross section of a woven fabric specimen under stress normal stresses σ_x, σ_y and shear stresses τ_{xy} or σ_k, σ_l, τ_{kl} generally act (Fig. 1a).

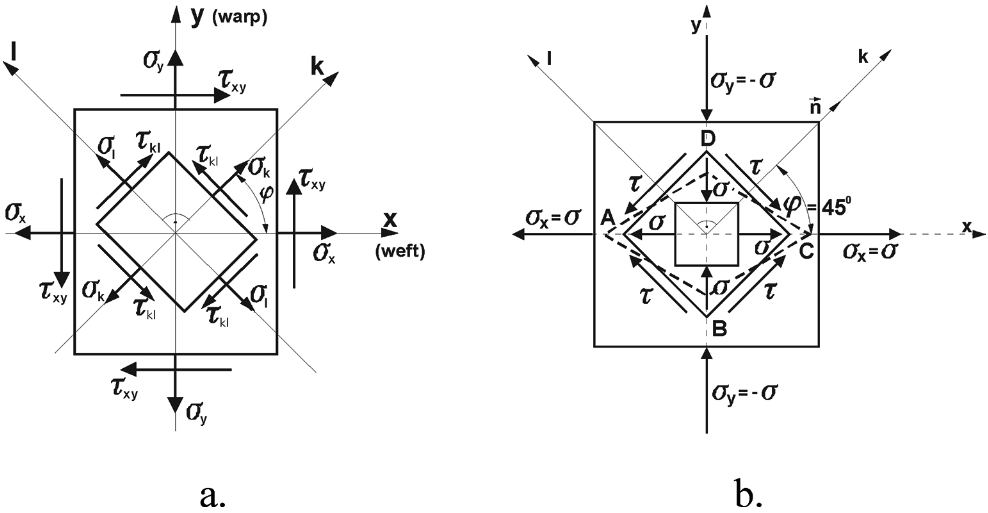


Fig. 1 – Woven fabric element: a) state of plane stress in woven fabric specimen, b) pure shear behavior

For a particular state of plane stress in an element we can determine the plane in which only shear stresses act and normal stresses are zero [15]. Parallelepiped forms of fabric specimens on whose sides only act normal stresses $\sigma_x = \sigma$ and $\sigma_y = -\sigma$ are observed, Fig. 1b. In the plane with an angle φ=45° with the x-axis according to Equation (1) normal stress is σ_k=0, and shear stress is $\tau_{kl} = \tau = -\sigma$. Such a case of stress is called a pure shear.

$$\sigma_k = \sigma_x \cdot \cos^2\varphi + \sigma_y \cdot \sin^2\varphi + \tau_{xy} \cdot \sin 2\varphi = \sigma \cdot \cos 2\varphi \quad (1a)$$

$$\tau_{kl} = \frac{\sigma_y - \sigma_x}{2} \cdot \sin 2\varphi + \tau_{xy} \cdot \cos 2\varphi = -\sigma \cdot \sin 2\varphi \quad (1b)$$

If a cube is cut with sides perpendicular to the x and y axes, on these sides only normal stresses which are equal in magnitude but in opposite direction, Fig. 1b, would act. Pure shear is equivalent to the simultaneous stretching and pressure with equal intensity in mutually vertical directions. In pure shear the relative change of volume is $\varepsilon_v=0$. Shear stress changes only the body shape, but does not change its volume. The isolated element of the woven fabric ABCD which is subjected to pure shear is shown in Fig. 2. During shear deformation, the woven fabric yarns experience a large angular variation between the warp and weft yarns.

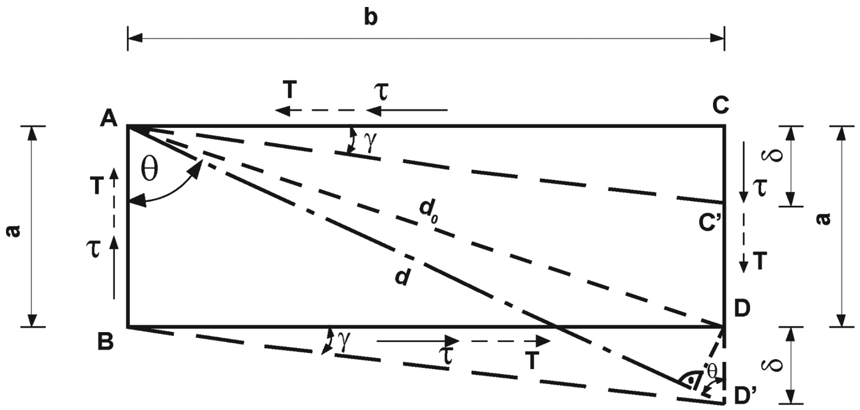


Fig. 2 – Woven fabric element subjected to pure shear – rectangular shape of the element

If side AB is motionless, then under the action of shear force T which acting in the plane of the element side shear stress τ will occur and it will come to the appearance of shearing side DC parallel with side AB for the amount CC'=DD'=δ (mm) which is called absolute shear (Fig. 2). Rectangle ABCD becomes a parallelogram ABC'D'. The side lengths of the woven fabric elements do not change, only the right angles between the element sides change, right angles become sharp or blunt angles. A change in the right angle is denoted with γ (rad) and is called relative shear, shear angle or relative angular (shear) strain. It is a measure of deformation. During the elastic deformation t shear angle γ is very small and it is equal to absolute shear divided by the spacing between the shear planes, Eq. (2):

$$\mathrm{tg}\,\gamma \cong \gamma = \frac{\delta}{b} \tag{2}$$

The value of the absolute shear δ depends not only on the value of shear stresses but also on the dimensions of the cut element. Shear stress τ (N/mm^2 = MPa) of the woven fabric can be directly calculated using shear forces. Shear strain is equal to the shear angle γ. It is assumed that the thickness of the woven fabric t (mm) is constant during shearing. Then the shear stress is calculated using Eq. (3)

$$\tau = \frac{T}{A} \tag{3}$$

where are: T (N) is a shear force acting on the side DC of the woven fabric element as a result of stress (assuming a uniform distribution of shear stresses on the surface side), A (mm^2) is a surface side DC of woven fabric element.

The connection between the shear angle γ and the shear stress τ is shown by Eq. (4) which represents the Hooke's law of shear and applies for elastic, homogeneous isotropic material in a linear region, i.e. where the relationship between shear stress and shear strain is linear. G (N/mm^2 = MPa) is shear modulus.

$$\tau = G \cdot \gamma \tag{4}$$

For an orthotropic and elastic material when the k- and l-axes do not coincide with the main x- and y-axes of orthotropy, the anisotropic behaviors of materials under loads can be written in matrix form according to Hooke's law [14]:

$$\begin{Bmatrix} \varepsilon_k \\ \varepsilon_l \\ \gamma_{kl} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_k} & -\frac{\nu_{lk}}{E_k} & \alpha_k \\ -\frac{\nu_{kl}}{E_l} & \frac{1}{E_l} & \alpha_l \\ \alpha_k & \alpha_l & \frac{1}{G_{kl}} \end{bmatrix} \cdot \begin{Bmatrix} \sigma_k \\ \sigma_l \\ \tau_{kl} \end{Bmatrix} \tag{5}$$

σ_k and σ_l are normal stresses, τ_{kl} is shear stress, ε_k, ε_l is normal strain (relative extension strain), γ_{kl} is shear strain (relative angle strain), E_k, E_l is modulus of elasticity, G_{kl} is shear modulus, α_k, α_l are elasticity coefficients, ν_{kl}, ν_{lk} is Poisson's ratio for arbitrary coordinate system k, l.

2.1. Shear modulus of woven fabrics

The functional relationship between stress and strain cannot be determined theoretically, but only by experimental tests of samples made of certain materials. Mechanical properties are mainly investigated within the area of elasticity which means in terms of low load [16]. Diagrams of shearing and diagrams of extension have a similar shape. It is assumed that force- shear angle curve of the woven fabric is an approximate straight line before the yield point. Therefore, elastic performance equation can be applied here. Shear modulus is the initial, linear elastic slope of the stress-strain curve in shear. It is the numerical constant that describes the elastic properties of a woven fabric under the application of shear forces. For orthotropic elastic materials, shear modulus G_{kl}, in various directions of cutting samples, i.e. in the coordinate system k, l whose axes do not coincide with the main axes x, y is obtained by using the expression for the transformation of the elastic constants, which states [14]:

$$\frac{1}{G_{kl}}=\left(\frac{1}{E_x}+\frac{1}{E_y}+\frac{2\cdot\nu_{xy}}{E_x}\right)\cdot 4\cos^2\varphi\cdot\sin^2\varphi+\frac{1}{G_{xy}}\cdot\left(\cos^2\varphi-\sin^2\varphi\right)^2=\frac{1}{G_\varphi} \quad (6)$$

φ is the cutting angle of the samples due to the weft (Fig. 1), E_x, E_y is the modulus of elasticity in two main directions (weft direction φ=0°, warp direction φ=90°); G_{xy} is the shear modulus between both principal directions; ν_{xy} is the Poisson's ratio. Shear modulus G_{kl} changes depending on the angle φ, and will be denoted as $G_\varphi=G_{kl}$.

Shear modulus G_φ in any given direction can be calculated by Eq. (6). The numerical values of E_x, E_y, G_{xy}, ν_{xy} are obtained by experimental tests of woven fabric samples in the laboratory. In standard conditions the value of ν_{xy} is very difficult to determine by experimental measurements. The theoretical treatment suggests that measurements of the modulus in two directions (weft and warp direction) are insufficient to define the shear modulus of a woven fabric. An investigation of the third direction is therefore necessary, and the most convenient direction is φ=45°. Therefore, measurements were carried out in three directions by considering samples cut along the warp, weft, and 45° directions. Therefore, when considering φ=45° values, Eq. (6) gives:

$$\frac{2\cdot\nu_{xy}}{E_x}=\frac{1}{G_{45^0}}-\frac{1}{E_x}-\frac{1}{E_y} \quad (7)$$

Substituting Eq. (7) into Eq. (6), we get

$$\frac{1}{G_\varphi}=\left(\frac{4}{G_{45^0}}\right)\cos^2\varphi\,\sin^2\varphi+\frac{1}{G}\left(\cos^2\varphi-\sin^2\varphi\right)^2 \quad (8)$$

Thus, woven fabric shear modulus in various directions can be predicted from Eq. (8) when its values in the warp or weft directions and under the angle of 45° are measured. Because shear modulus provides a measure of the resistance to rotational movements between the warp and weft yarns at the intersecting points when the woven fabric is subjected to small shear deformation, the relationship between both principal directions should be determined. However, if differences in the shear modulus values between the warp and weft directions are large, we take the average value in both principal directions to calculate the shear modulus in various directions given in Eq. (8). Eq. (8) indicates the mathematical relation between shear modulus G_φ in any given direction and values of G and $G_{45°}$.

3. Experimental testing

In the experimental part of the paper, the impact of anisotropy of woven fabrics and the impact of different types of weaves on shear properties were tested. The experimental study of shear properties of the woven fabric when shear force acts on the samples that are cut at different angles 0°, 15°, 30°, 45°, 60°, 75°, 90° in the direction of the weft was conducted. The values of the shear force in relation to the shear angle were measured, as well as breaking force and shear angle at break. Based on the experimentally obtained values, the initial shear modulus was calculated in various directions.

3.1. Test samples and the apparatus

To carry out this study, three cotton woven fabrics of different types of weaves (plain weave, twill and sateen) were available. Structural properties of the tested woven fabrics are shown in Table 1. Standard ISO 5084:1996 describes a method for the determination of the thickness of fabric.

Table 1 – Description of woven fabric

Fabric structure	Yarn fibers	Yarn count (tex)		Yarn density (cm^{-1})		Mass (g/m^2)	Thickness (mm)
		warp	weft	warp	weft		
Plain	Cotton	30	30	24	24	151	0.39
Twill	Cotton	30	30	24	24	150	0.39
Sateen	Cotton	30	30	24	24	148	0.38

Before testing all samples were conditioned under standard atmospheric conditions (relative humidity 65 ± 2%, temperature of 20 ± 2 ° C). Five tests were carried out on the tensile tester for each mentioned cutting direction of the specimen (0°, 15°, 30°, 45°, 60°, 75°, 90°), Fig. 3. For each cutting direction, the average values obtained from five measurements will be shown in diagrams and will be used to calculate the initial shear modulus.

To determine shear properties of the fabric, the clamps for shearing woven fabrics were designed, manufactured and schematically shown in Fig. 4a, and consist of the left (fixed) clamp and the right (movable) clamp. The force acting on the right clamp causes its vertical displacement. The left clamp is placed on the upper plate on which there is a measuring probe, and the right clamp to the lower plate on

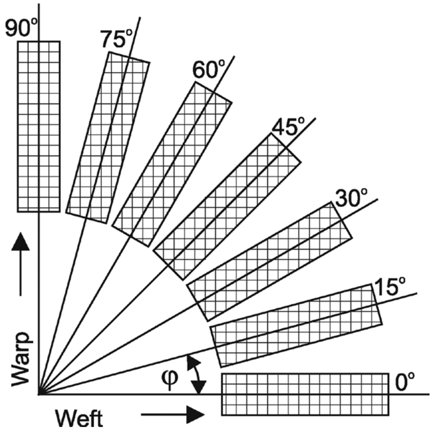
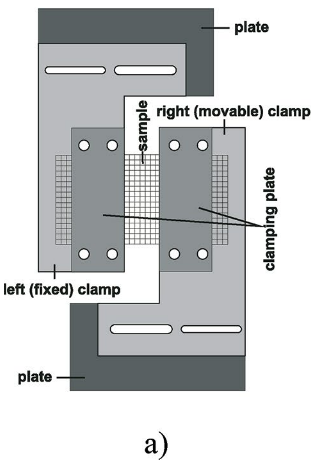


Fig. 3 – Schematic view of directions (angles) of cutting specimens

which the movable clamp is usually placed. The distance between the left and right clamp can be adjusted in a range from 0-50 mm. The maximum specimen size that can be fixed within the clamp is 75 mm.

For this testing, specimens were cut with dimensions 125 x 50 mm, fastened in the clamps of the instrument at a distance of b=50 mm, and subjected to the force acting in the plane of the fixed side of specimen till rupture (Fig. 4b). Sample dimensions are: a=50 mm and b=50 mm.



a) b)

Fig. 4 – Sample testing in the clamps: (a) schematic view, (b) photo

A tensile tester Statimat M of the German manufacturer "Textechno" was used for testing. This tensile tester is an automatic, microprocessor-controlled instrument operating on the principle of the constant deformation speed. Two parallel clamps at a distance of 25 mm are fixed on the tensile tester and the pulling speed of the right clamp is 100 mm/min. The action of an external force T causes the shearing of right fixed side of the specimen in relation to the left side for δ. Forces in parallel clamps causing the shear condition in the plane of the woven fabric specimen, whereby the state of deformation in the woven fabric are uniform. In this study the value of the pulling forces T in the right clamps and its corresponding vertical displacements δ were measured. The angle between the warp and weft yarns change and this leads to the appearance of shear strain in the woven fabric specimen.

4. Overview of test results and discussion

The Microsoft Excel software was used for statistical analysis of data at $p<0.05$ for five measurements. The diagrams (T- δ) of the average values of test results of force action T and the corresponding vertical displacements δ until breakage of samples that are cut at different angles to the direction of the weft are shown in Figures 5-7.

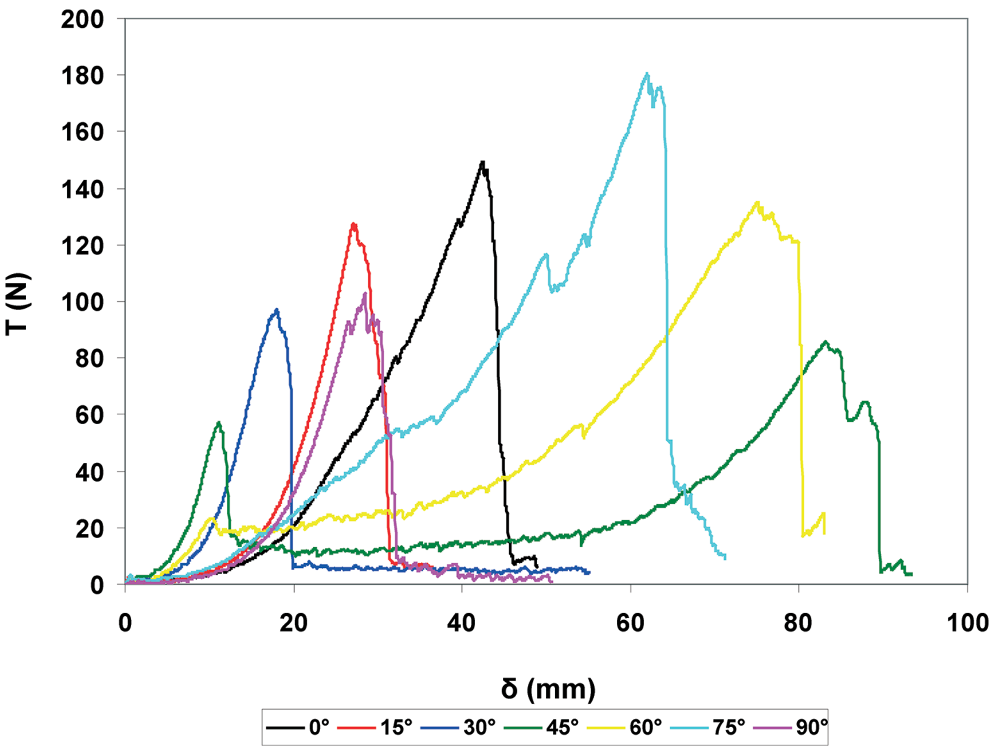


Fig. 5 – Diagram T- δ (force- vertical displacement) for plain weave

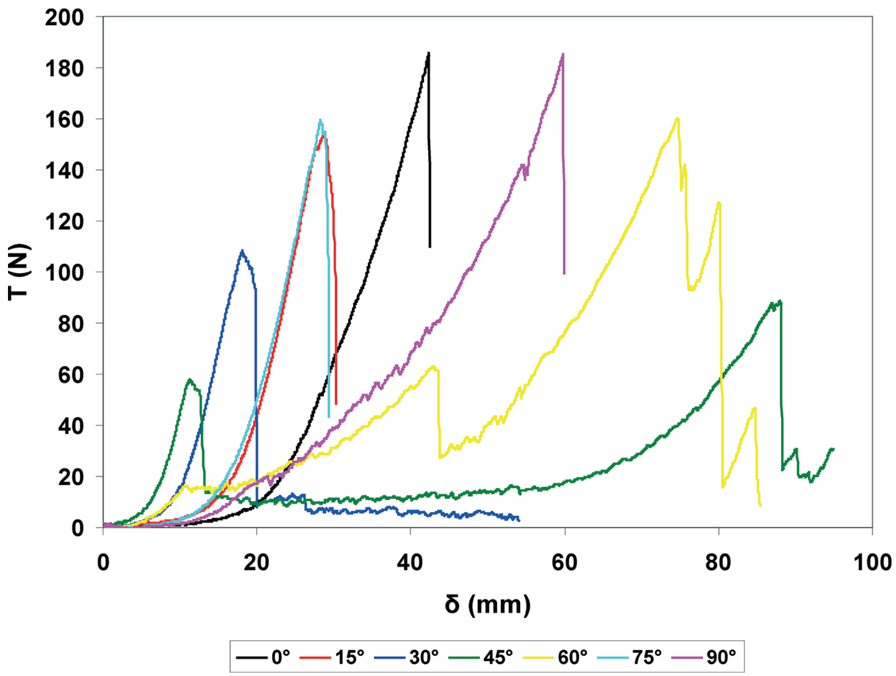


Fig. 6 – Diagram T- δ (force- vertical displacement) for twill weave

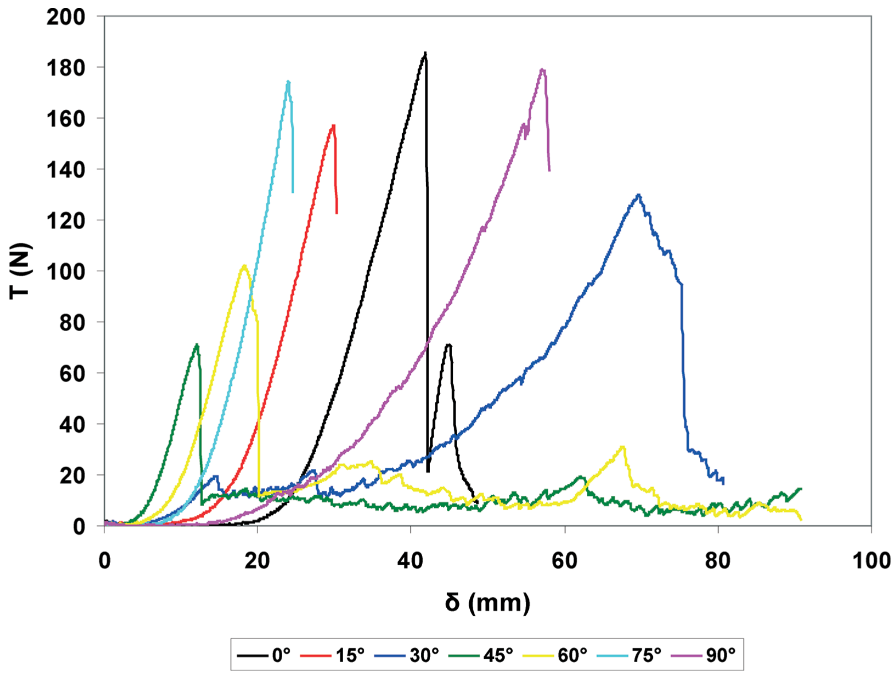


Fig. 7 – Diagram T- δ (force- vertical displacement) for sateen weave

Based on the diagrams of the measured values of force T and corresponding vertical displacement δ from Figures 5-7, the average values of the shear angle γ and the corresponding shear stress τ were calculated using Eq. (2) and Eq. (3). These values are shown in the diagrams in Figures 8-10, up to the value of the shear angle γ = 8°. The surface on which τ acts is A= t·a (mm^2). The related average values of breaking shear force $T_φ$ (N) and shear angles at break $γ_φ$ (rad) are given in Table 2 in all directions of cutting samples in plain, twill and sateen weave.

Table 2 – Average values of breaking shear force $T_φ$ corresponding shear angle at break $γ_φ$

φ(°)	Plain		Twill		Sateen	
	$γ_φ$ (rad)	$T_φ$ (N)	$γ_φ$ (rad)	$T_φ$ (N)	$γ_φ$ (rad)	$T_φ$ (N)
0	0.85	149.5	0.85	185.9	0.84	185.8
15	0.54	127.5	0.57	153.6	0.60	157.4
30	0.36	97.2	0.36	108.4	1.39	129.9
45	1.66	85.6	1.76	88.9	0.24	71.2
60	1.50	135.0	1.49	160.7	0.36	102.4
75	1.24	180.5	0.56	160.2	0.48	175.0
90	0.57	102.7	1.20	185.7	1.14	179.5

Shear forces $T_φ$ at break have maximum values for plain weave that were cut at an angle of 75°. Shear forces for twill and sateen weaves had the maximum value for the cutting angle 0°. All weaves reached the minimum value of $T_φ$ at an angle of 45°. Shear angle $γ_φ$ at break had the maximum value for plain and twill weave that were cut at an angle of 45°. For sateen weave, shear angle at break had the maximum value for the cutting angle 30°.

The values of shear forces on the complementary angles and from warp and weft directions varied with shear strain. When the vertical displacement or shear strain was very small, the values of shear forces from the warp and weft directions were very close. This also applied to the values of shear force for complementary angles However, at the later stage, the difference between above mentioned values increased when the strain increased.

During the woven fabric shearing, buckling in the woven fabric specimen occurred at a certain shear angle. According to Kawabata [17] woven fabric specimens which are subjected to the shear after exceeding the value of the shear angle γ = 8° tend to buckle. Shear angle γ = 8° corresponds to a vertical displacement of δ=6.98 mm. This value specifies the limit of in plane deformation after which a sample begins its out of plane deformation and it is called buckling zone. The appearance of buckling causes errors in the measurement results. The shear stress and shear angle curve up to the value of $\gamma = 8°$ (until the beginning of buckling during the shear) is shown in Figures 8-10.

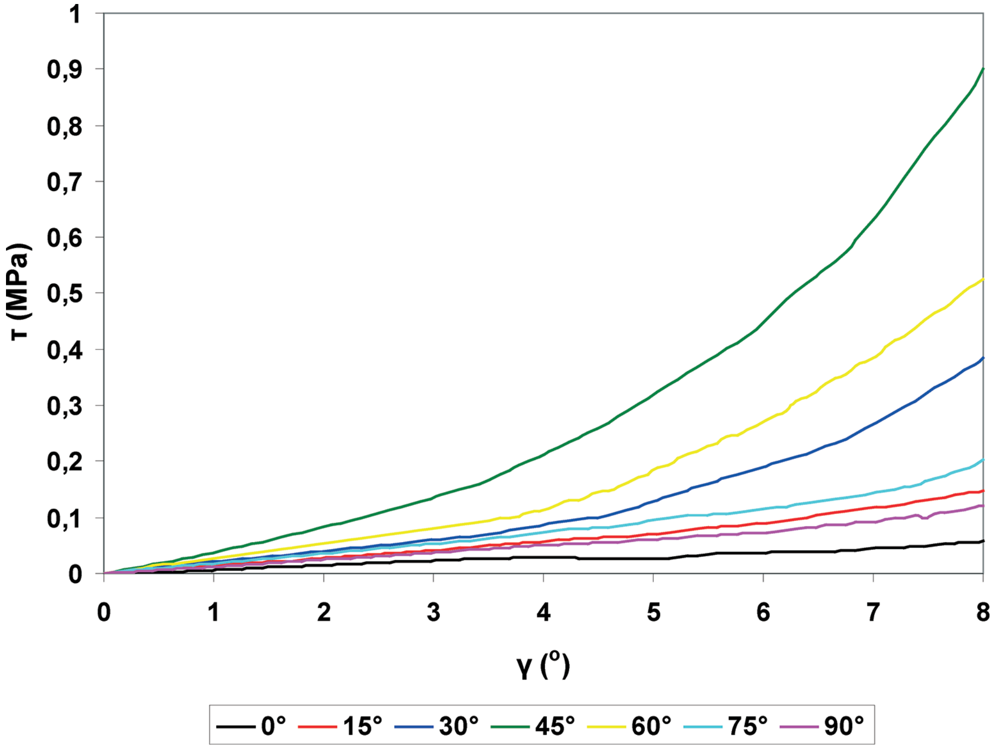


Fig. 8 – Diagram τ-γ (shear stress–shear angle) for plain weave

In Figures 8-10, at the same shear angle the highest value of shear stress τ appears in the samples which have been cut at angle of 45°. The values of shear stresses τ are very similar for complementary angles of the cutting samples. Shear stress τ takes on the minimum values for warp and weft directions. For samples that are cut in weft and warp directions at a very small increment of shear stress, values of shear angle are greatly increasing. Shear stress in relation to the shear angle has the highest increase at an angle of 45°. This applies only to area in which there is no buckling of woven fabric. When the fabric sample is subjected to the deformation imposed by pure shear test, in the initial stage, warp and weft yarns are perpendicular to each other, and the rotation relative to each other is limited by internal friction between the warp and weft. By contrast, in the later stage, the fabric structure changes from orthotropic to skewed structure, where the warp and weft yarns are no longer perpendicular to each other. The difference between warp and weft increases more and more as shear angle (shear strain) increases.

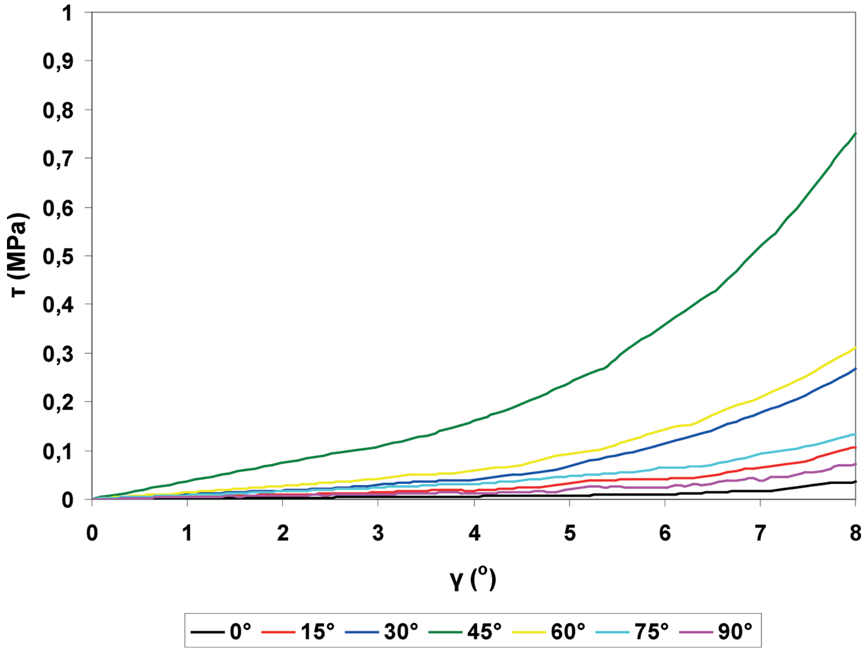


Fig. 9 – Diagram τ-γ (shear stress–shear angle) for twill weave

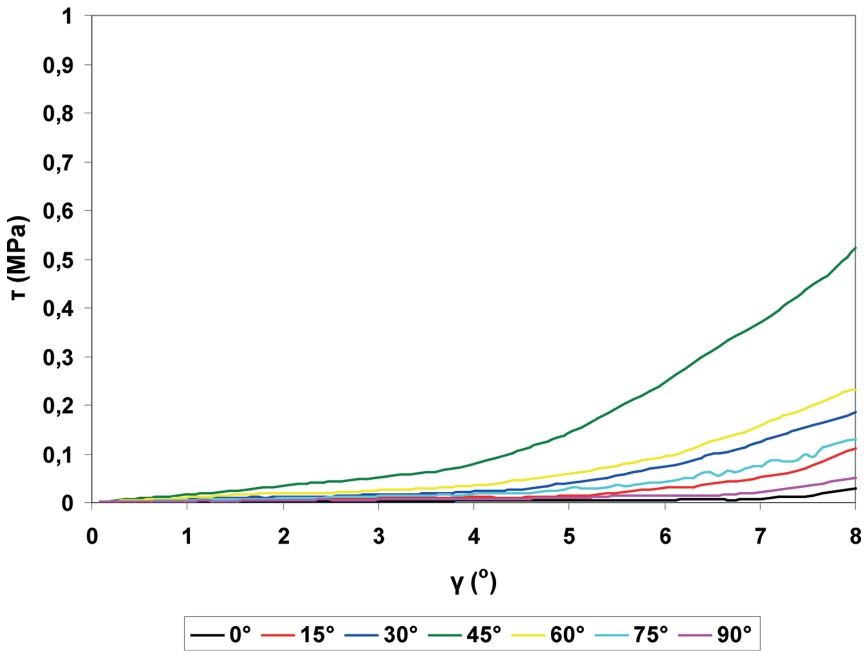


Fig. 10 – Diagram τ-γ (shear stress–shear angle) for sateen weave

5. Determining the initial shear modulus

Based on the experimentally obtained force-shear angles curves, the values of initial shear modulus were obtained and compared with the corresponding calculated values. Deviation in percentage between experimental and calculated values of initial shear modulus will also be calculated.

5.1. Experimental values of the initial shear modulus

From the presented diagrams, in Figures 5-7, the values of shear force in the elastic range are used. We determined shear modulus G_φ from a particular region on force – shear angle curve that is determined by monitoring the experimental data obtained from an experimental set-up with regression control chart [18]. In this area of the curve, the relationship between shear stress and shear strain is linear. The shear modulus G_φ is defined as a slope of its shear stress- shear strain curve (τ- γ) in the elastic deformation region. The Hooke's law for shearing can be applied:

$$G_\varphi = \mathrm{tg}\,\alpha = \frac{\tau}{\gamma} = \frac{T}{\gamma \cdot a \cdot t} (\mathrm{MPa}) \tag{9}$$

where A=a ·t is the area of the sample in which shear force acting.

Using values T and γ in elastic range and using Eq. (9), the average values of initial shear modulus G_φ in relation to an arbitrary direction of cutting of the woven fabric samples are calculated. Linear regression equations are placed on the shear stress-shear strain curves in the elastic range. In Figures 8-10, the slope of the curve, i.e. the coefficient of line direction represents the shear modulus G_φ for all samples. The curve τ- γ is shown up to value of the shear angle γ= 8° (0.14 rad). The shape of linear equation is: τ=G γ.

Table 3 – Experimentally obtained values of shear modulus G_φ (MPa)

Sample	$G_{0°}$	$G_{15°}$	$G_{30°}$	$G_{45°}$	$G_{60°}$	$G_{75°}$	$G_{90°}$
Plain	0.46	0.81	1.20	2.44	1.59	1.02	0.73
Twill	0.08	0.26	0.57	1.30	0.84	0.45	0.17
Sateen	0.05	0.15	0.29	1.08	0.45	0.23	0.09

The obtained experimental values of shear modulus G_φ in dependence on the change of the cutting angle of the samples are given in Table 3. The diagram of experimental values G_φ for each 15° is shown in Figure 11.

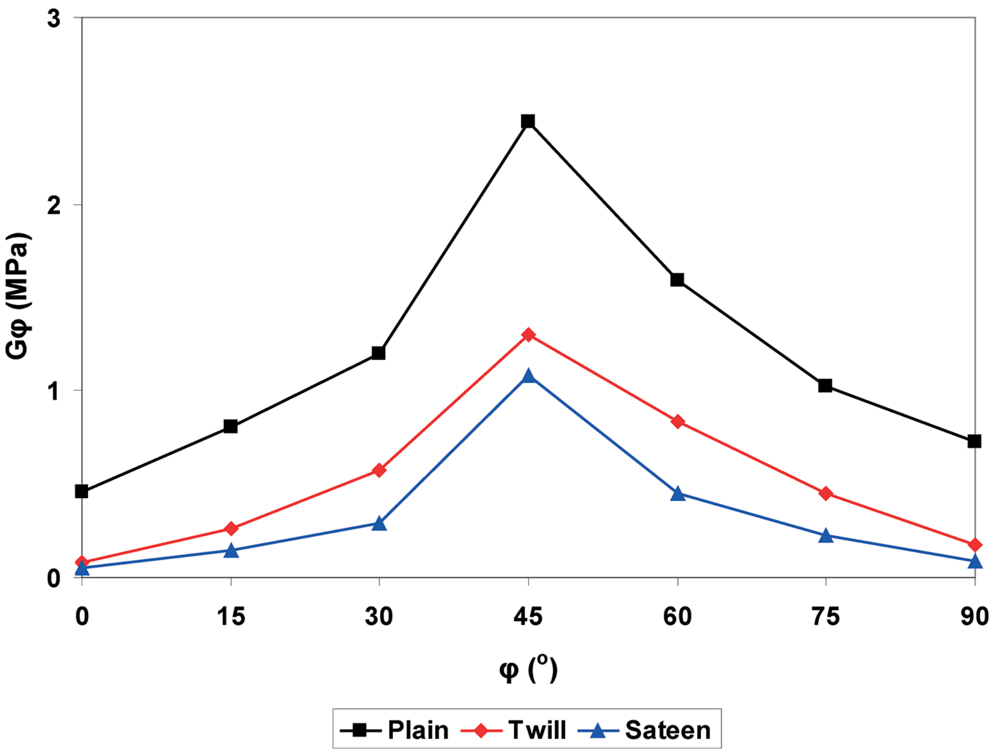


Fig. 11 – Diagram of experimental values of shear modulus G_φ (MPa) for each 15°

The diagram is almost symmetrical curve in relation to the angle of 45°. At that angle G_φ assumes the highest value for all woven fabric samples because initial slope of the stress-strain curve in shear is the biggest at that angle, Figure 8-10. When the samples are cut in the warp direction (φ=90°) and weft direction (φ=0°) shear modulus G_φ have the lowest value for all woven fabric samples because initial slope of the stress-strain curve in shear is the smallest at that angle, Figure 8-10. The values G_φ in the warp and weft direction are almost equal for each woven fabric sample or it is observable that shear modulus G_φ are almost equal for complementary angles.

5.2. Calculation of initial shear modulus in relation to an arbitrarily selected coordinate system

According to Eq. (8) and based on the experimental data $G_{0°}$ or $G_{90°}$ and $G_{45°}$ from Table 3, the values of initial shear modulus G_φ were calculated, depending on the change of the cutting angle of the samples. The calculated values of G_φ for each 15° are shown in Table 4.

Table 4. The theoretically calculated values of initial shear modulus $G_φ$ (MPa)

Sample	$G_{0°}$	$G_{15°}$	$G_{30°}$	$G_{45°}$	$G_{60°}$	$G_{75°}$	$G_{90°}$
Plain	0.46	0.56	1.04	2.44	1.82	0.92	0.73
Twill	0.08	0.10	0.22	1.30	0.85	0.24	0.17
Sateen	0.05	0.07	0.16	1.08	0.38	0.12	0.09

The diagram of their calculated values $G_φ$ (MPa) for each 5° is shown in Figure 12.

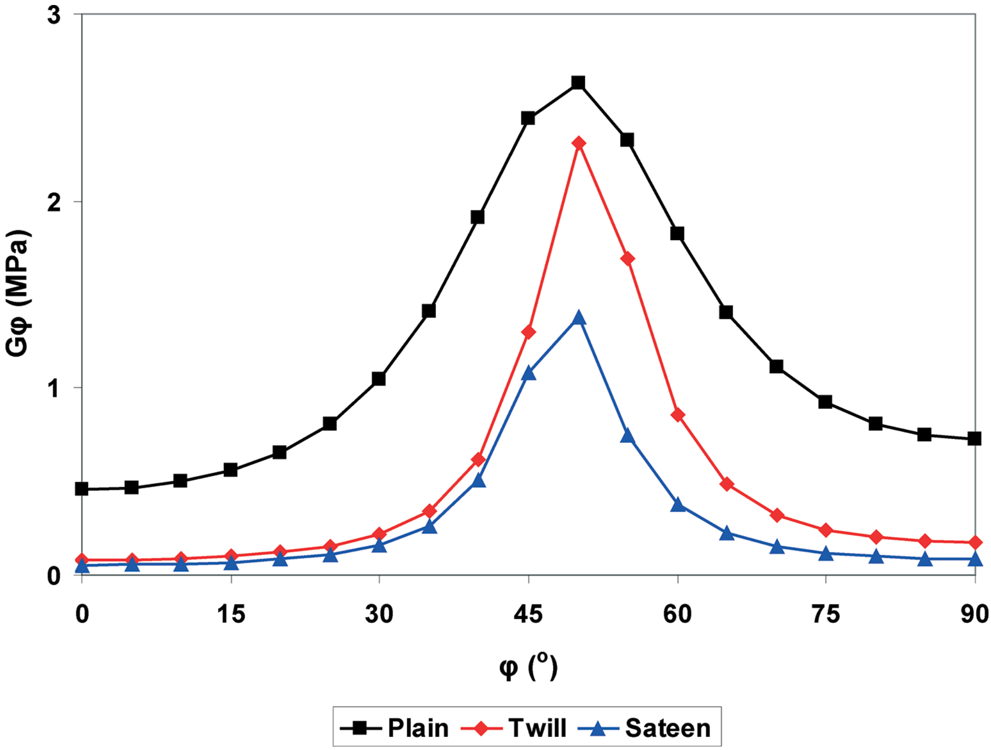


Fig. 12 – Diagram of calculated values of shear modulus $G_φ$ (MPa) for each 5°

Table 5 shows percent deviations between experimental values $G_φ$ in Table 3 and calculated values $G_φ$ in Table 4. Deviations D (%) were calculated using the expression (10):

$$D = \frac{G_{\varphi,\exp} - G_{\varphi,calc}}{G_{\varphi,\exp}} \cdot 100(\%) \tag{10}$$

Table 5 – Percent deviations D (%) between experimental and calculated values G_φ

Sample	0°	15°	30°	45°	60°	75°	90°
Plain	0	31.2	12.8	0	–14.6	10.0	0
Twill	0	62.2	61.8	0	–2.2	46.3	0
Sateen	0	53.8	45.6	0	16.2	47.2	0

In the warp (90°) and weft (0°) directions and under the angle of 45°, percent deviations between the experimental and calculated values of the initial shear modulus G_φ are 0%. It follows from Eq. (8) due to the periodicity of the sine and cosine functions for these values. Negative deviation values show that the obtained calculated values G_φ are higher than the experimental values of G_φ. Absolute values of deviations between the experimental and calculated values of the shear modulus are in a range from 0% to 62.2%. Deviations are maximal for twill weave, but minimal for plain weave.

6. Conclusion

Woven fabrics can be defined as orthotropic materials for which in the linear elastic range of the curve shear stress-shear angle Hooke›s law for anisotropic material behavior in calculating shear modulus when samples of woven fabric are cut in an arbitrary direction can be applied. Shear properties of the woven fabric are determined when shear force acts on woven fabric specimens which are cut at different angles to the weft direction. Due to the anisotropy of woven fabric its shear properties change in various directions. Shear modulus varies depending on the angle φ (cutting direction of the sample). Fundamental differences in shear properties in various directions between different fabrics will be present due to some inherent differences in their physical behavior, their finishes, and perhaps yarn or fiber stiffness, the contact area at the intersecting points of two yarn sets or the fiber packing density in the yarns. Any combination of these factors can confer different shear characteristics and shear modulus on woven fabrics, even when they are made from the same material. The shear modulus G_φ is almost symmetrical to the angle of 45° and the maximum value is reached exactly at that angle. Shear modulus values increase with increasing weft density for any cutting direction of the sample.

For the plain weave of the woven fabric, shear modulus values are from 0.46 MPa to 2.44 MPa. For twill weave shear modulus values are from 0.08 MPa to 1.30 MPa and for sateen weave shear modulus values are the lowest from 0.05 MPa to 1.08 MPa.

A good agreement between experimental results and the calculated values of the initial shear modulus was shown; thus, the theoretical equations can be used with high accuracy to calculate the initial shear modulus of the woven fabric in various directions only for symmetrical weaves. Hence, the balanced orthogonal plain weave fabric was considered. Thus, measurements had to be implemented when shear force acting only on the specimens that were cut in the warp and weft direction and at an angle of 45°. The theoretical equation for initial shear modulus cannot be used for unbalanced weaves such as twill and sateen. The woven fabric was subjected to shear up to $\gamma = 8°$ because after this point woven fabric specimens tended to buckle. The resulting buckling causes errors in measurement results and that requires attention. The woven fabric samples that are cut at an angle of 45° have the highest shear resistance. The lowest shear resistance had samples that were cut in the warp and weft direction. The same values of shear forces in woven fabrics cause the maximum shear deformation when the samples were cut in the warp and weft direction and minimum shear deformation when the samples were cut at an angle of 45°. This applies only to the area in which no buckling of the woven fabric occurred.

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Determination of Wind Loading Patterns and Structural Response of Constructions in Coastal Area of Croatia – Field Full-Scale Experiment

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Abstract: Two prominent characteristic local winds, Bora and Sirocco, are worldwide recognized and researched winds. However, there has been modest research of their effects on structures in Croatia. The Bora wind is characterized as downslope wind and it is known for its gustiness and turbulent characteristics. Both local winds have the similar distribution of mean wind speeds at standard meteorological level (10 m above the ground level) averaged at 10 minutes interval. Key differences of these local winds have been presented in this research with respect to structural dynamics.

Dynamic features of winds are difficult to simulate by numerical or physical models without detailed field investigations. In the presented experimental study simultaneous measurements of wind speed profile and structural response were conducted for the first time in Croatia. The data obtained from meteorological measurements enabled us to perform statistical analysis of wind records, to describe underlying stochastic processes and to highlight differences between stated prominent local winds. The final results of described operations are extrapolated measurements in the spatial and temporal domain. Parallel to this research, the proprietary numerical model was developed which enables the input of enhanced wind series as an additional layer of validation via an independent data set.

Keywords: full scale field experiment, profile wind speed and direction measurements, structural response, numerical model

Introduction

Due to a specific geolocation and terrain morphology, the Croatian wind climate is very diverse and complex. Dominant local winds in Croatia are identified according to their genesis. Extensive research was done on meteorological aspects of local winds in Croatia (Stiperski et al., 2012, Horvath et al. 2009). However, their effects on constructions are not well investigated. The local wind Bora is worldwide known due to similarity with other downslope types of wind. The first international research campaign on the Bora was done by a delegation of Japanese scientists, which resulted in the publication Yoshino, 1976.

A full-scale field experiment was performed to gain insight into wind loading of constructions in Croatia. The location of the test was the hill Bobani, near the city of Split. The site was suitable for examining properties of winds Bora and Sirocco, as it was unobstructed in both directions. The experiment was conducted as a part of scientific projects “Dynamic wind loading of constructions” and “Reliability of structures and risk estimation under extreme loading” (lead researcher is the author, B. Peros) (Bajić, 2005, Barle et al., 2010, Peroš et al. 2011).

Truss antenna tower was used as the case study. The experiment included measurements of a vertical profile of wind speed and direction, and structural response, which was followed by an analysis of the obtained data and the development of the numerical model. All meteorological data was verified using the data from the nearby meteorological station, which is part of the National Hydrometeorological Service.

The described field experiment has been conducted since 2007 with occasional interrupts. This manuscript is based on the data acquired in the period 2007 – 2009 when the longest campaigns of structural response measurements were carried out.

The goals of the described experiment were:
- Development of the database of wind speeds and corresponding structural responses
- Differentiation in effects on constructions of the local Bora and Sirocco winds
- Comparison of the obtained data with the current norms regarding wind loading
- Development of the numerical model for case study construction, capable of introducing wind loading in the form of field-recorded time series
- Examination of the dynamic structural response of the investigated structure under realistic wind loading
- Validation of the numerical model based on structural response records

The behavior of the free-standing lattice tower under environmental wind loading was previously presented in the papers by Glanville and Kwok, 1997 and Holmes, 1996. Their primary interest was to define the structural behavior concerning displacements in the wind direction. A more modern approach to full-scale environmental wind loading experiments is found in papers concerning structural health monitoring – mainly wind turbines (Wei-Hua et al. 2016). Recent experimental studies have been tackling problems using air tunnels (Hermon, 2015). Several experimental studies are combating problem of fatigue in construction with dominant wind loading (Barle et al., 2011).

Materials and methods

The field experiment was conducted on location "Bobani", municipality Klis, just near the city of Split. The testing site is a leased active communication antenna tower. The antenna tower is used both as the carrier of the meteorological equipment and as case study and the field laboratory was set in an adjoined shed, which was originally used as storage for communication equipment. The geographic location of the site is 43°35›40» N, 16°26›43» E with an absolute height of 520 meters above sea level (Picture 1). This location was chosen because of two main reasons. Firstly, the position comforts to World Meteorological Organization rules for meteorological measurement station, which states that the surrounding of the station should remain relatively unchanged during the duration of measurements. The data obtained from this kind of measurement stations are consistent in time and can be used in the stationary stochastic analysis.

Another reason for the selection of this location is similar terrain roughness for two dominant wind directions, usually connected to the prominent local Bora and Sirocco winds. There are also no significant differences in the terrain orography. The terrain surrounding antenna tower has low height vegetation, characterized by Davenport with surface roughness of 0.1 m. The stated classification is further verified from calculations done on measurements of wind speed profile. Using the recorded data, the surface roughness was estimated to 0.051m.

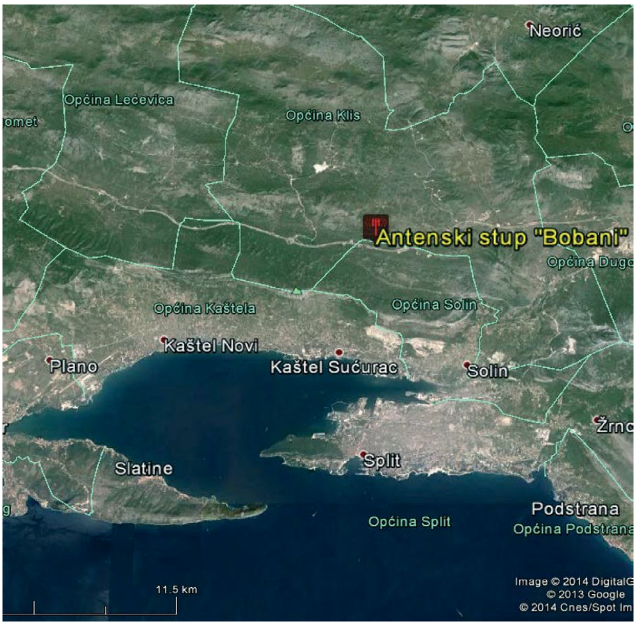

Fig. 1 – Location of field experiment

Fig. 2 – Antenna lattice tower with cantilever beams with meteorological instruments

The onsite antenna tower was a suitable case study for this type of experiment. High and slender spatial lattices are very susceptible to dynamic loading of wind. There were many documented cases of their collapse under strong winds over the world and in Croatia as well. The wind loading coefficients for inclined cylindrical shapes are well researched and documented. The construction is a triangular spatial lattice with a variable cross-section. The base width of the tower is 3.2 m and the top has a width of 1.2m. The total height of the construction is 39.2 m. The construction is mainly built from circular bars. The cross-section of the outer chords on lower levels are 114.3/4.5 mm, while the cross-sections of inner chords and outer chords upper level are 88.3/5.0 mm. The construction is built in segments (see Fig. 3) and fastened using endplates and bolts. The construction main material is steel S355.

The construction dynamics are calculated in numerical model SCIA Engineer. This preliminary calculation was used to determine the best position of accelerometers and strain sensors. The final locations of the sensors are shown in Fig. 3.

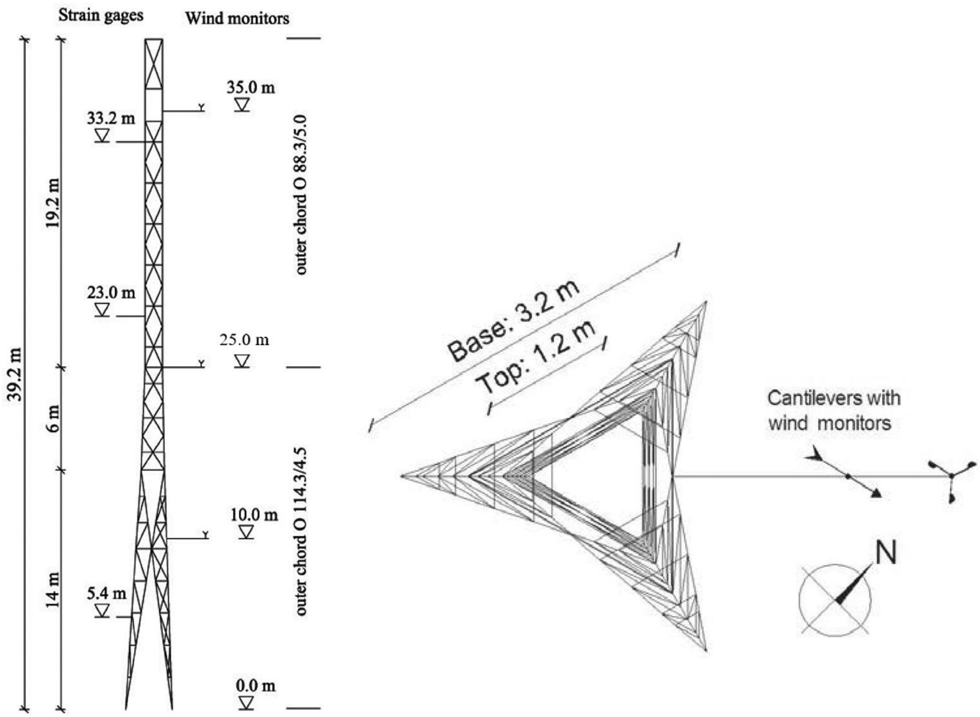

Fig. 3 – Antenna lattice tower plan

Measurement system

The meteorological measurement system was fitted on the target construction. The system consists of three cup anemometers and wind vanes, atmospheric pressure, humidity and temperature sensors and data loggers. Wind speed and direction sensors are positioned on three levels – 10, 25 and 35m above the ground. The data from these sensors are acquired with a sampling frequency of 1 Hz. The characteristics of the sensors are given in Table 1. The field laboratory is shown in Fig. 4.

Table 1 – Sensor characteristics

Type	Wind speed	Wind direction	Atmospheric temperature	Atmospheric humidity	Atmospheric pressure
	umSP 2.2	umDR 2.2	HIGROCLIP S,C,S3,C3	HIGROCLIP S,C,S3,C3	Vaisala PTB 220
Transducer	Cup anemoemter	Wind vane	PT100	ROTRONIC HYGROMER - C94	BAROCAP
Accuracy	0.2 m/s	5°	0.1°C	1%	0.1 hPa
Range	0.2…75 m/s	0°…360°	-40°C…+85°C	0…100%	500…1100hPa
Sampling rate	1 s	2.3 s	0.7s	0.7s	1s
Absolute working temperature	-40°C…+85°C	-40°C…+85°C	-40°C…+85°C	-40°C…+85°C	-40°C…+60°C

The structural response is measured as strains in all three outer chords of the lattice and as accelerations of characteristic points. The stress of the elements is measured on three levels – 5.4 m, 23.0 m and 33.2 m AGL. The accelerations are measured on three levels – 10m, 25m and 35.0m AGL. T-rosette strain gauges are positioned in the middle of the elements and configured in a full-bridge mode for the measurement of axial forces. The sample rate for the structural mesponse was 33 Hz, which was defined from the preliminary calculation of the construction dynamics. Two axial MEMS accelerometers were used, and they were aligned with the horizontal plane. The accelerometer range was 1.7 g. Measurements from both strain gauges and accelerometers were conditioned and digitalized in the field lab. The recording of the data was on the same PC used for meteorological data.

Antenna towers are very sensitive to lateral displacements, due to nature of mounted communication equipment. The analysis of movement under wind loads was also within the scope of this research.

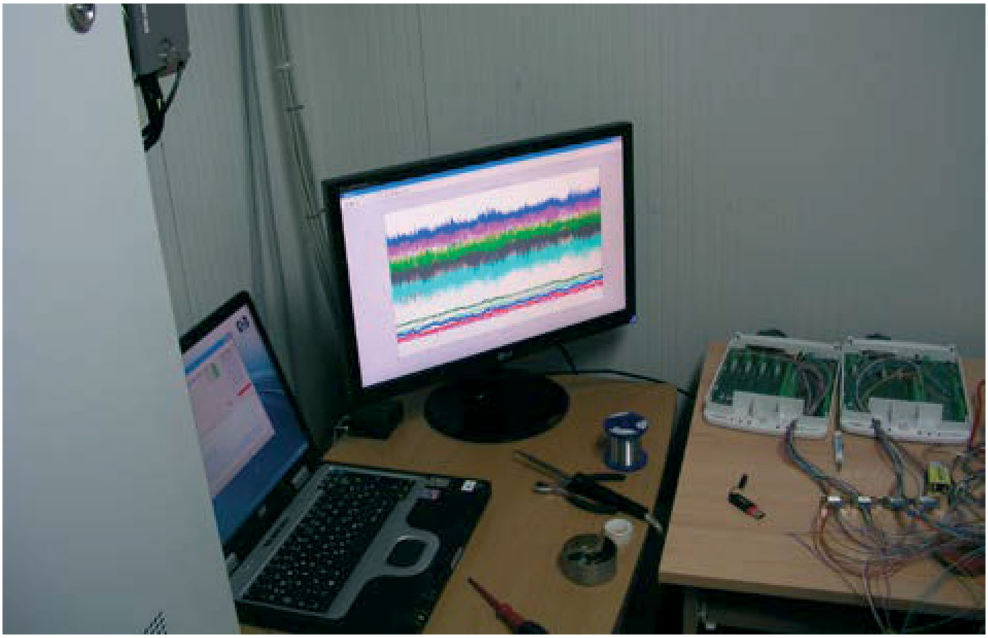

Fig. 4 – Analog to digital converters and PC for logging data

Nevertheless, it was hard to achieve a reliable long-term field measurement of the displacements of characteristic points. Using the spectral domain integration of acceleration data, we were able to estimate displacements, unburdened by drift errors in classical time domain integration (Divic, 2014).

Results and discussion

Wind speed and direction analysis were performed in 10-minute time intervals, by implementation of Reynolds decomposition into mean and fluctuating component. The 10-minute segments are continuous and non-overlapped to ensure the equal significance of every wind event. The described time segments were sorted considering the mean direction of wind speed. The sorted dataset consists of 1,248 records of the Bora wind and 1,053 records of the Sirocco wind.

A general overview of wind currents at the testing location is presented by wind rose graph of mean wind speed shown in Fig. 5. The dominant local winds are Bora (generally blowing from NE direction) and Sirocco (usually blowing from SE direction). Frequent, but not so intensive is Levante wind from E direction. From wind rose graph it is observable that Sirocco is a more frequent wind while Bora has higher peak values of speed.

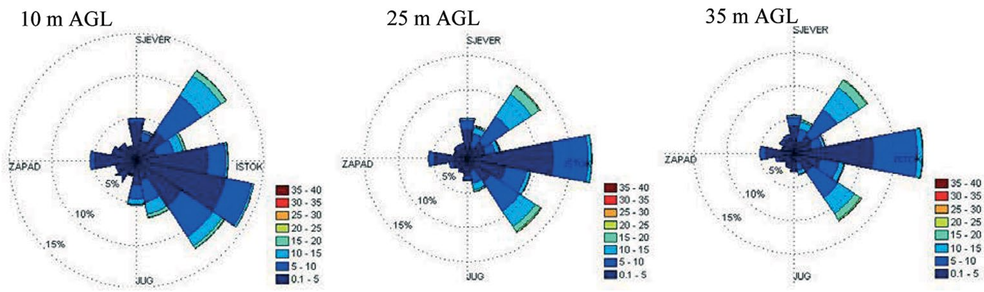

Fig. 5 – Wind roses

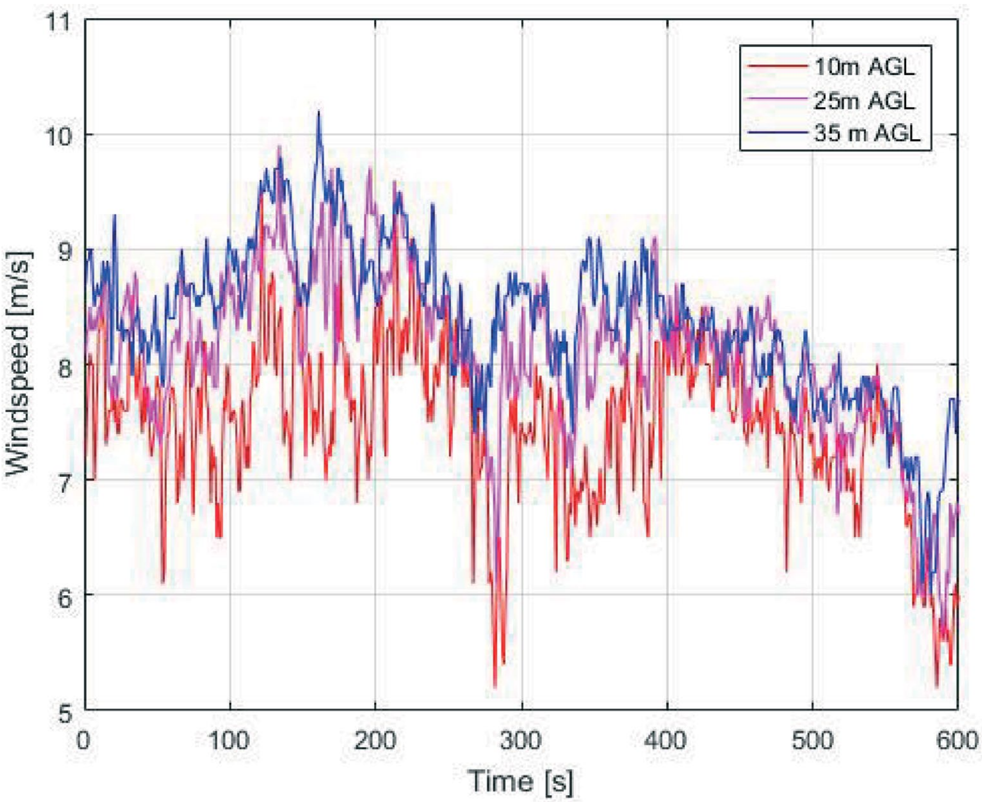

Fig. 6 – Time series of wind speed

The measured wind speed is decomposed into mean wind velocity U and wind speed fluctuation u by Reynolds decomposition.

To describe the mean vertical wind profile from measurements, the logarithmic law was used. It states that the distribution of mean wind speed is governed by Equation (1).

$$U(h) = U_{10}\left(\frac{h}{10}\right)^{\alpha}$$

where U(h) is mean wind speed at level h, U10 is mean wind speed at 10 m A.G.L. and α is the rate of change of wind speed over the height. To retrieve this parameter from measurements, a simple method of data fitting is used according to Equation (1). Equation (2) is obtained using the method of least squares.

$$\alpha = \frac{\sum_i \left[\log\left(\frac{U(h)}{U_{10}}\right)\cdot\log\left(\frac{h_i}{h_{10}}\right)\right]}{\sum_i \left[\log\left(\frac{h_i}{h_{10}}\right)\right]^2}$$

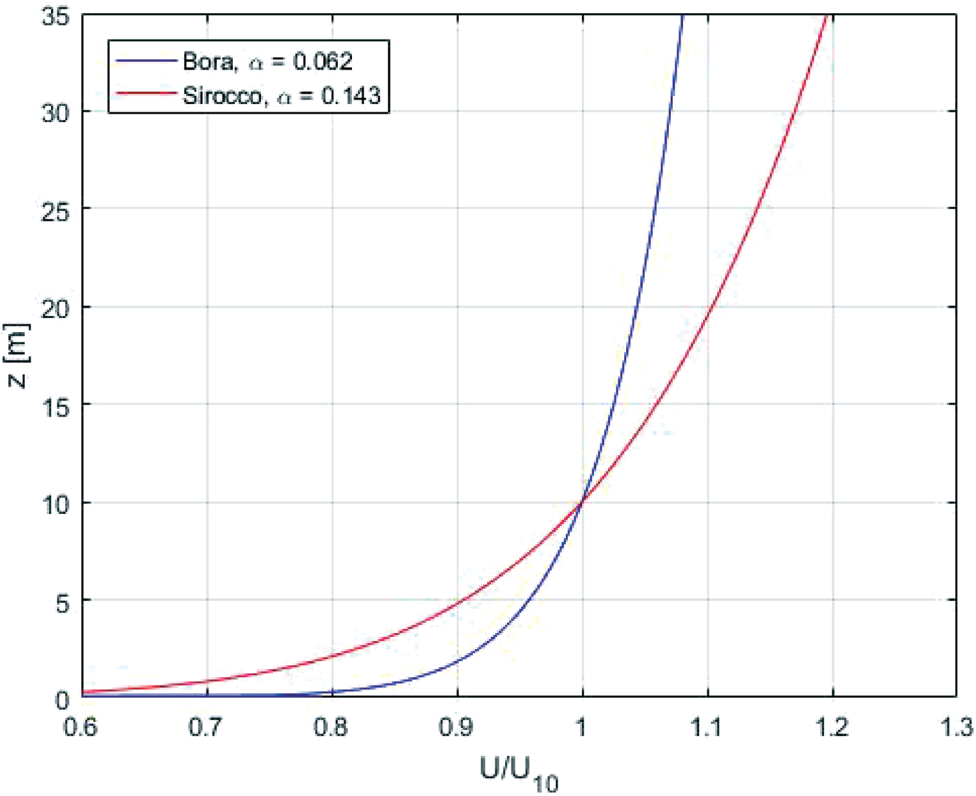

Fig. 7 – Distribution of mean wind speed over the height

The fluctuating component of wind speed obtained from Reynolds decomposition is intrinsically random. Every dataset consists of 600 data points (1 Hz sampling frequency multiplied by 600 seconds duration of the interval). Using statistical tests, the distribution of the fluctuating component is well matched with the normal distribution with null mean and variance obtained from an ensemble. The representative histograms and adjoining normal distributions are shown in Fig. 8.

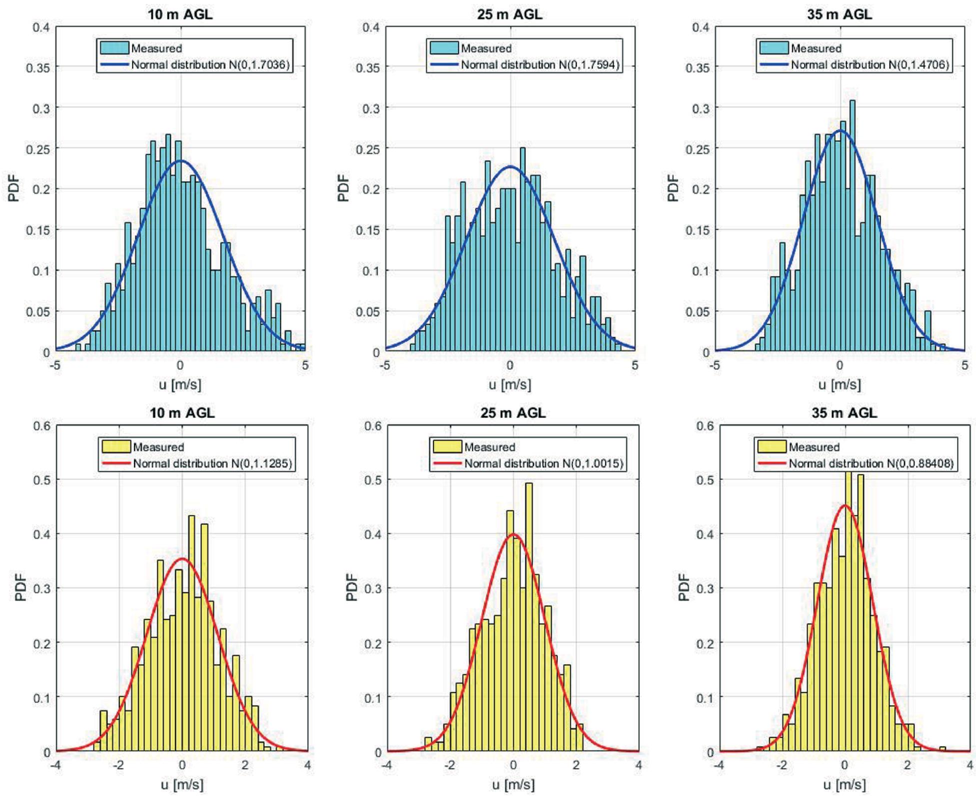

Fig. 8 – Histogram of fluctuating components and corresponding normal distribution

The longitudinal turbulence intensity coefficient is a measure of wind gustiness, and it is defined by Equation (3). The simple equation establishes a linear relationship between mean wind speed and standard deviation of fluctuating wind speed.

$$Iv = \frac{\sigma}{U}$$

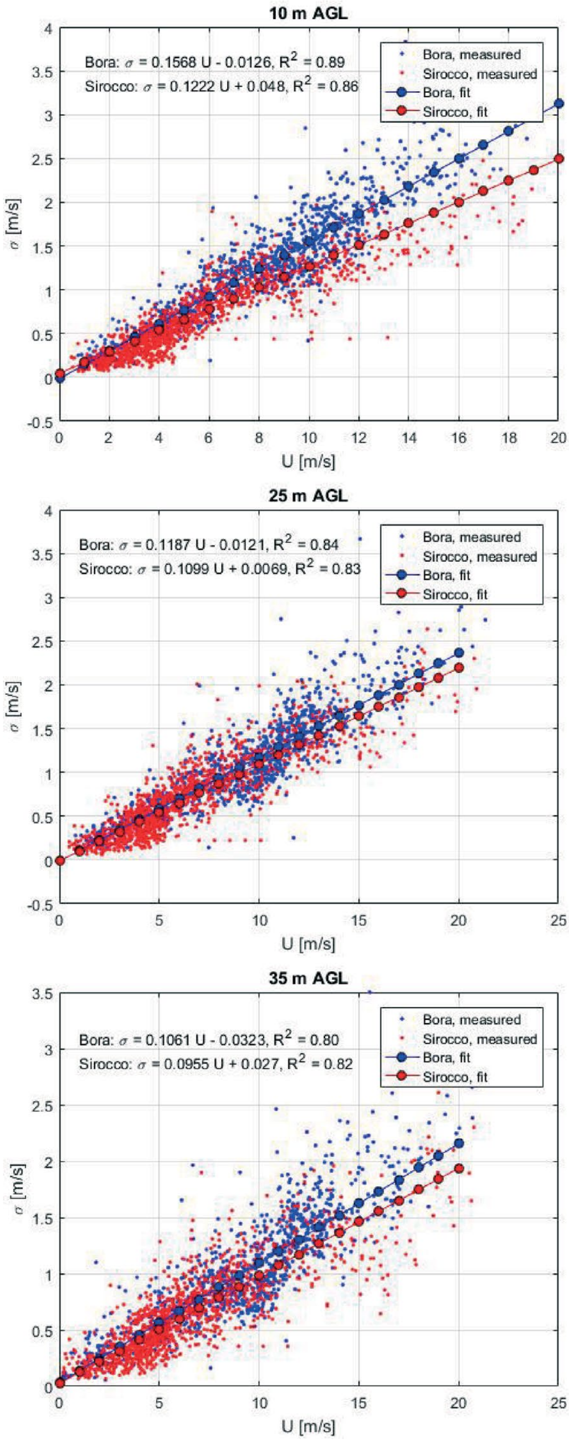

Fig. 9 – Relation on mean wind speed and standard deviation of fluctuating component of wind speed

In Fig. 9 along with graphs equations of the fits are given. The linear fit shows a good correlation between mean speed and standard deviation, with R^2 statistics form 0.80 up to 0.89. The additional component in fit is sufficiently small, which confirms the statement from Equation 3. The coefficient along with U member is the value of turbulence intensity.

The distribution of turbulence intensity over the height is calculated from every measured level (10m, 25m and 35m AGL). As an interpolant between data points, a logarithmic curve is used, which analogue to turbulence intensity approximation is given by Holmes, 2007. The parametric curve is given by Equation (4).

$$Iv(z) = \frac{a}{\ln(b \cdot z)}$$

In Fig. 10 along with the graphs, equation of fit and coefficient of determination R2 are given. Three points are a minimal set of data for two parametric curves to fit; therefore a high-value R2 is required to indicate the relationship. It is observable

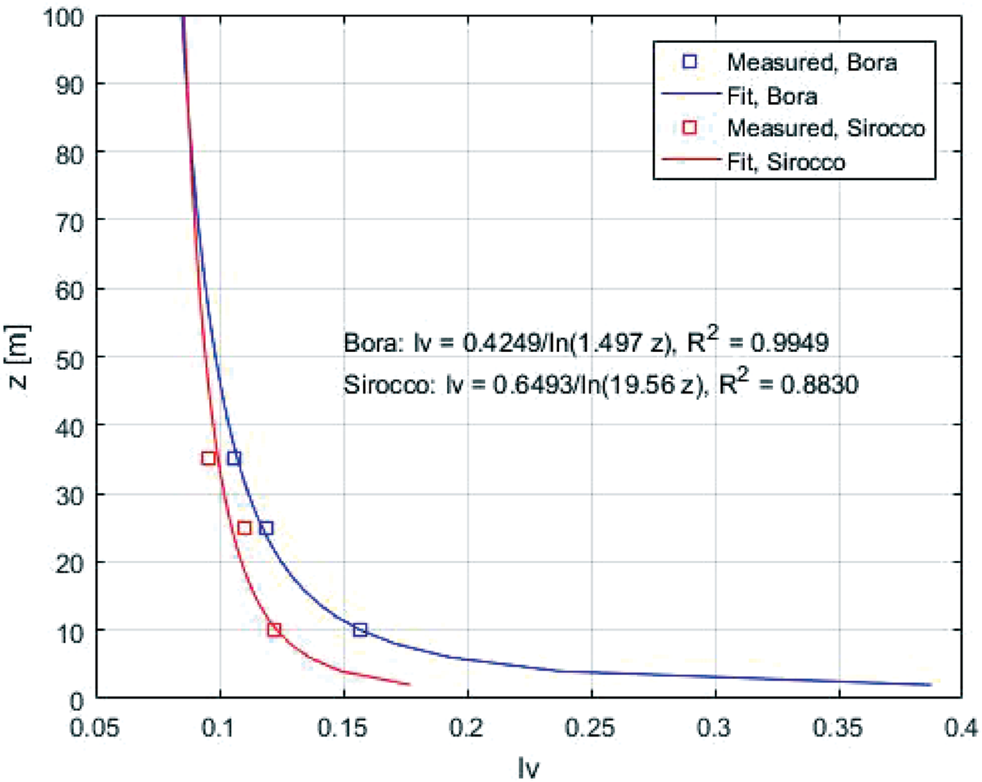

Fig. 10 – Distribution of turbulence intensity over the height

that the Bora wind is more variable than Sirocco, especially in an area below 10 m A.G.L.

Wind power spectra were obtained, and they represent the energy content of wind over frequency. The Fast Fourier Transform was used on the previously described datasets. For each set of data in one group, an analysis was performed, and the resulting power spectra were averaged over the frequency domain. This is shown in Fig. 11 for the Bora and Sirocco case, for three different measurement levels above the ground.

Our dataset was limited by the upper distinguishable frequency band, which was fixed at 0.5Hz defined by Nyquist frequency. To enhance the spectral description of data, a parametric von Karman – Harris spectrum was used. The dimensionless wind spectra by Harris (1990) is defined by Equation (5).

$$\frac{nS_u(n)}{\sigma_u^{\;2}} = \frac{4\left(\dfrac{nl_u}{U}\right)}{\left[1+70.8\left(\dfrac{nl_u}{U}\right)^2\right]^{5/6}}$$

Where f is frequency, $S_u(f)$ power spectra, l_u turbulence length scale and U mean wind speed.

Turbulence length scale is assessed from spectrum function fit. The parametric spectrum fits data sufficiently well, as shown in Fig. 12.

A detailed description of wind data at the location, both in the temporal and spatial domain, enables the generation of precise time series input for the numerical model. Fig. 13 shows an example of these time series. The original recording is denoted as a red line, and the rest of the field is generated using the procedure which was described above.

The structural response is measured as the acceleration of specific points and strain in chord elements. This data is mostly used as the validation of the numerical model for steel lattice constructions and as a method for fatigue assessment (Barle, 2011). Figs. 13 a and b show the acceleration spectra in two orthogonal directions and displacement and strain time-series caused by the typical Bora and Sirocco winds.

The limiting frequency for observing dynamic phenomena is, again, defined by the Nyquist rate, which is for this setup 16.5 Hz. The frequency range is sufficient for this type of construction, since the first natural frequency of the structure is 0.85Hz (observable in the spectra in Figures 13a and 13b) and following ten modes are under 10Hz.

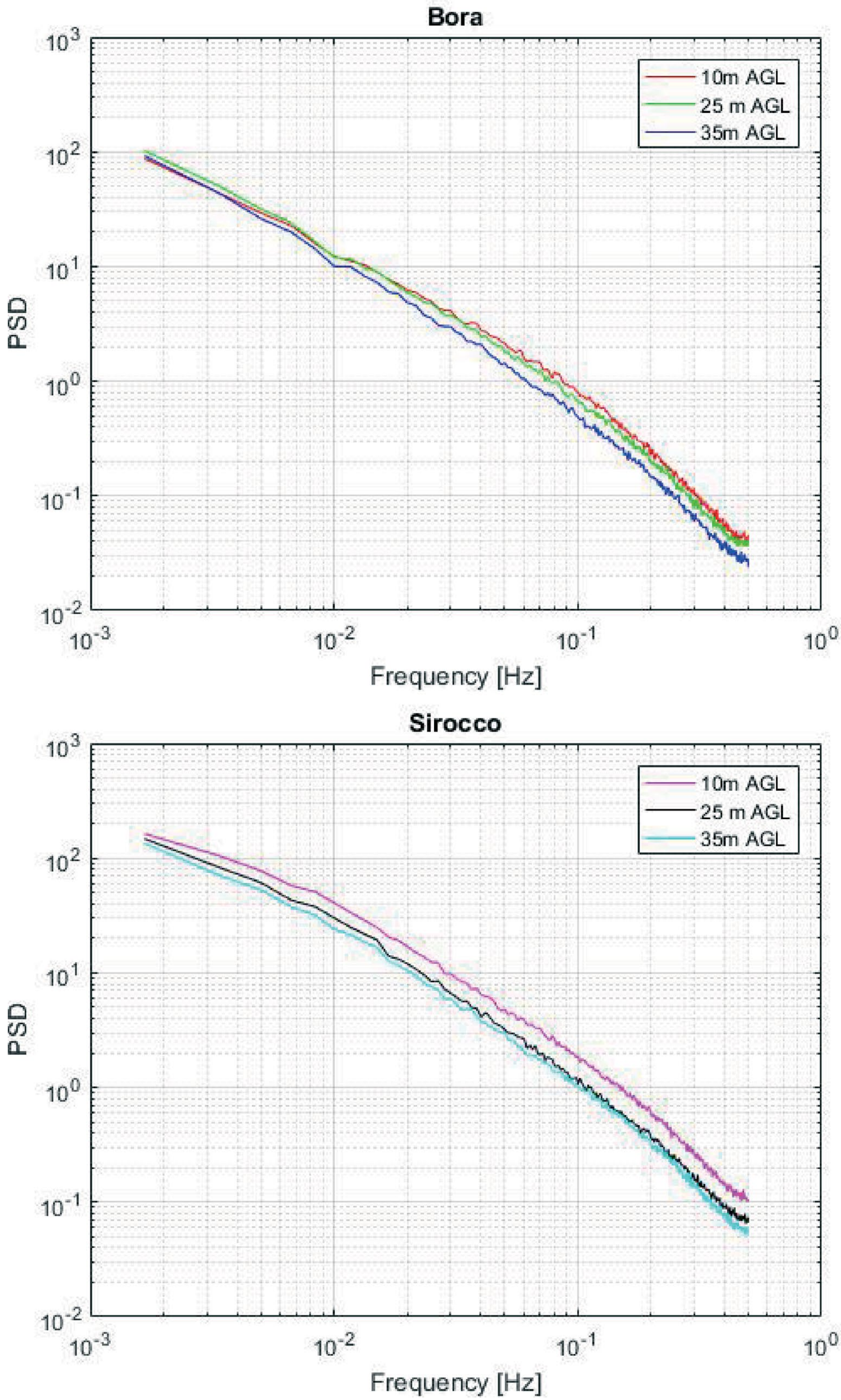

Fig. 11 – Mean spectra for measured wind speeds

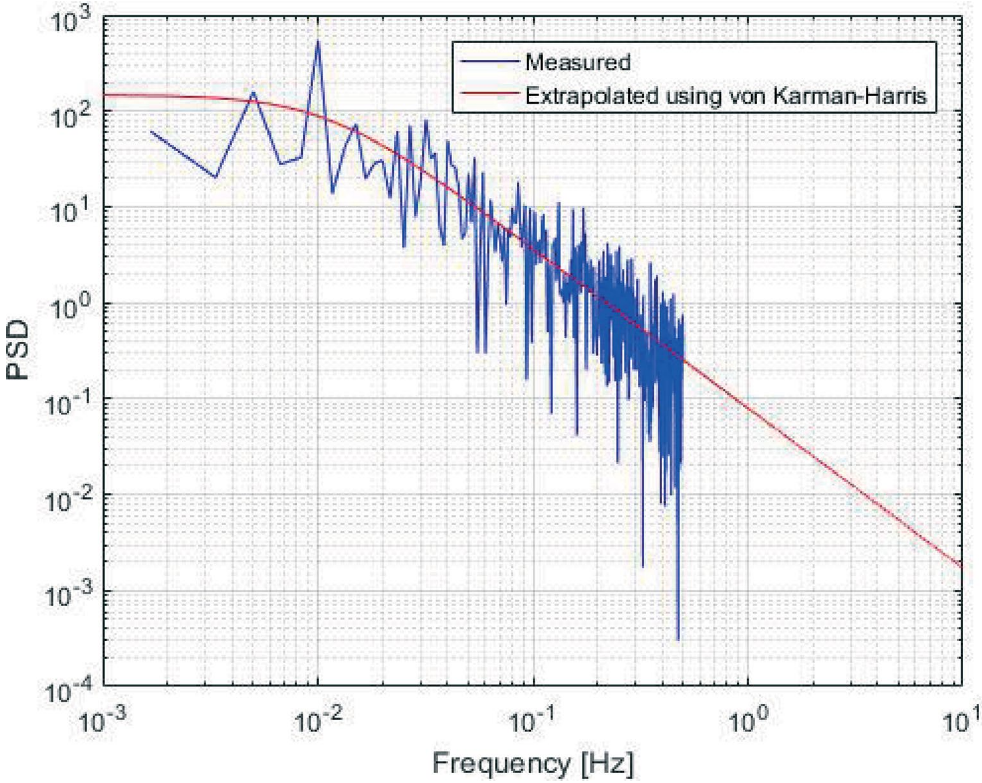

Fig. 12 – Power spectrum from measured data and fitted von Karman – Harris spectrum

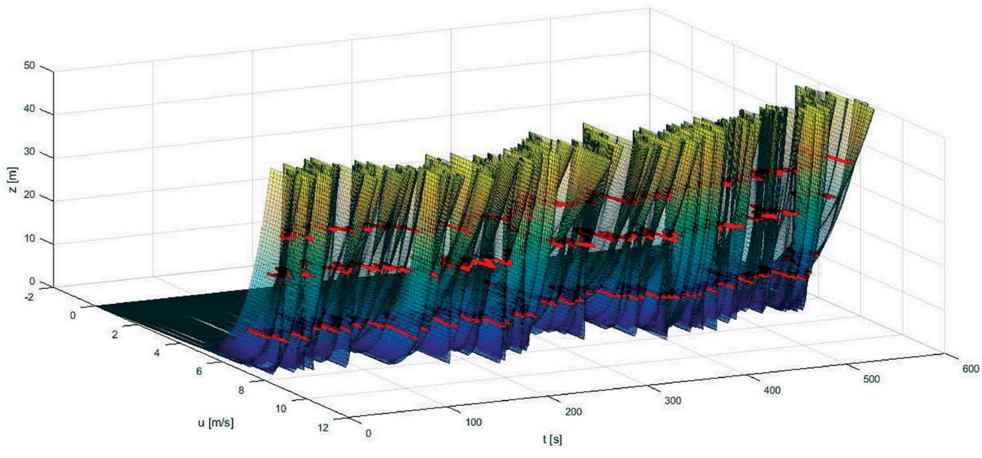

Fig. 13 – Enhanced wind series

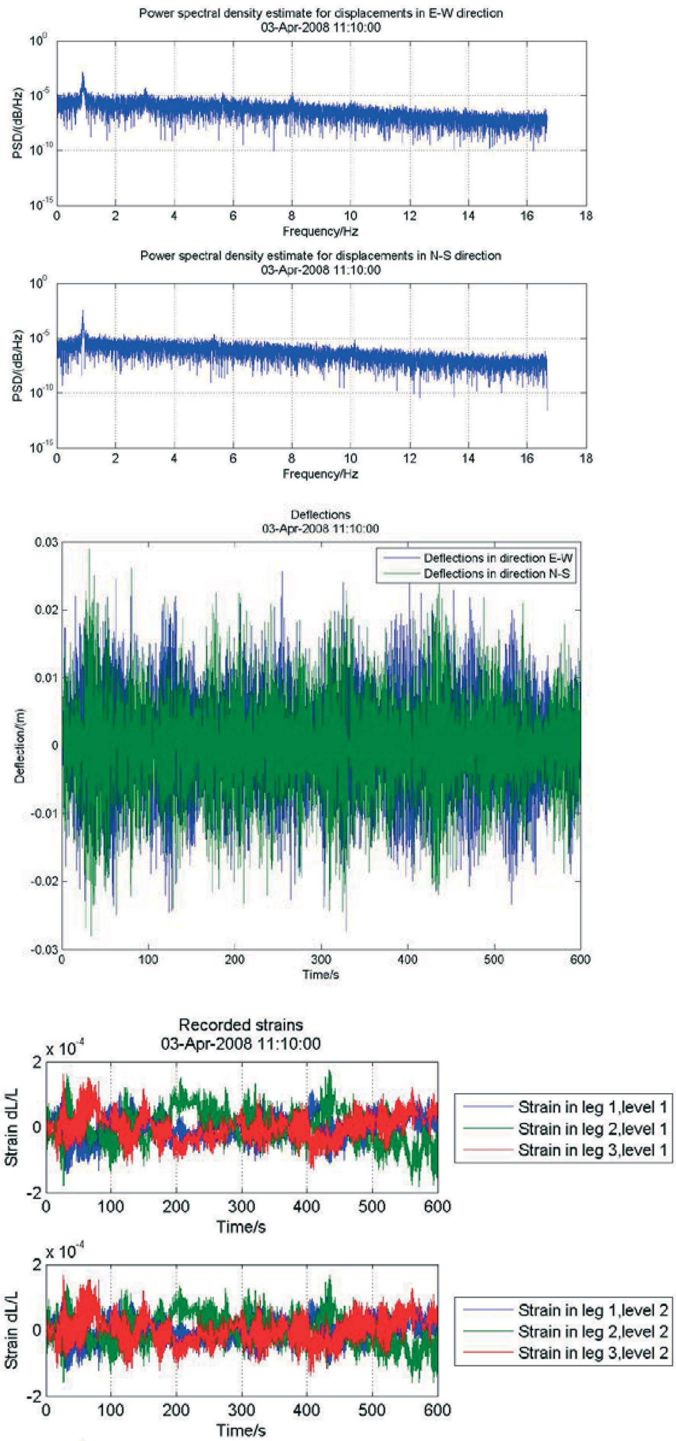

Fig. 13a – Structural response for the Bora

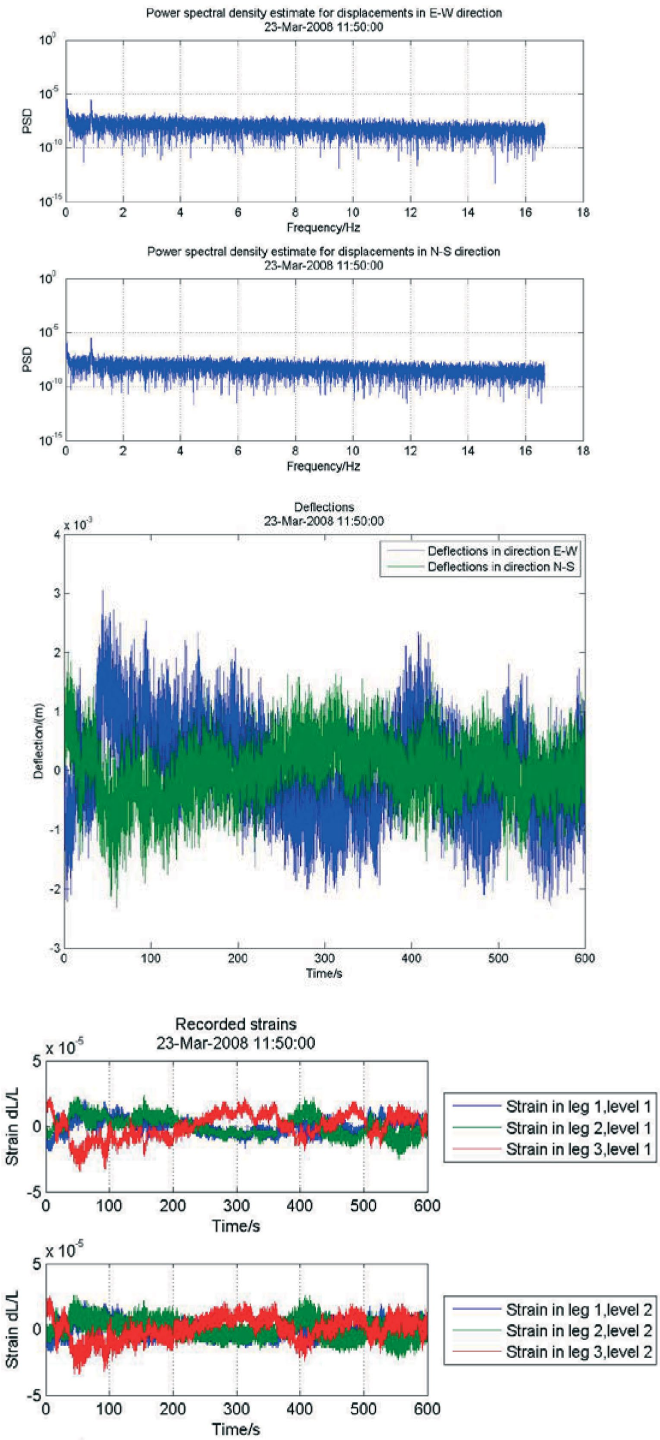

Fig. 13b – Structural response for the Sirocco

Conclusions

This paper presents the first experimental campaign with the aim of investigating differences between the local Bora and Sirocco winds in the context of construction loading. By inspecting wind roses, a similar distribution of wind speeds at 10 m AGL is observable. The distribution of the mean wind speed over the height creates a significantly higher parameter α for the Sirocco wind (0.143) than for the Bora wind (0.062). Due to the formulation of this vertical profile, both distributions have the same values at a height of 10m AGL. The higher coefficient for the Sirocco means a higher mean speed for heights above 10 m AGL, hence the Bora wind has a higher wind speed below 10m AGL.

The fluctuating component is also described over the height. The Bora wind has higher values of variability concerning the mean wind speed than the Sirocco, especially in the area below 10 m AGL. At a height of 10m ALG, the turbulence intensity for the Bora is 0.156 and for the Sirocco is 0.122. An added variability increases the chance of high wind speeds for the Bora in the height domain 0 – 10m.

Spectral analysis of data sets showed a finer structure in time-series patterns. It is usable for data interpolation in combination with parametric von Karman – Harris spectrum. The reconstruction into time domain is possible via inverse Fourier Transform. As Fig. 13 shows, all this information combined creates more detailed spatial and temporal data. This data can be used either to interpolate actual measurements or to generate synthetic quasi-random wind fields for use in reliability analysis of structures.

A proprietary numerical model was simultaneously developed to investigate structural behavior further. The results of the model were compared to the measurements of structural response. The overall mean difference in strain obtained from measurements and model is 8.2% and for displacements is 11.2%. The difference is mostly due to measurement errors, uncertainty in material and geometry, and long-term structural effects.

Acknowledgements

The above research was conducted in projects supported by the Ministry of Education and Science of the Republic of Croatia. The authors are grateful for professional help from the National Hydrometeorological Service (namely A. Baijć, Z. Žibrat and other colleagues) and the Faculty of Electrotechnical Engineering, Mechanical Engineering and Naval Architecture of the University of Split (namely J. Barle and P. Đukić). The presented work was done in a PhD research project by Vladimir Divić under the supervision of Bernardin Peroš

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Surface Deformation Monitoring in the Republic of Croatia with MT-InSAR

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Abstract: The Multi-Temporal Synthetic Aperture Radar Interferometry (MT-InSAR) has proven to be a very useful tool in providing a high precise detailed characterization of surface deformation processes over wide areas. The first application in the Republic of Croatia was applied over the wider Zagreb area in the project "The Geodynamic GPS Network of the City of Zagreb". The project was established in 1997 with the aim to answer the need for a better understanding of an ongoing geodynamic processes in the area. The research was carried out with GPS campaigns, whereas the MT-InSAR technique was introduced into the project in 2015. The Persistent Scatterers MT-INSAR technique was applied on Envisat ASAR data in 2015 and on Sentinel-1 data in 2017. The paper provides a revisit of the research with Envisat-ASAR data and preliminary results of the Sentinel-1 data. Furthermore, we discuss other possible MT-InSAR applications in the area.

Keywords: Geodynamic GPS Network of the City of Zagreb, InSAR, surface deformation monitoring, geodynamic processes

Introduction

The first application of Multi-temporal Interferometric Synthetic Aperture Radar (MT-InSAR) technique in the Republic of Croatia was done through the project "The Geodynamic GPS Network of the City of Zagreb". The MT-InSAR was applied for surface deformation monitoring of the wider Zagreb area in order to fully characterize an ongoing geodynamical processes in the area. The latest significant earthquakes occurred in 1880(VIII MCS) and 1905(VII-VIII MCS) and left devastating effects on Zagreb and nearby settlements (Herak et al, 2009). The wider Zagreb area is located in the NW part of Croatia and it is considered as one of three most seismic active zones in the country.

The Geodynamic GPS Network of the City of Zagreb project was initiated in 1997 by GPS network establishment. The project's aim was to provide a better understanding of ongoing geodynamic processes with precise GPS observations of the network. Since then, nine GPS campaigns were conducted (1997, 2001, 2004, 2006, 2007, 2008, 2009, 2015 and 2017) on 43 specially stabilized GPS monuments. The results of the project are extensively documented in; Pribičević et al 2004, Medak & Pribičević 2004, Đapo 2005, Pribičević et al 2007, Đapo 2009, Pribičević et al 2011 and Pribičević et al 2012, Pribicevic et al. 2016. Moreover, the MT-InSAR technique was introduced in the project in 2015 (Pribicevic et al. 2017).

MT-InSAR is an advanced InSAR processing technique that provides ground deformation detection with an improved accuracy in the order of a few millimeters per year. (Hooper et al, 2012, and references therein). Moreover, it provides an unsurpassed spatial resolution and great coverage of surface deformations in the area. InSAR is the remote sensing technique that relies on the determination of a phase difference in the received electromagnetic signal (EM) acquired by spaceborne SAR imaging of the area at two distinct times. Taking into consideration the geometry of spaceborne SAR imaging and height of the imaging satellite, the phase difference can be connected with a change in the EM propagation length that can

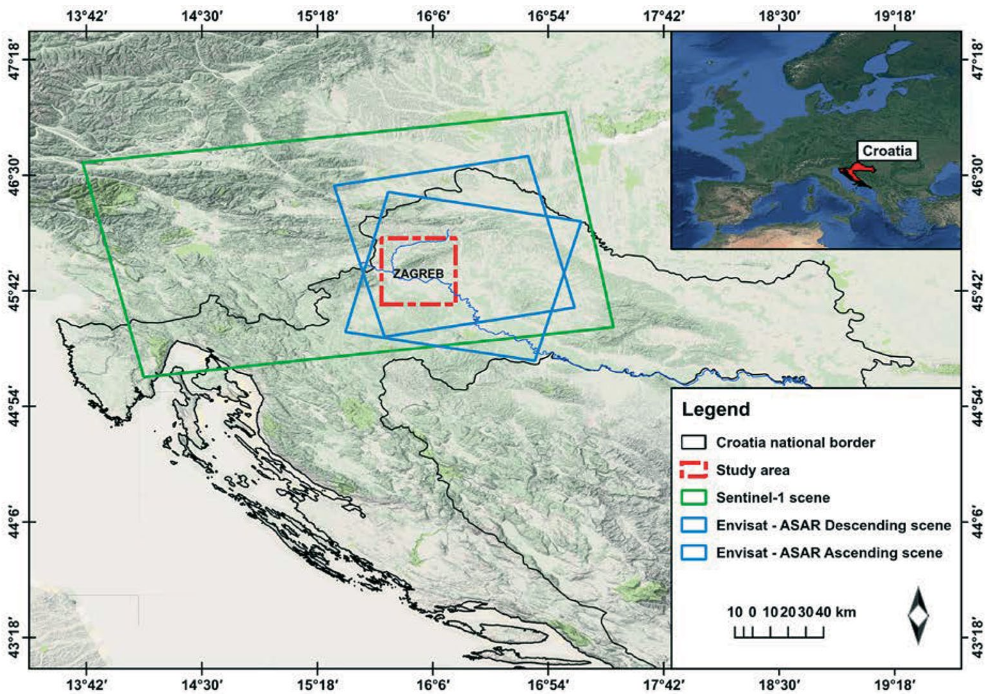

Fig. 1 – MT-InSAR application over the wider Zagreb area, Croatia

be afterwards connected with a ground displacement. The final InSAR result is a map of phase differences over the imaging area called interferogram. Furthermore, MT-InSAR methods work on the principle of stacking multiple interferograms that cover a certain time period. Based on the different approach of interferogram stack generation and an extraction of ground displacement information from interferograms, the methods can be generally divided on Persistent Scatterers, Small Baseline Subset or their combination. The comparison of different MT-InSAR approaches was discussed in Osmanoglu et al. 2016.

In this paper we present an overview of Persistent Scatterers MT-InSAR technique and its application in “The Geodynamic GPS Network of the City of Zagreb” project. The MT-InSAR Persistent Scatters technique was applied on ENVISAT satellite data in 2015 and on Sentinel1 data in 2017. We revisit the research on the Envisat data presented in Pribicevic et al. 2017 and also present for the first time preliminary results of the Sentinel1 data. Scene coverage of ever satellite mission is depicted in Fig. 1. Moreover, we discuss the future MT-InSAR research and its other possible applications in the area.

Interferometric Synthetic Aperture Radar (InSAR)

Interferometric Synthetic Aperture Radar (InSAR) is a remote sensing technique based on the Radio Detection and Ranging (radar) technology. The technique uses two Synthetic Aperture Radar (SAR) observations over the same area acquired at distinct times to measure ground displacements expressed as a phase change in received EM pulses. It can be used for continuous monitoring applications of various geophysical and surface processes occurring on the Earth’s surface; such as earthquakes, volcanic eruptions, landslide, uprising and subsidence events, glacial movements and etc.

Today, the most common SAR platform are satellites that orbit the Earth in a near-polar orbits at altitudes ranging from 500 km to 800km above the Earth’s surface. The SAR satellites orbit the Earth in two directions concerning the direction to the North Pole (ascending orbit) or to the South Pole (descending pole). The angle between satellite orbit and true North-South is called squint angle and it slightly varies depending on the satellite but is in the range up to 10 degrees. The SAR is an active imaging radar system that emits and receives an electromagnetic (EM) pulse with a wavelength in the microwave spectral domain. The imaging geometry is side-looking in order to ensure a precise discrimination of different received backscattered EM pulses. The system gathers spatial data stored in the form of an image where every pixel contains a piece of information concerning the received backscattered EM pulse. The stored information are amplitude and phase values of the each received backscattered EM pulse. The phase information is directly correlated with the emitted EM wavelength, thus, any change between the emitted and received signal's wavelength can be expressed as a phase shift. InSAR technique exploits the phase change information in order to determine surface displacements occurred in the area of interest between two spaceborne SAR acquisitions. The map of phase change values over the area of interest is called interferogram. The relationship between a ground displacement and corresponding phase change in two SAR signals acquired over the same area is depicted Fig. 2.

The relationship between a change in electromagnetic signal's phase and ground movement (URL1)

Phase change (Δφ) can be expressed with the following equation:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha \tag{1}$$

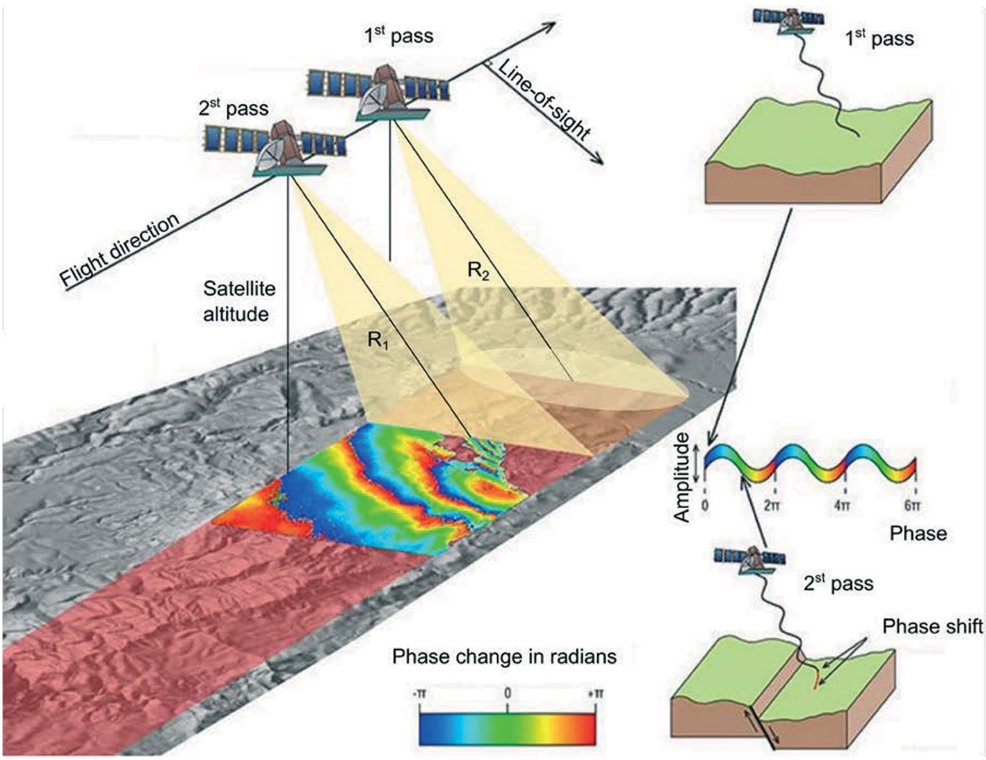

Fig. 2 – InSAR; imaging geometry and interferogram generation (URL2)

where λ is wavelength, ΔR is displacement and α is phase shift due to different atmospheric conditions at the time of two radar acquisitions. The determination of a true ground displacement is not a trivial task as a phase change is also affected by; topography distortions produced from slightly different viewing angles of two satellite acquisitions (t), atmospheric delay effects produced from interaction between EM signal with wet atmosphere layers (a) and other noise. Therefore, equation 1 can be extended to;

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha + t + noise. \tag{2}$$

Phase change regarding topography can be removed from the total phase change information by stimulating the phase change related to the viewing geometry and topography provided by an external digital terrain model. The technique of topographic phase change removal is called Differential InSAR (DinSAR). Another significant noise contributor is atmosphere, which is completely random and hard to remove. The techniques to deal with this problem emerged in the late 1990'ies by stacking the multiple interferograms and removing the noise with a statistical analysis. The process was referred to as Interferogram Stacking or Multi-temporal InSAR (MT-InSAR). The two most used MT-InSAR techniques are Small Baseline Subset (SBAS) and Persistent Scatter (PS) technique.

Multi-temporal InSAR Persistent Scatter technique

Multi-temporal InSAR Persistent Scatterer is a part of the second generation of InSAR techniques. The base algorithm was developed at the Politecnico di Milano (Polimi) in 1999 (Ferretti et al. 2001). The algorithm determines a phase shift only on the stable backscatter ground points, so called permanent scatterers. Permanent scatterers (PS) are defined as a ground EM reflectors that maintain a stable amplitude and coherent phase properties in time. Thus, points with a good signal to noise ration can be considered as PS candidates. PS points are usually man-made objects but can also be natural objects like rock outcrops, un-vegetated earth surfaces and boulders. In most cases the best PS points are high objects, which are stable in time due to their best refractive capabilities. The main aim of MT-InSAR PS technique is to mitigate phase changes caused by the atmospheric delay in order to better determine the true ground displacement. This can be accomplished by using the spectral analysis of the interferogram stack in order to identify PS points. Further analysis is performed on the PS points in the spatial and time domain for determination of deformation trend model. After the initial removal of flat surface and topography phase contributors, other variations in the interferometric phase are considered to be produced by atmosphere as the other noise sources can be neglected.

Therefore, the PS technique is based on the statistical analysis of interferometric data where bigger input overall provides a more reliable model. The minimum recommended number of SAR scenes is 15. The precision of the surface deformation with the PS technique is around a few millimeters per year.

MT-InSAR PS results over the wider Zagreb area

MT- InSAR Persistent Scatterer technique was introduced for the first time in the project in 2015. The aim of MT-InSAR utilization was to condense the deformation results provided from GPS network. Moreover, the idea was to provide a detailed characterization of surface deformation with a special focus on urban areas in an area 50 by 50 km around the City of Zagreb. The PS MT-InSAR technique was applied to images acquired with Envisat – An Advanced Synthetic Aperture Radar (ASAR) on descending and ascending orbit. The images were stacked based on the orbit direction regarding their viewing geometry. The total number of satellite radar images used in processing were 23 of descending track and 17 of ascending track. Each stack covered the time period 2004-2009. The MT-InSAR processing was done with Stanford method for Persistent Scatterers / Multi Temporal InSAR (StaMPS/MTI). The MT-InSAR results were 121,490 PS points for descending track and 95,530 for ascending track. The velocity models of the area on both tracks show values in a range of -3 to 3 millimeters per year regarding the defined reference point. The research is described to a great extent in Pribicevic et al. 2017. The results are depicted in the figure

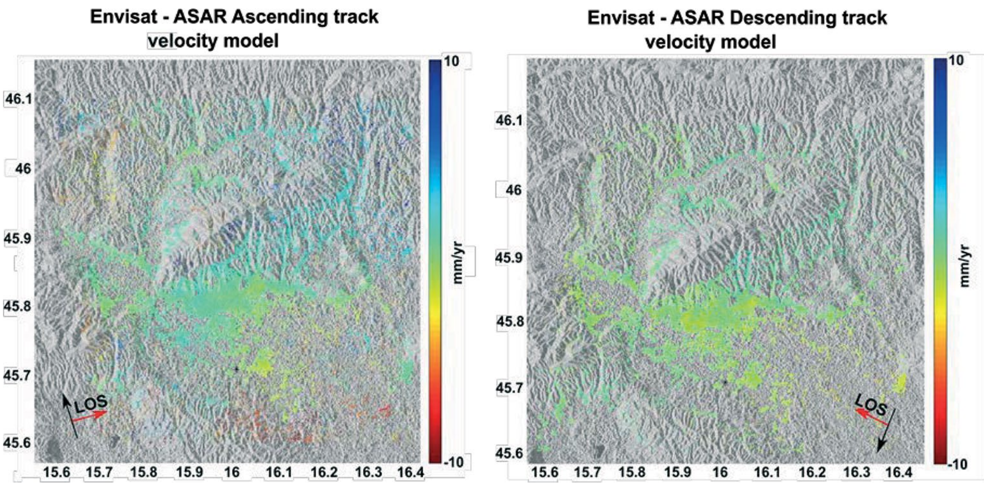

Fig. 3 – Envisat ASAR MT-InSAR results

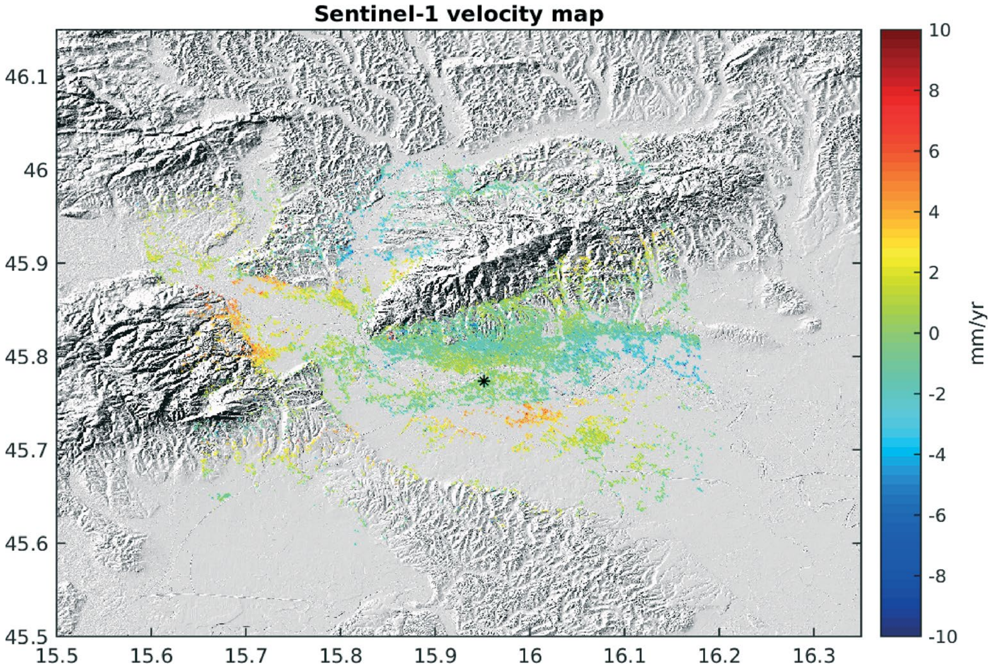

Fig. 4 – Sentinel1 MT-InSAR results

Envisat-ASAR data provided first PS results over the area of interest and revealed that the area is prone to a high level of temporal decorrelation due to a vegetation cover. The processing revealed that a high level of noise in the interferograms can be expected already with a temporal baseline above 30 days and a spatial baseline of 300 meters between two C-band spaceborne SAR acquisitions. The next MT-InSAR application was performed with Sentinel-1 data in 2017. Sentinel -1 is a part of European Space Agency program Copernicus comprised of two satellites carrying C-band SAR instrument. The first satellite Sentinel-1A was launched on April 2014 and the second Sentinel-1B on April 2016. Sentinel 1 is a state-of art space program that proved to have an excellent orbit and acquisition control keeping the spatial separation between acquisitions over the same area around 100m. Moreover, a temporal baseline of the mission was defined with revisit time of each satellite, which is 12 days with a 6 days difference between them. Therefore, it was expected to achieve an improved signal to noise ratio in interferogram stack with Sentinel-1 data, which would provide a more reliable velocity model of the area. The PS MT-InSAR processing was carried out with SarPROZ software on 41 Sentinel-1 images covering the period 2015-2017. Only swath 2 imaging mode was processed with a defined area of interest. The result was a velocity map with an average range of values between -2 and 2 millimeter per year on 33731 PS points. All MT-InSAR are one dimensional line-of-sight values that represent the movement towards to or away from the satellite under the viewing angle.

Discussion

The MT-InSAR results show overall small amplitudes of surface velocities in the area. The model reveals more or less no surface deformation in the urban parts of the area with an exception of a few possible locations of the landslide activity. The MT-InSAR research confirmed that the area experiences a very slow ground deformation processes with no significantly emphasized geodynamical activity. Nevertheless, it does not necessarily mean that there is no risk for future seismic hazard events, especially taking into account that the last series of strong earthquakes occurred ~120 years ago. We imply that future research needs to be considered with new satellite missions. The Sentinel-1 results are very promising and we expect to obtain more reliable results with a longer time span of investigations. Moreover, we detect several other possible applications for MT-InSAR that need to be considered. The first one concerns the monitoring of structure stability in the city. The results indicate a potential deformation activity on the bridges over the Sava River that needs to be further investigated. Second, according to the Croatian Geological survey in 2011, there are more than 700 registered landslide locations in the urbanized city area. MT-InSAR results correlated with some of the known landslide locations, especially with the largest one called Kostanjek. Nevertheless, further analysis needs to be done in landslide investigation with MT-InSAR technique in the area. Moreover, another possible MT-InSAR application in future could concern the ongoing Zagreb aquifer depletion. According to Nakić et. al. 2013 and references therein, groundwater levels are already on their minimum levels (defined as the upper elevations of the well screens) in some well, whereas the total annual abstraction from the well fields exceeds the annual renewable groundwater reserves. Depletion of groundwater reserves definitely presents a potential threat to the city as could eventually result in the following subsidence events.

Conclusions

MT-InSAR has proven to be a useful tool for surface deformation monitoring over wide areas. The MT-InSAR research over the wider Zagreb area has shown that the area exhibits a slow deformation processes that could eventually lead to a strong earthquake and it is necessary to continue with further research. Moreover, the MT-InSAR results show promising applications in other geological processes. The potential applications in the wider Zagreb area could be monitoring landslide activities, structure stability and potential aquifer depletion effects.

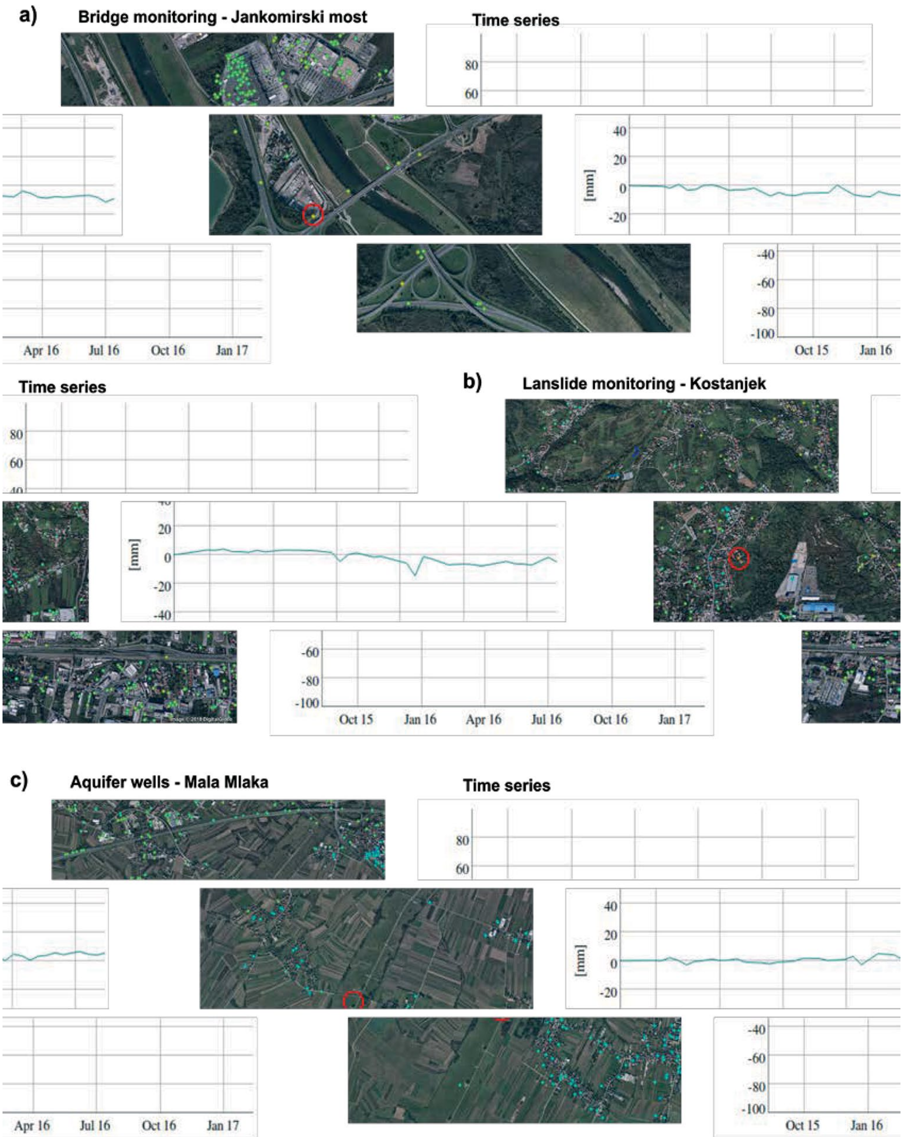

Fig. 5 – Other MT-InSAR applications over the wider Zagreb area: a) landslides b) structure stability and c) aquifer depletion monitoring **Fig. 5** – Other MT-InSAR applications over the wider Zagreb area: a) landslides b) structure stability and c) aquifer depletion monitoring

Acknowledgements

We would like to thank the City of Zagreb for funding the project "The Geodynamic GPS Network of the City of Zagreb" and European Space Agency for providing the satellite radar images necessary for MT-InSAR processing. Moreover, we would like to thank Daniele Perissin for giving us the opportunity to use SARPROZ software.

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Liquid-Liquid Equilibria in Two Systems Comprising Propionic Acid, Water and Organic Solvent

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Abstract: Liquid-liquid phase equilibria (LLE) in the systems H2O(1) – *n*-butyl acetate(2) – propionic acid(3) at 35°C and H2O(1) – dimethyl adipate(2) – propionic acid(3) at 25°C was experimentally determined with a combination of turbidimetric titration and refractometry methods. Experimental binodal curves were modeled with Hlavatý equation and tie lines with Othmer-Tobias equation to provide an excellent agreement with the data. UNIFAC LLE model was not found suitable for the prediction of LLE in the systems studied. NRTL and UNIQUAC model parameters were determined as well. The correlation was found fair, but much worse than that obtained by the empirical approach of Hlavatý and Othmer-Tobias.

Keywords: Liquid-liquid equilibria, propionic acid, *n*-butyl acetate, dimethyl adipate

Introduction

There is an increasing demand for propionic acid produced by the fermentation route, using whey lactose as a substrate and *Propionibacterium* microorganisms (Bodie et al., 1986; Goswami and Srivastava, 2000). The product may be classified as “natural” and may serve as a replacement for “artificial” chemical preservatives – fungistatic agents in the bakery industries. The same is valid for sodium, calcium and potassium propionates as food additives. Propionic acid finds other uses in the manufacturing of cellulose thermoplasts, artificial aromas and fragrances, etc., where it serves as an esterification agent (Playne, 1985).

The fermentation products are generally dilute water solutions of propionic acid, with many impurities. The product may be separated by liquid-liquid extraction, commonly performed at near ambient temperatures to reduce costs and avoid possible thermal degradation. Many solvents were investigated experimentally with this respect and phase diagrams in the system $H_2O(1)$ – solvent(2) – propionic acid(3) were derived. The list of solvents include aromatics, e.g. benzene (Utkin et al., 1971), toluene (Alessi et al., 1984; Ghanadzadeh et al., 2010; Badakhshan et al., 1985; Kim and Park, 2005) o-xylene (Kim and Park, 2005) and cumene (Çehreli, 2006); linear and cyclic aliphatics, such as petroleum ether (Utkin et al., 1971), *n*-heptane (Alessi et al., 1984), cyclohexane (Ghanadzadeh et al., 2010; Özmen et al., 2004; Badakhshan et al., 1985), methylcyclohexane (Ghanadzadeh et al., 2010), *n*-hexane (Özmen et al., 2004); alcohols: 1-butanol (Solimo et al., 1997; Zurita et al., 1998; Kim and Park, 2005), cyclohexanol (Özmen et al., 2004), 2-butanol (Radwan and Al Muhtaseb, 1997), longer-chain aliphatic alcohols (Senol, 2005; Ghanadzadeh et al., 2008, Bilgin and Arisoy, 2006; İsmail Kırbaşlar et al., 2006; Raja Rao et al., 1958); ketones: methyl isopropyl ketone (Vakili-Nezhaad et al., 2004; Roy et al., 2007; Taghikhani et al., 2001), methyl isobutyl ketone (Vakili-Nezhaad et al., 2004; Roy et al., 2007; Arce et al., 1993; Kim and Park, 2005), methyl *n*-butyl ketone (Taghikhani et al., 2001), methyl ethyl ketone (Arce et al., 1995), methyl *n*-propyl ketone (Arce et al., 1995), cyclohexanone (Çehreli et al., 2005b), methyl isoamyl ketone, diisobutyl ketone and ethyl isoamyl ketone (Özmen, 2006); ethers: di-*n*-propyl ether (Özmen, 2007) or di-*i*-propyl ether (Özmen et al., 2004) or nitriles: butanenitrile (Letcher and Redhi, 2002) or chlorinated solvents: dichlorometane (Mohsen-Nia et al., 2009). However, many of these solvents are toxic; downstream separation of propionic acid may be a very demanding task if products for the food industry are required.

Esters are among the most investigated solvents due to their low toxicity, such as monofunctional cyclohexyl acetate (Özmen et al., 2004), ethyl acetate(Utkin et al., 1971; Kim and Park, 2005), *n*-butyl acetate (Utkin et al., 1971; Çehreli et al., 1999), *n*-propyl acetate and *i*-propyl acetate (Çehreli et al., 1999), or bifunctional dimethyl phthalate (Özmen et al., 2005), diethyl phthalate (Çehreli et al., 2005a), dimethyl adipate, dimethyl succinate and dimethyl glutarate (İsmail Kırbaşlar et al., 2007a), diethyl succinate, diethyl glutarate and diethyl adipate (İsmail Kırbaşlar et al., 2007b), dimethyl maleate (Özmen, 2008). The problem of downstream separation remains, however, to be resolved.

In this article we contribute new data for the two systems, i.e. $H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3) at 35°C (first data at this temperature) and $H_2O(1)$ – dimethyl adipate(2) – propionic acid(3) at 25°C. The data are compared with literature findings and suitable model correlations and/or predictions.

Materials and Methods

Chemicals. Propionic acid (p.a. purity ≥99.8%, M=74.08 g mol^{-1}, ρ=0.990 g cm^{-3}, boiling point 141°C) was obtained from Fluka. *n*-butyl acetate (p.a. purity ≥99.5%,, M=116.16, ρ=0.880 g cm^{-3}, boiling point 126°C) was obtained from Kemika, Zagreb, Croatia. Dimethyl adipate (p.a. purity >99%, M=174.20) was obtained from Fluka. The chemicals were used without any further treatment. Milli-Q water (18 MΩ cm^{-1} water, Millipore, Bedford, MA, USA) was used in all experiments.

Solubility curve and refractive index measurements. All the measurements were performed at indicated temperatures, in a thermostated air bath. Solutions of propionic acid in water were carefully titrated by dropwise addition of *n*-butyl acetate or dimethyl adipate with a glass syringe through a silicone septum sleeve stopper to prevent evaporation of the components until incipient turbidity was observed. For other branch of solubility curves, the measurements were performed by titrating solutions of propionic acid in *n*-butyl acetate or dimethyl adipate with water in a similar manner. The overall volume of solutions never exceeded 4 ml (4 ml vials). After observing the initial turbidity, the solutions were left overnight at corresponding temperatures to settle into two layers. Refractive indices of the major layer were determined by an Abbe refractometer (RL3 type, PZO Warszawa, Poland), thermostated again at selected temperatures. Triplicate measurements were performed.

Tie lines. Two-phase three-component solutions (approx. 4 ml) were prepared by weighing the components. The solutions were shaken well and left in a thermostated air bath at 25°C or 35°C for a day to settle and reach equilibrium separation. The refractive indices of the two coexisting phases were determined (in triplicate) using the above mentioned instrument at corresponding temperatures.

Results

Solubility curve and refractive index measurements. Solubility curve data are presented in Table 1.

Table 1 – Experimentally determined binodal curve compositions and corresponding refractive indices (triplicate averages).

H2O(1) – n-butyl acetate(2) – propionic acid(3), 35°C			H2O(1) – dimethyl adipate(2) – propionic acid(3), 25°C		
w_2	w_3	n_D	w_2	w_3	n_D
0.0184	0.0627	1.3373	0.0345	0.0000	1.3358
0.0194	0.1278	1.3426	0.0280	0.0562	1.3411
0.0124	0.1854	1.3480	0.0404	0.1000	1.3454
0.0296	0.2169	1.3507	0.0451	0.1434	1.3500
0.0345	0.2605	1.3540	0.0641	0.1771	1.3545
0.0489	0.3089	1.3586	0.1025	0.2250	1.3612
0.0835	0.3399	1.3630	0.1422	0.2510	1.3651
0.0949	0.3622	1.3633	0.1840	0.2748	1.3732
0.2285	0.4330	1.3772	0.2385	0.2989	1.3789
0.2853	0.4352	1.3788	0.2845	0.3115	1.3840
0.3651	0.4432	1.3828	0.3377	0.3273	1.3900
0.4417	0.4222	1.3851	0.3184	0.3245	1.3871
0.4887	0.3936	1.3857	0.4033	0.3256	1.3940
0.5683	0.3494	1.3867	0.4582	0.3072	1.3974
0.6576	0.2988	1.3875	0.5383	0.2951	1.4016
0.7457	0.2280	1.3879	0.5750	0.2614	1.4047
0.8079	0.1765	1.3880	0.6458	0.2228	1.4091
0.8669	0.1209	1.3884	0.7280	0.1790	1.4111
0.9303	0.0612	1.3883	0.7621	0.1501	1.4139
			0.8369	0.1023	1.4184
			0.8973	0.0590	1.4209
			0.9610	0.0000	1.4223

Following the work of Hlavatý (Hlavatý, 1972), three equations have been fitted to the data, but with experimental mass instead of mole fractions as variables. These are the modified equations of Hlavatý:

$$w_3 = A_1 w_A \ln w_A + A_2 (1 - w_A) \ln w_A + A_3 w_A (1 - w_A), \tag{1}$$

β-function equation:

$$w_3 = B_1 (1 - w_A)^{B_2} w_A^{B_3} \tag{2}$$

as well as logγ-function equation:

$$w_3 = C_1 \left(-\ln w_\mathrm{A}\right)^{C_2} w_\mathrm{A}^{C_3} . \tag{3}$$

where w_A is defined as:

$$w_\mathrm{A} = \frac{w_2 + 0.5 w_3 - w_2'}{w_2'' - w_2'} \tag{4}$$

and w_2' and w_2'' are the mass fractions of component 2 in the absence of component 3 (in this case mass fractions describe the mutual solubility of water and organic ester. The equation parameters, $A_{1\text{-}3}$, $B_{1\text{-}3}$ and $C_{1\text{-}3}$, were determined by minimizing the functions:

$$OF_1 = \sqrt{\frac{1}{n_\mathrm{b}} \left(w_{3,\mathrm{exp}} - w_{3,\mathrm{mod}}\right)^2} , \tag{5}$$

and are shown in Table 2. n_b is the number of binodal data points. All the equations behave quite similarly in describing the binodal curves, the Hlavatý equation producing somewhat better results than the others. Therefore, this equation was selected for further calculations.

Table 2 – Model parameters of the empirical binodal curve correlations.

Hlavatý	□	log□
H_2O(1) – *n*-butyl acetate(2) – propionic acid(3), 35°C		
A_1=-0.395868	B_1=1.40078	C_1=1.28192
A_2=-0.429353	B_2=0.825051	C_2=0.785559
A_3=0.626771	B_3=0.83448	C_3=1.12037
w_2''=0.9833	w_2''=0.9833	w_2''=0.9833
w_2'=0.0300	w_2'=0.0300	w_2'=0.0300
OF_1=0.0105273	OF_1=0.0106949	OF_1=0.0121922
H_2O(1) – dimethyl adipate(2) – propionic acid(3), 25°C		
A_1=-0.294197	B_1=1.05564	C_1=0.961382
A_2=-0.184108	B_2=0.885395	C_2=0.842681
A_3=0.61914	B_3=0.833761	C_3=1.14201
w_2''=0.9661	w_2''=0.9661	w_2''=0.9661
w_2'=0.0240	w_2'=0.0240	w_2'=0.0240
OF_1=0.00818113	OF_1=0.00818337	OF_1=0.00882725

By examining refractive index, n_D, vs. composition plots corresponding to binodal curves, best sensitivity was observed for the lower (water) phase in both systems, with respect to the mass fraction of propionic acid, w_3. The proposed equations are:

$$n_D = -14.8514 + 11.1556\, w_3 , \tag{6}$$

$$n_D = -196.748 + 283.119\, w_3 - 101.685\, w_3^2 , \tag{7}$$

for the systems with *n*-butyl acetate at 35°C and dimethyl adipate at 25°C, respectively.

Tie lines. Overall compositions and refractive indices (triplicate averages) of equilibrium lower (water) phase are given in Table 3. Using the refractive indices, it was possible to determine the corresponding w_3 values for the water phase from Eqs. 6 and 7, respectively, w_2 values from the Hlavatý equation, and w_1 values from the mass balance requirement $w_1+w_2+w_3=1$. Compositions of the upper phase were deduced from the overall mass balance and Hlavatý equation. The results are added in Table 3.

Table 3 – Overall compositions, composition of equilibrium phases and refractive index values (triplicate averages) of water phase.

H_2O(1) – *n*-butyl acetate(2) – propionic acid(3), 35°C						
Overall		Lower (water) phase			Upper (organic) phase	
w_2	w_3	n_D(35°C)	$w_{2,aq}$	$w_{3,aq}$	$w_{2,org}$	$w_{3,org}$
0.4560	0.0538	1.3359	0.0205	0.0513	0.9351	0.0565
0.4053	0.1365	1.3402	0.0170	0.0993	0.8117	0.1754
0.4079	0.1553	1.3415	0.0168	0.1138	0.7882	0.1956
0.4010	0.1781	1.3425	0.0169	0.1250	0.7505	0.2264
0.3742	0.2183	1.3443	0.0176	0.1450	0.6783	0.2808
0.3584	0.2523	1.3468	0.0197	0.1729	0.6273	0.3153
0.3494	0.2867	1.3483	0.0218	0.1897	0.5678	0.3514
0.3204	0.3330	1.3512	0.0273	0.2220	0.4828	0.3945
0.2895	0.3746	1.3546	0.0371	0.2600	0.4010	0.4253

$H_2O(1)$ – dimethyl adipate(2) – propionic acid(3), 25°C						
Overall		Lower (water) phase			Upper (organic) phase	
w_2	w_3	n_D(25°C)	$w_{2,aq}$	$w_{3,aq}$	$w_{2,org}$	$w_{3,org}$
0.4913	0.0309	1.3382	0.0247	0.0264	0.9272	0.0351
0.4792	0.0482	1.3397	0.0267	0.0426	0.9051	0.0534
0.4755	0.0808	1.3409	0.0288	0.0553	0.8426	0.1018
0.4492	0.1104	1.3426	0.0325	0.0727	0.7873	0.1410
0.4342	0.1324	1.3437	0.0352	0.0837	0.7430	0.1701
0.4261	0.1617	1.3454	0.0399	0.1001	0.6880	0.2035
0.4089	0.1978	1.3481	0.0484	0.1250	0.6197	0.2404
0.3980	0.2191	1.3496	0.0537	0.1382	0.5763	0.2610
0.3820	0.2496	1.3522	0.0636	0.1600	0.5132	0.2865
0.3721	0.2731	1.3543	0.0724	0.1766	0.4636	0.3026

Modeling and discussion

Comparison with literature data. The experimental results for the system $H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3) at 35°C are compared with available results of other authors (Utkin et al., 1971; Çehreli et al., 1999) available at different temperatures. The results are shown in Fig. 1. The position of binodal curve varies little with the temperature in the investigated range, seemingly by decreasing the homogeneous region with increasing temperature. All the data show higher mass fractions of propionic acid in the organic phase with comparable tie line slopes. The results for the system $H_2O(1)$ – dimethyl adipate(2) – propionic acid(3) at 25°C are compared with available literature data (İsmail Kırbaşlar et al., 2007a) in Fig. 2. In this case the match is fairly good, again pointing to higher mass fractions of propionic acid in the organic phase.

Plait Points. Plait points in the investigated systems may be determined by the Treybal method (Treybal et al., 1946), by intersecting the linear relationship of $\log(w_3/w_1)$ in the aqueous phase vs. $\log(w_3/w_2)$ in the organic phase (Hand, 1930), with the binodal curve (i.e. its Hlavatý's equation representation) as plotted by $\log(w_3/w_1)$ vs. $\log(w_3/w_2)$. The procedure is illustrated in Fig. 3. The determined

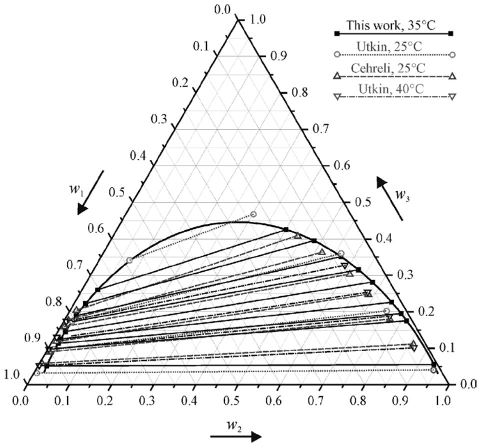

Fig. 1 – Comparison of experimentally determined binodal curve and tie lines with literature tie line data (Utkin et al., 1971; Çehreli et al., 1999) for the system H_2O(1) – *n*-butyl acetate(2) – propionic acid(3).

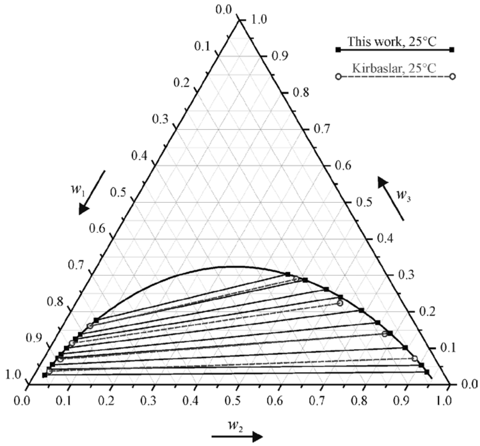

Fig. 2 – Comparison of experimentally determined binodal curve and tie lines with literature tie line data (İsmail Kırbaşlar et al., 2007a) for the system H_2O(1) – dimethyl adipate(2) – propionic acid(3).

plait point coordinates are: $\{w_2=0.1104, w_3=0.3843\}$ and $\{w_2=0.1480, w_3=0.2649\}$ for the system with *n*-butyl acetate at 35°C and dimethyl adipate at 25°C, respectively.

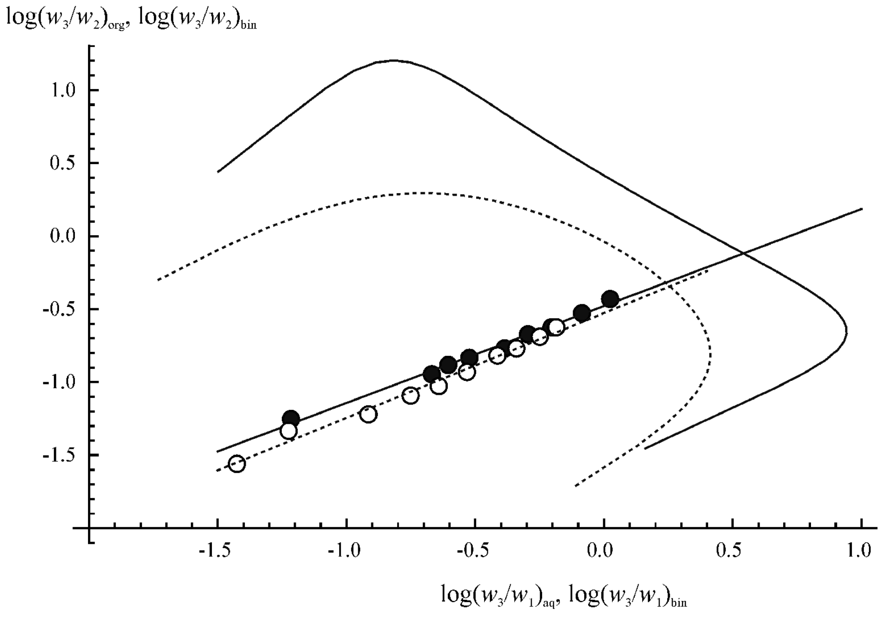

Fig. 3 – Treybal-Hand plot for determining plait points for the system H_2O(1) – *n*-butyl acetate(2) – propionic acid(3) [black circles, solid lines] and system H_2O(1) – dimethyl adipate(2) – propionic acid(3) [white circle, dotted lines].

Othmer Tobias correlation. Othmer-Tobias plot (Othmer and Tobias, 1942) is a revised version of Hand's plot that takes into account the mutual solubility of two (partially) immiscible solvents. Tie line data are approximated with the correlation of the form:

$$\frac{w_{2,\mathrm{aq}} + w_{3,\mathrm{aq}}}{w_{1,\mathrm{aq}}} = k\left(\frac{w_{1,\mathrm{org}} + w_{3,\mathrm{org}}}{w_{2,\mathrm{org}}}\right)^n \tag{8}$$

or, by applying mass balance for both phases:

$$\frac{1 - w_{1,\mathrm{aq}}}{w_{1,\mathrm{aq}}} = k\left(\frac{1 - w_{2,\mathrm{org}}}{w_{2,\mathrm{org}}}\right)^n . \tag{9}$$

with k being roughly the distribution coefficient and n, again roughly, describing the curvature of the equilibrium line in the Hand coordinates plot. Model parameters k and n are easily determined from the experimental data, by minimizing the function:

$$OF_2 = \sqrt{\frac{1}{n_\mathrm{d}}\sum_{i=1}^{n_\mathrm{d}}\left[\log\left(\frac{1 - w_{2,\mathrm{aq}}}{w_{2,\mathrm{aq}}}\right) - \log K - n\log\left(\frac{1 - w_{3,\mathrm{org}}}{w_{3,\mathrm{org}}}\right)\right]^2} . \tag{10}$$

Where, n_d is the number of experimental tie-lines. The results are shown in Fig. 4. The linearity of the plots indicates the consistency of data. The parameters are $\{K, n\}=\{0.315, 0.556\}$ and $\{K, n\}=\{0.288, 0.653\}$ for the systems with *n*-butyl

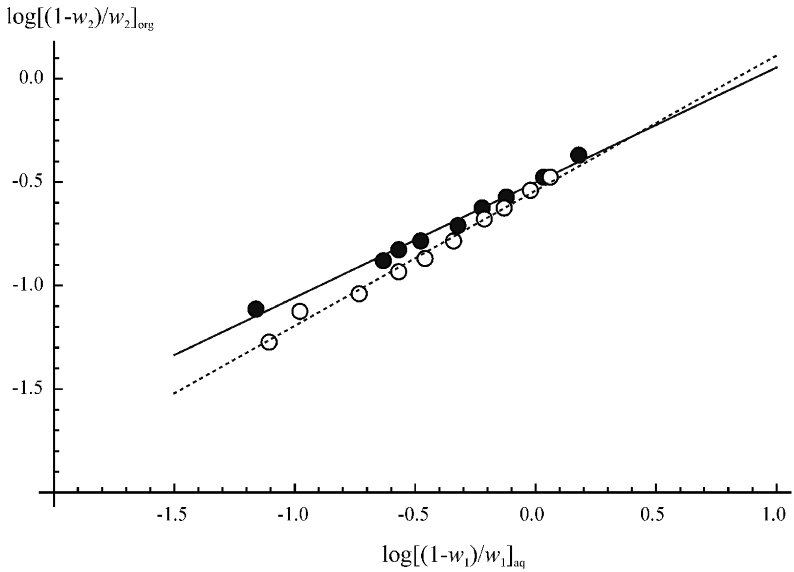

Fig. 4 – Othmer-Tobias plot for the system $H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3) [black circles, solid lines] and system $H_2O(1)$ – dimethyl adipate(2) – propionic acid(3) [white circle, dotted lines].

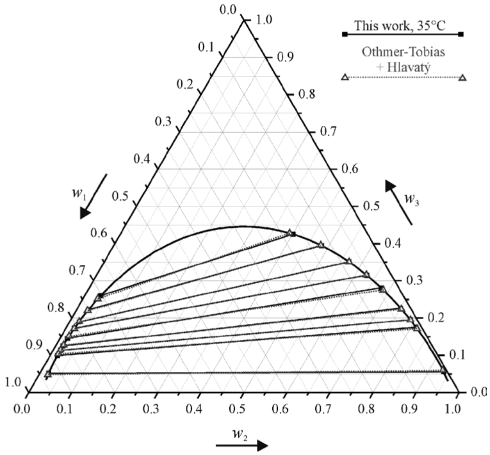

Fig. 5 – Comparison of experimentally determined binodal curve and tie lines with Othmer-Tobias correlation for the system $H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3).

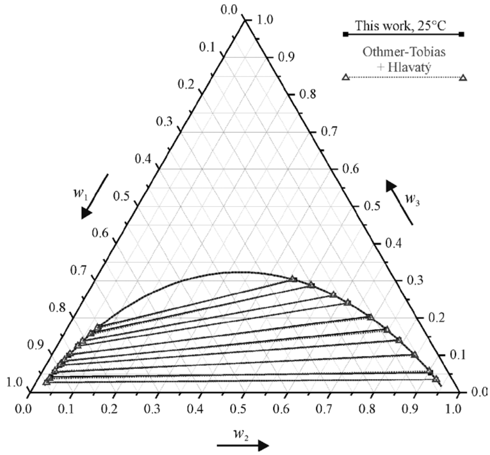

Fig- 6 – Comparison of experimentally determined binodal curve and tie lines with Othmer-Tobias correlation for the system $H_2O(1)$ – dimethyl adipate(2) – propionic acid(3)

acetate and dimethyl adipate, respectively. The parameters may serve, together with the Hlavatý parameters as given in Table 2, for the complete reconstruction of the phase diagram as presented in Figs. 5 and 6.

UNIFAC model. UNIFAC LLE model (Magnussen et al., 1981) as a group contribution model allows for the prediction of LLE data. Here, we used the ChemCAD

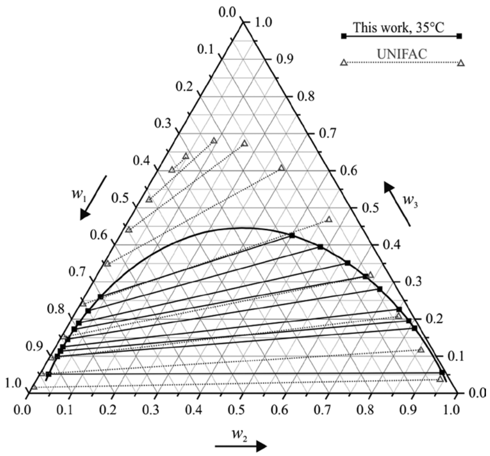

Fig. 7 – Comparison of experimentally determined binodal curve and tie lines with UNIFAC LLE prediction for the system $H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3).

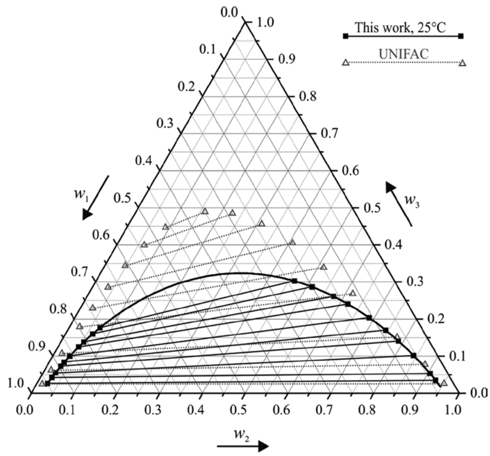

Fig. 8 – Comparison of experimentally determined binodal curve and tie lines with UNIFAC LLE prediction for the system $H_2O(1)$ – dimethyl adipate(2) – propionic acid(3).)

6.3.1. software with built-in thermodynamic data tables (UNIFAC LLE) to calculate the phase diagrams of the investigated systems. Dimethyl adipate was added as new component according to common rules of sectioning the components into functional groups. The results are shown in Figs. 7 and 8. For both systems, UNIFAC LLE predicts too large a region of immiscibility.

NRTL and UNIQUAC models. NRTL model (Renon and Prausnitz, 1968) takes into account local concentration variations as induced by differences between Gibbs interaction energies of the same and unlike species. Interaction energy parameters for pairs of species are t_{ij} and t_{ji}. The additional nonrandomness parameter $a_{ij}=a_{ji}$ is introduced into the model, giving a set of three parameters per pair of components. The excess Gibbs function, g^{ex}, is:

$$\frac{g^{\mathrm{ex}}}{RT}=\sum_{i=1}^{n_\mathrm{c}}x_i\left[\frac{\sum_{j=1}^{n_\mathrm{c}}\tau_{ji}G_{ji}x_j}{\sum_{k=1}^{n_\mathrm{c}}G_{ki}x_k}\right], \tag{11}$$

with:

$$G_{ij}=\exp\left(-\alpha_{ij}\tau_{ij}\right), \tag{12}$$

n_c is the number of components. Commonly, α-parameters are set fixed; for the systems with water and propionic acid, fixed α-values are in most cases either all 0.2 or all 0.3. In this article we tested all eight possible combinations of three α-values set at either 0.2 or 0.3.

τ-parameters were regressed from the experimental data.

UNIQUAC model (Abrams and Prausnitz, 1975) gives excess Gibbs function as a sum of two contributions, combinatorial, $g^{ex,C}$, based on the lattice theory that accounts for the size and shape differences of the species:

$$\frac{g^{\mathrm{ex,C}}}{RT}=\sum_{i=1}^{n_\mathrm{c}}x_\mathrm{i}\ln\frac{\Phi_i}{x_i}+\frac{z}{2}\sum_{i=1}^{n_\mathrm{c}}q_ix_i\ln\frac{\Theta_i}{\Phi_i}, \tag{13}$$

and residual, $g^{ex,R}$, accounting for the interaction energies between molecules, expressed by:

$$\frac{g^{\mathrm{ex,R}}}{RT}=-\sum_{i=1}^{n_\mathrm{c}}q_ix_i\ln\left(\sum_{j=1}^{n_\mathrm{c}}\Theta_j\tau_{ji}\right), \tag{14}$$

The model includes a set of two adjustable interaction parameters t_{ij} and t_{ji} per pair of components. F_i, Q_i and x_i are volume, area and molar fractions of component i, respectively, z is the lattice coordination number and q_i is the surface parameter of component i. The formulas for calculating Fi and Qi from volume and surface parameters, r_i and q_i of the components, respectively, are:

$$\Phi_i = \frac{x_i r_i}{\sum_{j=1}^{n_c} x_j r_j}, \tag{15}$$

$$\Theta_i = \frac{x_i q_i}{\sum_{j=1}^{n_c} x_j q_j}. \tag{16}$$

r_i and q_i of the components are calculated using the group contribution approach and group parameters as given in (Magnussen et al., 1981), using the following formulae:

$$r_i = \sum_{k=1}^{n_g} \nu_{ki} R_k , \tag{17}$$

$$q_i = \sum_{k=1}^{n_g} \nu_{ki} Q_k . \tag{18}$$

where R_k and Q_k are volume and surface parameters of structural group k, respectively. Thus, both models have six adjustable interaction parameters to be determined from experimental data. In this paper, we have chosen the two-step Sorensen-Arlt method (Sorensen and Arlt, 1979). In the first step, function:

$$OF_3 = \sum_{j=1}^{n_d} \sum_{i=1}^{n_c} \left(\frac{x_i^{\mathrm{I}} \gamma_i^{\mathrm{I}} - x_i^{\mathrm{II}} \gamma_i^{\mathrm{II}}}{x_i^{\mathrm{I}} \gamma_i^{\mathrm{I}} + x_i^{\mathrm{II}} \gamma_i^{\mathrm{II}}} \right)_j^2 + Q\left(\tau_{12}^2 + \tau_{21}^2 + \tau_{13}^2 + \tau_{31}^2 + \tau_{23}^2 + \tau_{32}^2 \right) \tag{19}$$

is minimized with respect to parameters. In the denominator of the first term on the right-hand side of equation (double sum with respect to number of components, n_c=3, and number of tie-lines, n_d) one can recognize the liquid-liquid equilibrium equation, $a_i^{\mathrm{I}}=a_i^{\mathrm{II}}$ or $(x_i g_i)^{\mathrm{I}}=(x_i g_i)^{\mathrm{II}}$, written in terms of component activities, a_i, or activity coefficients, g_i. The second term is the so-called penalty function, used to penalize for the unrealistically large values of τ producing minima in OF3 in NRTL. Therefore, we used the empirical value of penalization factor Q=0.001 for NRTL and Q=0 for UNIQUAC.

The optimal set of τ-parameters describes the equilibrium fairly well, but does not provide the best possible tie line description, which is more important from the engineering point of view. Therefore, the obtained optimal set serves as an initiation for the second step, where the following function is minimized:

$$OF_4 = \sum_{j=1}^{n_\mathrm{d}} \sum_{i=1}^{n_\mathrm{c}} \sum_{p=\mathrm{I}}^{\mathrm{II}} \left[\left(x_i^p\right)_\mathrm{exp} - \left(x_i^p\right)_\mathrm{mod} \right]_j^2 + Q\left(\tau_{12}^2 + \tau_{21}^2 + \tau_{13}^2 + \tau_{31}^2 + \tau_{23}^2 + \tau_{32}^2\right) \tag{20}$$

where the number of components is $n_\mathrm{c}=3$, n_d is again the number of tie lines and p takes values of I and II that denote the phases in the system. Penalty function is again used with $Q=0.001$ for NRTL and $Q=0$ for UNIQUAC.

Model parameters are summarized in Table 4, together with average absolute prediction errors in mole fractions as calculated by:

$$A = \sqrt{\frac{OF_4 - Q\left(\tau_{12}^2 + \tau_{21}^2 + \tau_{13}^2 + \tau_{31}^2 + \tau_{23}^2 + \tau_{32}^2\right)}{n_\mathrm{d} \cdot n_\mathrm{c} \cdot 2}}\,. \tag{21}$$

Table 4 – Optimal NRTL and UNIQUAC model parameters and prediction errors.

	$H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3), 35°C		$H_2O(1)$ – dimethyl adipate(2) – propionic acid(3), 25°C	
	NRTL	UNIQUAC	NRTL	UNIQUAC
A	0.01170	0.01840	0.01290	0.01206
α_{12}	0.3	–	0.3	–
α_{13}	0.3	–	0.3	–
α_{23}	0.3	–	0.3	–
τ_{12}	1.3754	0.4657	1.1720	0.1164
τ_{13}	4.3436	0.9066	3.6943	0.8341
τ_{21}	0.7579	1.1105	0.4594	2.5049
τ_{23}	–2.3066	0.7059	–2.9203	1.8967
τ_{31}	3.4223	$1.264 \cdot 10^{-5}$	0.7594	0.2237
τ_{32}	1.6619	0.8095	0.5813	0.2358

Experimental and calculated compositions are compared in Table 5. The agreement seems to be reasonably good, providing an accurate description of the size of the two-phase region, which was not the case for UNIFAC. NRTL model was found to be much better for the $H_2O(1)$ – *n*-butyl acetate(2) – propionic acid(3) system at 35°C than UNIQUAC and UNIQUAC described the system $H_2O(1)$ – dimethyl adipate(2) – propionic acid(3) at 25°C slightly better than NRTL. However, much more is revealed from the triangular diagrams plotted in weight fractions, Figs. 9

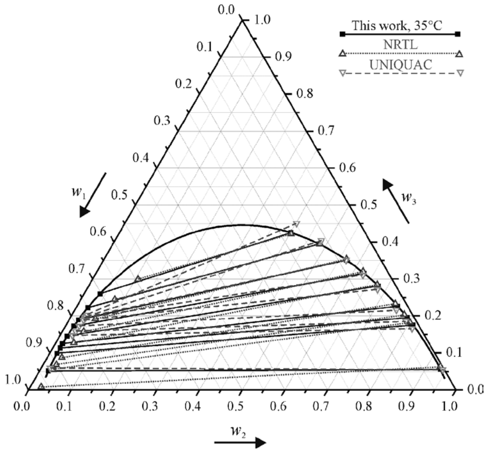

Fig. 9 – Comparison of experimentally determined binodal curve and tie lines with NRTL and UNIQUAC LLE correlation for the system H_2O(1) – *n*-butyl acetate(2) – propionic acid(3).

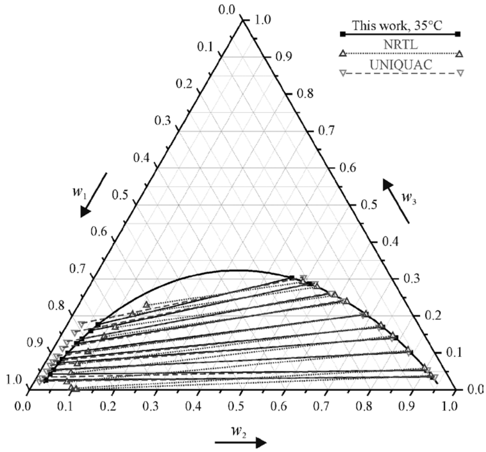

Fig. 10 – Comparison of experimentally determined binodal curve and tie lines with NRTL and UNIQUAC LLE correlation for the system H_2O(1) – dimethyl adipate(2) – propionic acid(3)

and 10. Mass fractions of the water-rich phase are described with less accuracy than for the ester-rich phase for both systems and both models. UNIQUAC was much better in predicting the variation of the slope of tie lines with the increase of propionic acid content, possibly due to better description of the combinatorial part of excess Gibbs energy. However, NRTL may be improved in this respect by allowing a free variation of α-parameters instead of using preset combinations of α-parameter values. But, this would increase the complexity of fitting procedure and jeopardize its convergence properties. Another way to improve the NRTL correlation is the variation of the penalizing factor Q, but this would be a pure trial and error procedure.

Conclusions

In this work the liquid-liquid phase equilibria in the two systems comprising water, an ester compound and propionic acid were studied, both experimentally and using available thermodynamic models, in search of suitable solvents for the extraction of propionic acid from water solutions or fermentation broths. The systems investigated were H_2O(1) – *n*-butyl acetate(2) – propionic acid(3) at 35°C (first data at this temperature) and H_2O(1) – dimethyl adipate(2) – propionic acid(3) at 25°C. Binodal curves and tie lines were determined with a combination of turbidimetric titration and refractive index measurements to show fair agreement with literature data. Experimental binodal curves were modeled with the five-parameter Hlavatý equation and tie lines with the two parameter Othmer-Tobias equation to provide

Table 5 – Comparison of experimental and calculated compositions (molar fractions) of equilibrium liquid phases.

H_2O(1) – *n*-butyl acetate(2) – propionic acid(3), 35°C											
Experimental				NRTL				UNIQUAC			
Lower(water) phase		Upper (organic) phase		Lower (water) phase		Upper (organic) phase		Lower (water) phase		Upper (organic) phase	
x_2	x_3	x_2	x_3	x_2	x_3	x_2	x_3	x_2	x_3	x_2	x_3
0.0034	0.0132	**0.8676**	**0.0822**	0.0041	0.0021	0.8777	0.0945	0.0035	0.0154	0.8975	0.0823
0.0029	0.0265	**0.6938**	**0.2351**	0.0049	0.0145	0.6730	0.2407	0.0053	0.0413	0.6776	0.2167
0.0029	0.0308	**0.6572**	**0.2557**	0.0052	0.0180	0.6363	0.2613	0.0056	0.0451	0.6379	0.2364
0.0029	0.0341	**0.5983**	**0.2830**	0.0059	0.0236	0.5827	0.2877	0.0060	0.0497	0.5810	0.2622
0.0031	0.0403	**0.4907**	**0.3185**	0.0076	0.0357	0.4856	0.3228	0.0065	0.0553	0.4810	0.3002
0.0036	0.0493	**0.4205**	**0.3314**	0.0093	0.0458	0.4171	0.3365	0.0067	0.0573	0.4126	0.3203
0.0040	0.0550	**0.3463**	**0.3360**	0.0117	0.0582	0.3475	0.3402	0.0067	0.0582	0.3458	0.3347
0.0052	0.0667	**0.2551**	**0.3269**	0.0166	0.0796	0.2579	0.3287	0.0068	0.0587	0.2617	0.3440
0.0075	0.0819	**0.1833**	**0.3048**	0.0243	0.1064	0.1843	0.3022	0.0069	0.0603	0.1950	0.3431
H_2O(1) – dimethyl adipate(2) – propionic acid(3), 25°C											
0.0027	0.0067	0.6747	0.0601	0.0125	0.0004	0.6598	0.0658	0.0013	0.0057	0.7041	0.0633
0.0029	0.0110	0.6321	0.0877	0.0108	0.0012	0.6122	0.0956	0.0014	0.0082	0.6397	0.0912
0.0032	0.0144	0.5203	0.1478	0.0087	0.0056	0.5027	0.1530	0.0016	0.0133	0.5053	0.1446
0.0037	0.0193	0.4345	0.1830	0.0086	0.0125	0.4212	0.1863	0.0017	0.0172	0.4140	0.1764
0.0040	0.0225	0.3746	0.2017	0.0091	0.0194	0.3671	0.2036	0.0019	0.0202	0.3565	0.1940
0.0046	0.0274	0.3105	0.2160	0.0106	0.0294	0.3094	0.2169	0.0021	0.0244	0.2976	0.2092
0.0058	0.0353	0.2442	0.2228	0.0134	0.0439	0.2494	0.2238	0.0024	0.0308	0.2390	0.2204
0.0066	0.0397	0.2086	0.2221	0.0157	0.0537	0.2182	0.2238	0.0027	0.0356	0.2097	0.2238
0.0080	0.0473	0.1643	0.2157	0.0200	0.0689	0.1789	0.2192	0.0034	0.0443	0.1752	0.2253
0.0093	0.0536	0.1349	0.2071	0.0242	0.0815	0.1529	0.2126	0.0041	0.0521	0.1538	0.2243

excellent correlation of the entire experiment with seven empirical parameters per system. In addition, it was shown that UNIFAC predictive activity coefficient model was not able to describe the data with sufficient accuracy. NRTL and UNIQUAC model parameters were determined from the experimental data using the procedure suggested by Sorensen and Arlt. The correlation was fair, but much worse than that obtained by the purely empirical approach of Hlavatý and Othmer-Tobias.

List of symbols

A	Average absolute deviation of experimental and calculated molar fractions, [1]
A_{1-3}	Parameters of Hlavatý empirical equation for binodal curve, [1]
aq	Subscript denoting aqueous (or lower) phase
B_{1-3}	Parameters of β-empirical equation for binodal curve, [1]
C_{1-3}	Parameters of log γ-empirical equation for binodal curve, [1]
exp	Subscript denoting experimental value
g^{ex}	Molar excess Gibbs energy, [J mol^{-1}]
$g^{ex,C}$	Combinatorial part of molar excess Gibbs energy in UNIQUAC activity coefficient model, [J mol^{-1}]
$g^{ex,R}$	Residual part of molar excess Gibbs energy in UNIQUAC activity coefficient model, [J mol^{-1}]
G	Symbol appearing in NRTL model, exponential function of model parameters, [1]
I	Superscript denoting equilibrium liquid phase I
II	Superscript denoting equilibrium liquid phase II
k	Parameter of Othmer-Tobias correlation describing the distribution coefficient, [1]
mod	Subscript denoting model or calculated value
n	Parameter of Othmer-Tobias correlation describing the curvature of the equilibrium line, [1]
n_b	Number of binodal curve experimental data points
n_c	Number of components
n_D	Refractive index, [1]
n_d	Number of tie line experimental data points
n_g	Number of structural groups in a component
OF_{1-4}	Objective function to be minimized, [1]
org	Subscript denoting organic (or upper) phase
Q	Penalization factor, [1]
q_i	Surface parameter of component i in UNIQUAC activity coefficient model, [1]
Q_k	Surface parameter of structural group k, [1]
R	Gas constant, [J K^{-1} mol^{-1}]
r_i	Volume parameter of component i in UNIQUAC activity coefficient model, [1]
R_k	Volume parameter of structural group k, [1]
T	Temperature, [K]
w_2'	Maximum (equilibrium) solubility of component 2 in component 1 in terms of weight fraction, [1]
w_2"	Weight fraction of component 2 in solution comprising maximum (equilibrium) content of component 1, [1]
w_A	Composition variable of the empirical equations for binodal curve, [1]
w_i	Weight fraction of component i, [1]
x_i	Molar fraction of component i, [1]

z Lattice coordination number

a_{ij} Nonrandomness parameter of NRTL activity coefficient model, [1]

g_i Activity coefficient of component *i*, [1]

Q_i Area fraction of component *i*, [1]

n_{ki} Number of structural groups *k* in component *i*

t_{ij} Interaction parameter of NRTL or UNIQUAC activity coefficient models, [1]

F_i Volume fraction of component *i*, [1]

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Determining and Analyzing the Quality of GNSS RTK Positioning

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Abstract: The constant development of technology brought many changes into the geodetic profession. One of those changes is the usage of GNSS RTK measurement systems. The International Organization for Standardization (ISO) defines procedures to determine the precision of GNSS RTK measurement systems. This paper gives an overview of standard ISO 17123-8:2015 which specifies and defines field procedures to be adopted when determining and evaluating the precision of GNSS RTK field measurement systems and their ancillary equipment. The testing of the precision of GNSS RTK measuring systems Topcon HiPer SR was performed on March 8 and 9, 2018 in the test field at Klaićeva Street in Zagreb, near the Faculty of Geodesy. Coordinates and normal orthometric height present measuring data and based on them empirical standard deviations were calculated and statistical tests performed. Based on the results obtained in testing, it was concluded that the used GNSS RTK measuring system Topcon HiPer SR meets the measuring uncertainty declared by the manufacturer of the instrument.

Keywords: precision, ISO standard, GNSS RTK, CROPOS, positioning

Introduction

The International Organization for Standardization (ISO) is a worldwide organization which consists of national standards bodies. For creating and defining standards in respective fields, technical committees are founded. ISO standards that are defined for geodetic profession are defined by the ISO Technical Committee TC 172 (Optics and Photonics), Subcommittee SC 6 (Geodetic and Surveying Instruments).

The overview of international and national standards for testing and calibration of geodetic measuring instruments directly regulated by ISO/TC 172/SC 6 can be found in Zrinjski et al., (2010), Zrinjski et al., (2011), Zrinjski et al., (2013), Barković et al., (2014) and Zrinjski et al., (2015).

ISO 17123-8:2015

Standard ISO 17123-8:2015 specifies field procedures to be adopted when determining and evaluating the precision (repeatability) of Global Navigation Satellite System (GNSS) field measurement systems in real-time kinematic (RTK) and their ancillary equipment when used in building, surveying and industrial measurements. Primarily, these tests are intended to be field verifications of the suitability of an instrument for the required application at hand and to satisfy the requirements of other standards. They are not proposed as tests for acceptance or performance evaluations that are more comprehensive in nature (ISO, 2015).

Before commencing surveying, it is important to check that the receiver, antenna and their auxiliary equipment are in acceptable condition according to the methods specified in the manufacturer reference manual. Also, the centering precision and precision of the measured antenna height must be considered and be achieved with a standard deviation of 1 mm. The standard specifies two different field procedures: simplified test procedure and the full test procedure (ISO, 2015).

For both test procedures, the test field consists of a base point and two rover points with unknown coordinates which are selected on the field at convenience. The distance between the two rover points must be between 2 and 20 meters. The horizontal distance and height difference between the two rover points must be determined by means of geodetic methods other than RTK and with a precision greater than 3 millimeters, e.g. a total station and a precise level. These values are considered as nominal quantities.

In this paper only the full test procedure is presented. The test is intended for determining the experimental standard deviation for a single position and height measurement (ISO, 2015). The test consists of three series of measurements and each series consists of five sets. Each measurement set consists of successive measurements at points rover 1 and rover 2. The time interval between two consecutive measuring sets should be approximately 5 minutes. That means that the duration of one measuring series will be about 25 minutes. The start of consecutive measuring series should be at least 90 minutes. Hence, the repeated measuring series are intended to eliminate the influence caused by changes in the satellite configuration, changes in ionospheric and tropospheric conditions and other factors (Zrinjski et al., 2015).

When all the field measurements were performed, preliminary checking must be done, i.e. all the individual measurements are compared with the nominal quantities to detect any outlier. For each set j = 1, …, 5 of every series i = 1, 2, 3, the horizontal distance and height difference between the two rover points and their deviations from the nominal quantities are calculated (ISO, 2015):

$$\begin{aligned} D_{i,j} &= \sqrt{\left(x_{i,j,2} - x_{i,j,1}\right)^2 + \left(y_{i,j,2} - y_{i,j,1}\right)^2} \,, \\ \Delta h_{i,j} &= h_{i,j,2} - h_{i,j,1} \,, \\ \varepsilon_{D\,i,j} &= D_{i,j} - D^* \,, \\ \varepsilon_{h\,i,j} &= h_{i,j} - h^* \,, \end{aligned} \tag{1}$$

where $x_{i,j,k}$, $y_{i,j,k}$, $h_{i,j,k}$ are measurements from the j set at the rover point k (k = 1, 2) in the series i, $D_{i,j}$ and $\Delta h_{i,j}$ are the calculated horizontal distance and height difference, respectively, in the j set in series i, D^* and h^* represent the nominal quantities, and finally, $\varepsilon_{D\,i,j}$ and $\varepsilon_{h\,i,j}$ represent the deviations as stated. To determine if any gross errors are present, the calculated deviations must satisfy the following conditions (ISO, 2015):

$$\begin{aligned} \left|\varepsilon_{D\,i,j}\right| &\le 2.5 \cdot \sqrt{2} \cdot s_{xy} \,, \\ \left|\varepsilon_{h\,i,j}\right| &\le 2.5 \cdot \sqrt{2} \cdot s_{h} \,, \end{aligned} \tag{2}$$

where s_{xy} and s_h are predetermined standard deviations according to the full test procedure or the values specified by the manufacturer of the instrument. If any of the two criteria hasn't been fulfilled for any of the calculated distances of height differences, it is possible there are gross error present in the raw measurements and the whole field procedure should be repeated.

After the preliminary checking has been done, and it is determined whether there are any outliers present, the statistical values of interest are calculated. Firstly, by applying the least square adjustment on overall measurements in all the series, the best estimates of x, y and h for every rover point (k = 1, 2) are calculated (ISO, 2015):

$$\begin{aligned} \bar{x}_k &= \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} x_{i,j,k} \,, \\ \bar{y}_k &= \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} y_{i,j,k} \,, \\ \bar{h}_k &= \frac{1}{15}\sum_{i=1}^{3}\sum_{j=1}^{5} h_{i,j,k} \,. \end{aligned} \tag{3}$$

The individual residuals of measured coordinates x, y and h for all the measurements are calculated by subtracting every calculated measurement from the best estimates of the rover point coordinates (ISO, 2015):

$$r_{x\,i,j,k} = \bar{x}_k - x_{i,j,k},$$
$$r_{y\,i,j,k} = \bar{y}_k - y_{i,j,k}, \tag{4}$$
$$r_{h\,i,j,k} = \bar{h}_k - h_{i,j,k}.$$

Furthermore, the above residuals are all squared and summed including measurements for all point index $k = 1$ and $k = 2$ for x, y and h separately as (ISO, 2015):

$$\sum r_x^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{x\,i,j,k}^2,$$
$$\sum r_y^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{y\,i,j,k}^2, \tag{5}$$
$$\sum r_h^2 = \sum_{i=1}^{3}\sum_{j=1}^{5}\sum_{k=1}^{2} r_{h\,i,j,k}^2.$$

The empirical standard deviation of a single measured coordinate x, y and h are calculated as (ISO, 2015):

$$s_x = \sqrt{\frac{\sum r_x^2}{28}},$$
$$s_y = \sqrt{\frac{\sum r_y^2}{28}}, \tag{6}$$
$$s_h = \sqrt{\frac{\sum r_h^2}{28}},$$

where number 28 in the denominator presents the number of freedom degrees in the measurements of individual coordinates (x, y and h). The third formula in the expression above (s_h) gives the empirical standard deviation of the height h.

Finally, the empirical standard deviation of coordinates (x, y) is calculated as (ISO, 2015):

$$s_{xy} = \sqrt{s_x^2 + s_y^2} \,. \tag{7}$$

In general, statistical tests are used to determine whether an experiment belongs to the same population as a given theoretical value, in other words, we determine whether a hypothesis is acceptable or not. The purpose of applying statistical tests is to determine whether the calculated experimental standard deviations belong to the same population as the given theoretical values and to determine whether two samples from different experiments belong to the same population. Statistical tests are carried out using overall standard deviation of coordinates s_{xy} and height s_h obtained from the measurements. Statistical tests can only be applied to the full test procedure. Statistical tests must answer the questions given in Table 1.

Table 1 – Overview of statistical tests (ISO, 2015)

Question	Null hypothesis	Alternative hypothesis
a)	$s_{xy} \le \sigma_{xy}$	$s_{xy} > \sigma_{xy}$
b)	$s_h \le \sigma_h$	$s_h > \sigma_h$
c)	$\sigma_{xy} = \tilde{\sigma}_{xy}$	$\sigma_{xy} \ne \tilde{\sigma}_{xy}$
d)	$\sigma_h = \tilde{\sigma}_h$	$\sigma_h \ne \tilde{\sigma}_h$

Question a)

The null hypothesis is accepted if the calculated empirical standard deviation s_{xy} is smaller than or equal to the corresponding value σ_{xy}, declared by the instrument manufacturer, i.e. if it is fulfilled (ISO, 2015):

$$s_{xy} \le 1.15 \cdot \sigma_{xy} \,. \tag{8}$$

Question b)

The null hypothesis is accepted if the calculated empirical standard deviation s_h is smaller than or equal to the corresponding value σ_h, declared by the instrument manufacturer, i.e. if it is fulfilled (ISO, 2015):

$$s_h \le 1.22 \cdot \sigma_h \,. \tag{9}$$

Question c)

For two different measuring series, the test will indicate if the calculated empirical standard deviations s_{xy} and $\tilde{s}_{xy}$ belong to the same population. The null hypothesis is accepted if it is fulfilled (ISO, 2015):

$$0.59'' \frac{s_{xy}^2}{\tilde{s}_{xy}^2} \quad 1.70\,. \tag{10}$$

Question d)

For two different measuring series, the test will indicate if the calculated empirical standard deviations s_h and $\tilde{s}_h$ belong to the same population. The null hypothesis is accepted if it is fulfilled (ISO, 2015):

$$0.47'' \frac{s_{h}^2}{\tilde{s}_{h}^2} \quad 2.13\,. \tag{11}$$

All the above given expressions for statistical tests are given for the confidence level $k = 0.95$.

Testing and Analysis of the Precision of GNSS RTK Measurement System

The measurements were made in the test field at Klaićeva Street in Zagreb, near the Faculty of Geodesy, University of Zagreb on two points (A – rover 1, B – rover 2). Horizontal distance and height difference between these two points were determined during the first day of measurement on March 8, 2018. Horizontal distance was measured by means of a geodetic total station Topcon ES-65 (Ser. No. YL0085) with declared distance measuring accuracy of ±(2 mm + 2 ppm) (Topcon, 2018a) in four repetitions (two in both instrument positions). Nominal horizontal distance was calculated as arithmetic mean from repeated measurements and is 16.309 m. Height difference was determined by means of a precise level Leica NAK2 (Ser. No. 5048229) with the declared accuracy of 0.3 mm in two independent repetitions (Leica, 2018). Nominal height difference was calculated as arithmetic mean of these two measurements and it amounts 0.871 m.

The receiver used to collect measurements was Topcon HiPer SR (Ser. No. 1054-16245) with a declared measuring uncertainty for RTK measurements of ±(10 mm + 0.8 ppm) horizontally and ±(15 mm + 1 ppm) vertically (Topcon, 2018b).

To perform GNSS RTK measurements, the receiver was connected to CROatian POsitioning System (CROPOS) using High Precision Real-time Positioning Service (VPPS), which guarantees the accuracy of RTK measurements ±0.02 m horizontally and ±0.04 m vertically (CROPOS, 2018). The first measuring session (containing 3 series with 5 sets of measurements) was held on March 8, 2018 from 11:00 until 14:30 (Table 2 and Table 3), and the second session was held on March 9, 2018 from 7:30 until 11:00 (Table 4 and Table 5). The coordinates (*E*, *N*) of the two rover points (A, B) were determined in the Croatian Terrestrial Reference System 1996/Transverse Mercator (HTRS96/TM) and (*H*) in the Croatian Height Reference System 1971 of normal orthometric heights (HVRS71) (Official Gazette, 2004). All data was collected in a single epoch.

Measurement data was processed using Microsoft Excel 2016 according to the above presented ISO 17123-8:2015 full test procedure.

Table 2 – Measurements and nominal data deviations (first session)

Seq. No.	Series	Set	Rover point	Measurement			Horizontal distance	Height difference	Deviations	
				m			m	m	mm	
	i	j	k	y (E)	x (N)	h (H)	D_j	Δh_j	$\varepsilon_{D\,i,j}$	$\varepsilon_{h\,i,j}$
1	1	1	1	458390.508	5074463.974	119.178	–	–	–	–
2	1	1	2	458405.314	5074470.737	118.309	16.277	–0.869	–1	2
3	1	2	1	458390.509	5074463.975	119.188	–	–	–	–
4	1	2	2	458405.315	5074470.742	118.312	16.279	–0.876	1	–5
5	1	3	1	458390.506	5074463.981	119.186	–	–	–	–
6	1	3	2	458405.313	5074470.743	118.307	16.278	–0.879	0	–8
7	1	4	1	458390.508	5074463.984	119.183	–	–	–	–
8	1	4	2	458405.309	5074470.740	118.312	16.270	–0.871	–8	0
9	1	5	1	458390.508	5074463.974	119.192	–	–	–	–
10	1	5	2	458405.310	5074470.740	118.311	16.275	–0.881	–3	–10
11	2	6	1	458390.501	5074463.975	119.194	–	–	–	–
12	2	6	2	458405.308	5074470.736	118.319	16.278	–0.875	0	–4
13	2	7	1	458390.504	5074463.977	119.185	–	–	–	–
14	2	7	2	458405.305	5074470.737	118.328	16.272	–0.857	–6	14
15	2	8	1	458390.499	5074463.977	119.186	–	–	–	–

Seq. No.	Series	Set	Rover point	Measurement			Hori-zontal distance	Height differ-ence	Deviations	
				m			m	m	mm	
	i	j	k	y (E)	x (N)	h (H)	D_j	Δh_j	$\varepsilon_{D\,i,j}$	$\varepsilon_{h\,i,j}$
16	2	8	2	458405.311	5074470.737	118.307	16.282	–0.879	4	–8
17	2	9	1	458390.502	5074463.976	119.189	–	–	–	–
18	2	9	2	458405.312	5074470.726	118.318	16.276	–0.871	–2	0
19	2	10	1	458390.507	5074463.964	119.205	–	–	–	–
20	2	10	2	458405.312	5074470.727	118.329	16.277	–0.876	–1	–5
21	3	11	1	458390.504	5074463.972	119.191	–	–	–	–
22	3	11	2	458405.301	5074470.726	118.321	16.266	–0.870	–12	1
23	3	12	1	458390.503	5074463.978	119.181	–	–	–	–
24	3	12	2	458405.309	5074470.720	118.317	16.269	–0.864	–9	7
25	3	13	1	458390.500	5074463.974	119.178	–	–	–	–
26	3	13	2	458405.300	5074470.731	118.310	16.270	–0.868	–8	3
27	3	14	1	458390.502	5074463.979	119.168	–	–	–	–
28	3	14	2	458405.298	5074470.738	118.310	16.267	–0.858	–11	13
29	3	15	1	458390.502	5074463.975	119.191	–	–	–	–
30	3	15	2	458405.300	5074470.732	118.302	16.268	–0.889	–10	–18
Limit of each deviation [mm]				–	–	–	–	–	±39	±57

Table 3 – Measurements, residuals and experimental standard deviation (first session)

Seq. No.	Series	Set	Rover point	Measurement			Residual			Squared residual		
				m			mm			mm²		
	i	j	k	y (E)	x (N)	h (H)	r_y	r_x	r_h	r_y^2	r_x^2	r_h^2
1	1	1	1	458390.508	5074463.974	119.178	–4	2	8	16	4	64
2	1	1	2	458405.314	5074470.737	118.309	–6	–3	5	36	9	25
3	1	2	1	458390.509	5074463.975	119.188	–5	1	–2	25	1	4
4	1	2	2	458405.315	5074470.742	118.312	–7	–8	2	49	64	4
5	1	3	1	458390.506	5074463.981	119.186	–2	–5	0	4	25	0
6	1	3	2	458405.313	5074470.743	118.307	–5	–9	7	25	81	49

Seq. No.	Series	Set	Rover point	Measurement			Residual			Squared residual		
				m			mm			mm^2		
	i	*j*	*k*	*y (E)*	*x (N)*	*h (H)*	r_y	r_x	r_h	r_y^2	r_x^2	r_h^2
7	1	4	1	458390.508	5074463.984	119.183	–4	–8	3	16	64	9
8	1	4	2	458405.309	5074470.740	118.312	–1	–6	2	1	36	4
9	1	5	1	458390.508	5074463.974	119.192	–4	2	–6	16	4	36
10	1	5	2	458405.310	5074470.740	118.311	–2	–6	3	4	36	9
11	2	6	1	458390.501	5074463.975	119.194	3	1	–8	9	1	64
12	2	6	2	458405.308	5074470.736	118.319	0	–2	–5	0	4	25
13	2	7	1	458390.504	5074463.977	119.185	0	–1	1	0	1	1
14	2	7	2	458405.305	5074470.737	118.328	3	–3	–14	9	9	196
15	2	8	1	458390.499	5074463.977	119.186	5	–1	0	25	1	0
16	2	8	2	458405.311	5074470.737	118.307	–3	–3	7	9	9	49
17	2	9	1	458390.502	5074463.976	119.189	2	0	–3	4	0	9
18	2	9	2	458405.312	5074470.726	118.318	–4	8	–4	16	64	16
19	2	10	1	458390.507	5074463.964	119.205	–3	12	–19	9	144	361
20	2	10	2	458405.312	5074470.727	118.329	–4	7	–15	16	49	225
21	3	11	1	458390.504	5074463.972	119.191	0	4	–5	0	16	25
22	3	11	2	458405.301	5074470.726	118.321	7	8	–7	49	64	49
23	3	12	1	458390.503	5074463.978	119.181	1	–2	5	1	4	25
24	3	12	2	458405.309	5074470.720	118.317	–1	14	–3	1	196	9
25	3	13	1	458390.500	5074463.974	119.178	4	2	8	16	4	64
26	3	13	2	458405.300	5074470.731	118.310	8	3	4	64	9	16
27	3	14	1	458390.502	5074463.979	119.168	2	–3	18	4	9	324
28	3	14	2	458405.298	5074470.738	118.310	10	–4	4	100	16	16
29	3	15	1	458390.502	5074463.975	119.191	2	1	–5	4	1	25
30	3	15	2	458405.300	5074470.732	118.302	8	2	12	64	4	144
Average over series			1	458390.504	5074463.976	119.186	–	–	–	–	–	–
			2	458405.308	5074470.734	118.314						
Summation of the squared residual				–	–	–	–	–	–	592	929	1847
Experimental standard deviation s				4.60	5.76	8.12	–	–	–	–	–	–

Table 4 – Measurements and nominal data deviations (second session)

Seq. No.	Series	Set	Rover point	Measurement			Horizontal distance	Height difference	Deviations	
				m			m	m	mm	
	i	j	k	y (E)	x (N)	h (H)	D_j	Δh_j	$\varepsilon_{D\,i,j}$	$\varepsilon_{h\,i,j}$
1	1	1	1	458390.500	5074463.972	119.188	–	–	–	–
2	1	1	2	458405.307	5074470.735	118.319	16.278	–0.869	0	2
3	1	2	1	458390.499	5074463.968	119.195	–	–	–	–
4	1	2	2	458405.307	5074470.728	118.327	16.278	–0.868	0	3
5	1	3	1	458390.498	5074463.968	119.195	–	–	–	–
6	1	3	2	458405.312	5074470.730	118.329	16.284	–0.866	6	5
7	1	4	1	458390.501	5074463.965	119.198	–	–	–	–
8	1	4	2	458405.314	5074470.727	118.336	16.283	–0.862	5	9
9	1	5	1	458390.499	5074463.970	119.196	–	–	–	–
10	1	5	2	458405.312	5074470.734	118.317	16.284	–0.879	6	–8
11	2	6	1	458390.498	5074463.970	119.180	–	–	–	–
12	2	6	2	458405.311	5074470.736	118.312	16.285	–0.868	7	3
13	2	7	1	458390.496	5074463.972	119.186	–	–	–	–
14	2	7	2	458405.312	5074470.733	118.312	16.286	–0.874	8	–3
15	2	8	1	458390.499	5074463.970	119.186	–	–	–	–
16	2	8	2	458405.307	5074470.733	118.319	16.279	–0.867	1	4
17	2	9	1	458390.502	5074463.970	119.181	–	–	–	–
18	2	9	2	458405.307	5074470.729	118.321	16.275	–0.860	–3	11
19	2	10	1	458390.502	5074463.969	119.183	–	–	–	–
20	2	10	2	458405.310	5074470.730	118.317	16.278	–0.866	0	5
21	3	11	1	458390.498	5074463.971	119.182	–	–	–	–
22	3	11	2	458405.309	5074470.733	118.316	16.282	–0.866	4	5
23	3	12	1	458390.501	5074463.971	119.179	–	–	–	–
24	3	12	2	458405.308	5074470.735	118.306	16.279	–0.873	1	–2
25	3	13	1	458390.500	5074463.965	119.182	–	–	–	–
26	3	13	2	458405.312	5074470.735	118.310	16.286	–0.872	8	–1
27	3	14	1	458390.497	5074463.966	119.189	–	–	–	–
28	3	14	2	458405.309	5074470.731	118.308	16.284	–0.881	6	–10
29	3	15	1	458390.496	5074463.969	119.187	–	–	–	–
30	3	15	2	458405.306	5074470.734	118.317	16.282	–0.870	4	1
Limit of each deviation [mm]				–	–	–	–	–	±39	±57

Table 5 – Measurements, residuals and experimental standard deviation (second session)

Seq. No.	Series	Set	Rover point	Measurement m			Residual mm			Squared residual mm²		
	i	*j*	*k*	*y (E)*	*x (N)*	*h (H)*	r_y	r_x	r_h	r_y^2	r_x^2	r_h^2
1	1	1	1	458390.500	5074463.972	119.188	–1	–3	–1	1	9	1
2	1	1	2	458405.307	5074470.735	118.319	3	–3	–1	9	9	1
3	1	2	1	458390.499	5074463.968	119.195	0	1	–8	0	1	64
4	1	2	2	458405.307	5074470.728	118.327	3	4	–9	9	16	81
5	1	3	1	458390.498	5074463.968	119.195	1	1	–8	1	1	64
6	1	3	2	458405.312	5074470.730	118.329	–2	2	–11	4	4	121
7	1	4	1	458390.501	5074463.965	119.198	–2	4	–11	4	16	121
8	1	4	2	458405.314	5074470.727	118.336	–4	5	–18	16	25	324
9	1	5	1	458390.499	5074463.970	119.196	0	–1	–9	0	1	81
10	1	5	2	458405.312	5074470.734	118.317	–2	–2	1	4	4	1
11	2	6	1	458390.498	5074463.970	119.180	1	–1	7	1	1	49
12	2	6	2	458405.311	5074470.736	118.312	–1	–4	6	1	16	36
13	2	7	1	458390.496	5074463.972	119.186	3	–3	1	9	9	1
14	2	7	2	458405.312	5074470.733	118.312	–2	–1	6	4	1	36
15	2	8	1	458390.499	5074463.970	119.186	0	–1	1	0	1	1
16	2	8	2	458405.307	5074470.733	118.319	3	–1	–1	9	1	1
17	2	9	1	458390.502	5074463.970	119.181	–3	–1	6	9	1	36
18	2	9	2	458405.307	5074470.729	118.321	3	3	–3	9	9	9
19	2	10	1	458390.502	5074463.969	119.183	–3	0	4	9	0	16
20	2	10	2	458405.310	5074470.730	118.317	0	2	1	0	4	1
21	3	11	1	458390.498	5074463.971	119.182	1	–2	5	1	4	25
22	3	11	2	458405.309	5074470.733	118.316	1	–1	2	1	1	4
23	3	12	1	458390.501	5074463.971	119.179	–2	–2	8	4	4	64
24	3	12	2	458405.308	5074470.735	118.306	2	–3	12	4	9	144
25	3	13	1	458390.500	5074463.965	119.182	–1	4	5	1	16	25
26	3	13	2	458405.312	5074470.735	118.310	–2	–3	8	4	9	64
27	3	14	1	458390.497	5074463.966	119.189	2	3	–2	4	9	4
28	3	14	2	458405.309	5074470.731	118.308	1	1	10	1	1	100
29	3	15	1	458390.496	5074463.969	119.187	3	0	0	9	0	0
30	3	15	2	458405.306	5074470.734	118.317	4	–2	1	16	4	1
Average over series			1	458390.499	5074463.969	119.187	–	–	–	–	–	–
			2	458405.310	5074470.732	118.318						
Summation of the squared residual				–	–	–	–	–	–	144	186	1476
Experimental standard deviation s				2.27	2.58	7.26	–	–	–	–	–	–

Table 6 – Results of statistical tests

Question	Null hypothesis	Obtained result
a)	$s_{xy} \leq \sigma_{xy}$	7.37 ≤ 12.65
	$\tilde{s}_{xy} \leq \sigma_{xy}$	3.43 ≤ 12.65
b)	$s_h \leq \sigma_h$	8.12 ≤ 19.52
	$\tilde{s}_h \leq \sigma_h$	7.26 ≤ 19.52
c)	$\sigma_{xy} = \tilde{\sigma}_{xy}$	0.59 ≤ !4.61 ≤ !1.70
d)	$\sigma_h = \tilde{\sigma}_h$	0.47 ≤ 1.25 ≤ 2.13

The statistical test according to question a) is fulfilled and the null hypothesis is accepted. With a 95% probability it's concluded that the calculated experimental standard deviations of coordinates (x, y) for both measuring sessions (s_{xy} and $\tilde{s}_{xy}$) are smaller or equal to a corresponding theoretical value stated by the manufacturer (Table 6). Measurements were carried out with the expected precision.

The statistical test according to question b) is fulfilled and the null hypothesis is accepted. With a 95% probability it's concluded that the calculated experimental standard deviations of height for both measuring sessions (s_h and $\tilde{s}_h$) are smaller or equal to a corresponding theoretical value stated by the manufacturer (Table 6). Measurements were carried out with the expected precision.

The statistical test according to question c) is not fulfilled, the null hypothesis stating that the experimental standard deviations s_{xy} and $\tilde{s}_{xy}$ belong to the same population is rejected at the confidence level of 95% and alternative hypothesis is accepted (Table 6).

The statistical test according to question d) is fulfilled, the null hypothesis stating that the experimental standard deviations s_h and $\tilde{s}_h$ belong to the same population is accepted at the confidence level of 95% (Table 6).

Conclusions

Quality testing and calibration of surveying instruments are the basis of geodetic profession. Surveyors carry great responsibility in their work since they have a direct impact on property-legal affairs as well as forming important industrial, traffic and construction objects in the field. The accuracy guarantee of geodetic field works is possible only by thorough testing of surveying instruments. The best way to perform testing is by using ISO standards, since they are a set of standardized steps necessary to perform a reliable testing.

This paper gives a detailed review of standard ISO 17123-8:2015 for testing GNSS RTK measuring systems, as well as gathering measurements in the test field at Klaićeva Street in Zagreb, near the Faculty of Geodesy, University of Zagreb and their processing according to this standard. Subject of testing was Topcon HiPer SR GNSS receiver (Ser. No. 1054-16245), with declared accuracy of ±(10 mm + 0.8 ppm) horizontally and ±(15 mm + 1 ppm) vertically. RTK measurements are performed by connecting to CROPOS and using VPPS service. Coordinates of measured points are given in current official horizontal and vertical reference coordinate systems in Croatia (*E*, *N*, *H*).

Testing yielded the results of horizontal accuracy with a standard deviation of 7.37 mm for the first and 3.43 mm for the second measuring session. The achieved vertical accuracy was with a standard deviation of 8.12 mm for the first and 7.26 mm for the second measuring session. Null hypothesis was accepted in statistical tests according to questions a), b) and d), and alternative hypothesis was accepted in a statistical test according to question c). The conclusion is that measuring system Topcon HiPer SR meets measurement uncertainty needed for RTK measurements declared by the instrument manufacturer; however experimental standard deviations in horizontal plane did not belong in the same population.

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PART III – WHO IS WHO

Introduction to “Who is Who” in the Croatian Academy of Engineering

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Vice-President of the Academy

“Who is Who in the Croatian Academy of Engineering” includes pictures and information about: Emeriti of the Academy, Full Members of the Academy, Associates of the Academy, International Members of the Academy and Honorary Members of the Academy.

The information was updated on May 2, 2018. The basic information about Department membership and status is given, followed by degrees earned, year of earning the degree, area and institution giving the degree, contact information and key words defining members areas of scientific and professional activity and duties in the Academy.

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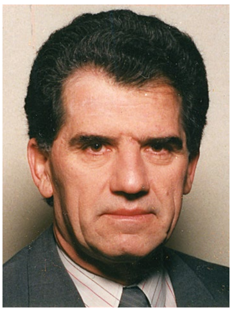

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	**Čavlina, Nikola**, Prof. Ph.D. Born: 1950 Department of Power Systems Full Member of the Academy (admitted 1998) B.Sc. in Electrical Engineering (1974), M.Sc. in Electrical Engineering (1979), Ph.D. in Electrical Engineering (1991), all from the Faculty of Electrical Engineering and Computing, University of Zagreb University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb tel: +385 1 6129999, fax: +385 1 6129007 e-mail: nikola.cavlina@fer.hr Nuclear Energy and Technology, Nuclear Reactor Safety, Environmental Imapct Assessment *Secretary of the Department of Power Systems (2009–2013) and (2013–2017)* *Chairman of the Committee for International Co-operation (2017–2021)*
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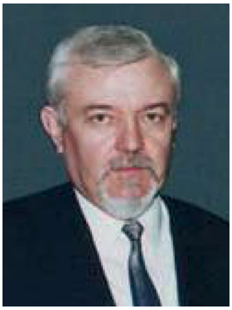
Naval Architecture, Ship Structures, Naval Hydrodynamics, Theory of Sea Keeping, Numerical Methods, Offshore Technology (Design)</td></tr>
<tr><td></td><td>Črnko, Josip, Prof. Ph.D.
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Separation of Metals from Secondary Raw Materials, Thermotechnology, Industrial Furnaces, Mathematical Models of Cooling of Steel Semiproducts, Possibilities of Structural Improvements in Heating Furnaces
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Deputy-Secretary of the Department of Mechanical Engineering and Naval Architecture of the Academy (2013–2017)
Member of the Committee for Economic and Regional Co-operation (2013–2017)

	**Dragčević, Zvonko**, Prof. Ph.D. Born: 1946 Department of Textile Technology Full Member of the Academy (admitted 2007) B.Sc. in Textile Technology (1971), M.Sc. in Textile Technology (1976), Ph.D. in Textile Technology (1981), all from the Faculty of Textile Technology, University of Zagreb University of Zagreb, Faculty of Textile Technology, Prilaz baruna Filipovića 30/III, 10000 Zagreb tel: +385 1 3712535, fax: +385 1 3712535 e-mail: zvonko.dragcevic@ttf.hr, zvonko.dragcevic@zg.t-com.hr; http://www.ttf.unizg.hr/ Industrial Engineering, Ergonomics, Technical Textile, Corrosion and Protection of Materials *Member of the Committee for Awards (2017–2021)* *Chairman of the Committee for Awards (2013–2017)* *Member of the Science Foundation Committee (2013–2017) and (2017–2021)*
	**Dragović-Uzelac, Verica**, Prof. Ph.D. Born: 1970 Department of Bioprocess Engineering Associate of the Academy (admitted 2017) B.Sc. in Biotechnology (1993), M.Sc. in Biotechnology (1998), Ph.D. in Biotechnology (1996), all at the Faculty of Food Technology and Biotechnology, University of Zagreb tel: +385 1 4605 128; fax: +385 1 4605 072 e-mail: vdragov@pbf.hr Food technology, Novel technique, Nutrition, Functional food, Bioactive molecules
	**Duić, Neven**, Prof. Ph.D. Born: 1965 Department of Power Systems Full Member of the Academy (admitted 2002) B.Sc. in Mechanical Engineering (1990), M.Sc. in Mechanical Engineering (1993), Ph.D. in Mechanical Engineering (1998), all from the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, 10000 Zagreb tel: +385 1 6168126, fax: +385 1 6156940 e-mail: Neven.Duic@fsb.hr; http://powerlab.fsb.hr/neven Energy Policy and Planning, Climate Change Mitigation, Energy Economics, Sustainable Development Policy and Resource Planning, Research and Innovation Policy, Combustion Engineering and Modelling *Secretary of the Department of Power Systems (2017–2021)* *Member of the Science Council (2010–2013)* *Member of the Committee for International Cooperation (2013–2017)*

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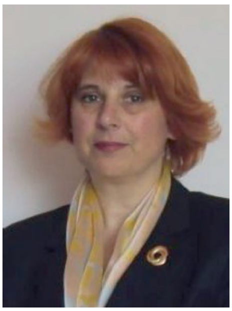
Head of the Centre for Lifelong Education (2005-2015)



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Processes of clothing production, intelligent clothing, clothing thermal properties, high-tech joining methods of textile

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Geodesy, Cartography, Map Projections, Digital Cartography, Geoinformatics,
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Genetic Toxicology, Ecotoxicology, Genotoxicity Action of Environmental Agents Antimutagenicity of Glucosinolates
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<tr><td></td><td>Franković, Bernard, Prof. Ph.D.
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</table>

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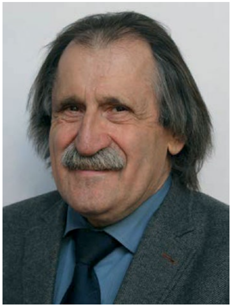

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B.Sc. in Petroleum Engineering (1980), Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, M.Sc. in Petroleum Engineering (1986) from Faculty of Mining and Geology, University of Belgrade, Ph.D in Petroleum Engineering (1993), Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb
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Drilling Technology, Drilling Fluids, Well Cementing, Workover and Completion Fluids, Environment Protection in Petroleum Engineering, Waste Management in Petroleum Engineering
Secretary-General of the Academy (2017–2021)
Member of the Scientific Council of the Academy (2013–2017)

Geršak, Jelka, Prof. Ph.D.
Born: 1954
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Clothing Engineering, Mechanics of Textile Materials, Objective Evaluation of Materials and Clothing, Modelling of Complex Textile Structures, Comfort, Thermo-physiological Comfort of Clothing, Intelligent Clothing

Glasnović, Antun, Prof. Ph.D.
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Separation Processes; Characterization of System, Design and Operation of Separation and Contacting Processes (Comminution, Filtration, Drying, Chrystallization, Mixing), Newton and Nonnewton Fluid Dynamic, Suspension, Rheology
Secretary of the Department of Chemical Engineering (2013–2017)
Deputy-Member of the HATZ Scientific Council (2017–2021)

Gold, Hrvoje, Prof. Ph.D.
Born: 1951
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Intelligent Transportation Systems, Transport Optimization, Remote Sensing
Secretary of the Department of Transport (2017–2021)

Golubović, Adrijano, Prof. Ph.D.
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Department of Graphical Engineering
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Graphic Technology, Chemical Technology, Analytical Chemistry, Surface Technology, Materials in Printing Processes, Colorimetric Measurement in Graphic Processes

Gomzi, Zoran, Prof. Ph.D.
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Chemical Engineering, Chemical Reaction Engineering, Kinetics and modeling,
Process Design and Development, Mathematical Modeling, Education
Secretary of the Department of Chemical Engineering and the Related Fields (2000-2003)
Member of the Scientific Council (2010-2013) and (2013–2017)

Grancarić, Ana Marija, Prof. Emer. Ph.D.
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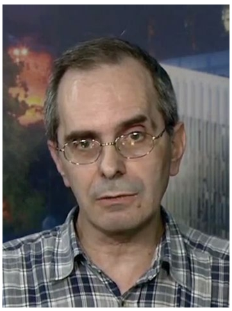
Electrical Engineering, Strategic Energy Planning, Energy Legislation, Power System Planning and Scheduling, Energy Sector Organization and Management, Energy Supply Costs and Energy Pricing Policy
Member of the Science Foundation Committee (2013–2017)
Chairman of the Committee for Development and Regional Relations (2005–2009)
Secretary-General of the Academy (2005–2009) and (2009–2013)

	**Grbac, Ivica**, Prof. Ph.D. Born: 1955 Department of Bioprocess Engineering Full Member of the Academy (admitted 2004) B.Sc. Forestry (1978), M.Sc. Forestry (1985), Ph.D. Forestry (1988) all from the Faculty of Forestry, University of Zagreb University of Zagreb, Faculty of Forestry, Svetošimunska 25, 10000 Zagreb tel: +385 1 2352454, fax: +385 1 2352531 e-mail: ivica.grbac55@gmail.com Furniture and Medicine Design, Construction and Quality of Wood Products, Interdisciplinary Research, Forestry, Wood Industry *Member of the Committee for Ethics (2013 – 2017) and (2017 – 2021)*
	**Grbavac, Vitomir**, Prof. Ph.D. Born: 1954 Department of Transport Full Member of the Academy (admitted 2004) B. Sc. (1980), Faculty of Organization and Informatics, University of Zagreb, B.Sc. law (1984), Faculty of Law, Zagreb, Ph.D Law (1986), Faculty of Law, University of Zagreb University of Zagreb, Faculty of Agriculture, Svetošimunska 25, 10000 Zagreb tel: +385 1 2393620, e-mail: Vitomir.Grbavac@hatz.hr Information and Communication Systems in Traffic, Information Systems, Evolution of Information Technology, Development Computer Systems, e-Education in Traffic
	**Grgić, Davor**, Assist. Prof. Ph.D. Born: 1959 Department of Power Systems Associate of the Academy (admitted 2002) B.Sc. in Electrical Engineering (1981), M.Sc. in Electrical Engineering (1989), Ph.D. in Electrical Engineering (2001) all from the Faculty of Electrical Engineering and Computing, University of Zagreb University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb tel: +385 1 6129994 e-mail: davor.grgic@fer.hr Nuclear Power Plants *Member of the Scientific Council (2017–2021)*

Grgić, Mislav, Prof. Ph.D.
Born: 1973
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Image and Video Compression, Digital Mammography, Face Recognition
Member of the HATZ Committee for International Co-operation (2009-2013)

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Digital Image and Video Processing, Picture Quality Assessment, Digital Television
Member of the Committee for Awards (2013–2017) and (2017-2021)
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Grladinović, Tomislav, Assoc. Prof. Ph.D.
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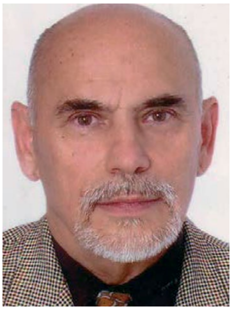
Biotechnology, Wood Technology, Production Management, Simulation Modeling, Computers in Simulation

	**Guzović, Zvonimir**, Prof. Ph.D. Born: 1958 Department of Power Systems Associate Member of the Academy (admitted 2017) B.Sc. in Mechanical Engineering (1982), M.Sc. in Mechanical Engineering (1988), Ph.D. in Mechanical Engineering (1998), all from the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, 10000 Zagreb tel: +385 1 6168532, fax: +385 1 6156940 e-mail: zvonimir.guzovic@fsb.hr; Aerodynamics, thermodynamics and heat transfer in steam and gas turbines; small hydro, geothermal and wind power plants
	**Haznadar, Zijad**, Prof. Ph.D. Born: 1935 Department of Electrical Engineering and Electronics Emeritus of the Academy (admitted 1993) B.Sc. Electrical Engineering (1959), M.Sc. Electrical Engineering, Ph.D. Electrical Engineering, (1964), all from the Faculty of Electrical Engineering, University of Zagreb University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb tel: +385 1 6129811, fax: +385 1 6170201, e-mail: zijad.haznadar@fer.hr Theory of Electromagnetic Fields, Numerical Calculation in Electrical Engineering *Secretary of the Department of Electrical Engineering and Electronics (1993 – 1997)* *Member of the Scientific Council (2010-2013)*
	**Herceg, Zoran,** Prof. Ph.D. Born: 1969 Department of Bioprocess Engineering Full Member of the Academy (admitted 2013) B.Sc. in Biotechnical Sciences (1994), M.Sc. (1997), Ph.D. in Food Technology (2000), all from University of Zagreb, Faculty of Food Technology and Biotechnology University of Zagreb, Faculty of Food Technology and Biotechnology, Pierottijeva 6, 10000 Zagreb tel: +385 1 4605037 e-mail: zherceg@pbf.hr Food Engineering, Innovative technique of food processing *Head of Biotechnical Center (2017-2021)*



Hnatko, Emil, Prof. Ph.D.
Born: 1941
Department of Transport
Emeritus of the Academy (admitted 2004)
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Engines and Vehicles, Thermodynamics and Construction, Maintenance of Internal Comobustion Engines and Motor Vehicles
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Deputy-Member of the Scientific Council (2013–2017)

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Computer Design, Diagnostics, Reliability, Fault Tolerance, Automation, Process Control, Image Processing

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Injection moulding, Extrusion, Additive Manufacturing, Recycling, Material Data

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Forestry Mechanization, Terrain-vehicle Systems, Special Forest Vehicles

Horvat, Predrag, Prof. Ph.D.
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Bioproces Engineering; Industrial Biotechnology

Hraste, Marin, Prof. Ph.D.
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Chemical Engineering, Unit Operation Transport Phenomena, Engineering of Particulate Systems: Particle Systems and Use of their Description to Predict Behavior in a Given Geometrical Shape
Secretary of the Department of Chemical Engineering of the Academy (1993–1997)

	**Hruškar, Mirjana**, Prof. Ph.D. Born 1966 Department of Bioprocess Engineering Associate of the Academy (admitted 2017) B.Sc. (1991), Faculty of Food Technology and Biotechnology, University of Zagreb, M.Sc. in Biotechnical Sciences (1997), Faculty of Food Technology and Biotechnology, University of Zagreb, Ph.D. in Biotechnical Sciences (2001), Faculty of Food Technology and Biotechnology, University of Zagreb, e-mail: mirjana.hruskar@unizg.hr; http://www.unizg.hr/o-sveucilistu/sveucilisna-tijela-i-sluzbe/prorektori/; http://www.pbf.unizg.hr/zavodi/zavod_za_poznavanje_i_kontrolu_sirovina_i_prehrambenih_proizvoda/laboratorij_ Food Safety, Food Quality, Food Analysis, Sensory Analysis, Quality Management
	**Ilić, Ivan**, Prof. emer. Ph.D. Born: 1934 Department of Electrical Engineering and Electronics Emeritus of the Academy (admitted 1994) B.Sc. Electrical Engineering (1956), M.Sc. Electrical Engineering (-), Ph.D. Electrical Engineering (1972), all from the Faculty of Electrical Engineering, University of Zagreb University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb tel:+385 1 6129639, fax: +385 1 6129705, e-mail: ivan.ilic@esa.fer.hr Electrical Engineering, Electrical Machines, Drive
	**Jambreković, Vladimir**, Prof. Ph.D. Born: 1962 Department of Bioprocess Engineering Full Member of the Academy (admitted 2015) B.Sc. in Wood technology (1991), University of Zagreb, Faculty of Forestry, M.Sc. (1996), Scientific Area of Biotechnical Sciences, Scientific Field of Wood Technology, University of Zagreb, Faculty of Forestry, Ph.D. (2000), Scientific Area of Biotechnical Sciences, Scientific Field of Forestry, University of Zagreb, Faculty of Forestry Dean – University of Zagreb Faculty of Forestry, Svetošimunska cesta 25, 10002 Zagreb tel: +385 1 2352479 fax: +385 1 2352544 e-mail: vjambrekovic@sumfak.hr Wooden composite materials *Deputy-Head of the Biotechnical Center (2017–2021)*

Janović, Zvonimir, Prof. Ph.D.
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Department of Chemical Engineering
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Chemical Engineering, Petrochemistry, Polymer Materials, Petrochemical Processes and Products, Polymerization Processes, High Performance Polymeric Materials, Rheologycal Modifiers
Secretary of the Department of Chemical Engineering of the Academy (2005 – 2009)

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Mechanical Engineering Design, Operational Strength, Gear Design, Damage Tolerant Design, Reliability, Fatigue Life Prediction, Mean Stress Influence on Fatigue Assessment, Fatigue Assessment at Combined HCF/LCF Loadin

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Robotics, Artificial Intelligence, Computer Methods in Designing and Programming of Automatic Systems
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Deputy-Secretary of the Department of Systems and Cybernetics (2017 – 2021)
Member of the Committee of Science Foundation (2017 – 2021)
Secretary of the Department of Systems and Cybernetics (2013 – 2017)
Member of the Committee for International Co-operation (2013 – 2017)

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University of Rijeka, Faculty of Engineering, Vukovarska 58, 51000 Rijeka, Croatia
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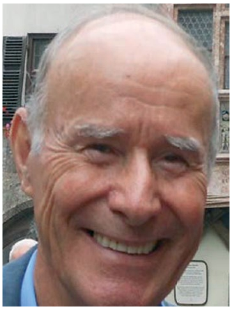
Wearable Antennas and Circuits, Self-adaptive Systems, Biomedical Applications, Computational Electromagnetics, Wave Propagation and Bioeffects of Radiation

	Jović, Franjo, Prof. Ph.D. Born: 1940 Department of Systems and Cybernetics Emeritus of the Academy (admitted 1993) B.Sc. Electrical Engineering (1963), M.Sc. Electrical Engineering (1967), Ph.D. Electrical Engineering (1972), all from the Faculty of Electrical Engineering and Computing, University of Zagreb University of Osijek, Faculty of Electrical Engineering, Kneza Trpimira bb, 31000 Osijek tel: +385 31 224615, fax: +385 31 224605 e-mail: fjovic90@gmail.com Process Control, Artificial Intelligence, Information Processing, Functional Networks, Process Monitoring, System Modeling, Qualitative Modeling *Chairman of the Committee for Ethics of the Academy (2009–2013) and (2013–2017)* *Deputy-Secretary of the Department of Systems and Cybernetics of the Academy (2013-2017)*
	**Jukić, Ante**, Prof. Ph.D. Born: 1971 Department of Chemical Engineering Associate of the Academy (admitted 2017) B.Sc. (1997), M.S. Chem. (2001), Ph.D. Chem. Eng. (2004) University of Zagreb, Faculty of Chemical Engineering and Technology, Marulićev trg 19, 10000 Zagreb tel: +385 1 4597281, fax: +385 1 4597260 e-mail: ajukic@fkit.hr Polymerization Processes, Functional and Nanostructured Polymer Materials, Energy and Fuels *Deputy-chairman of the Council of the centers and Deputy Head of the Center for Environmental Protection and Development of Sustainable Technologies (2017-2021*
	**Jukić, Tihomir,** Assoc. Prof. Ph.D. Born: 1954 Department of Architecture and Urban Planning Full Member of the Academy (admitted 2005) B.Sc. in Architecture (1979), M.Sc. in Architecture (1985), Faculty of Architecture, University of Zagreb, M.Sc. in Architecture, Faculty of Architecture, University of Twente, Ph.D. in Architecture (1998), Faculty of Architecture, University of Zagreb University of Zagreb, Faculty of Architecture, Kačićeva 26, 10000 Zagreb e-mail: jukic.tihomir@arhitekt.hr Urbanism, Environmental Planning *Secretary of the Department of Architecture and Urban Planning (2009–2013) and (2013–2017)* *Deputy-Member of the HATZ Scientific Council (2017–2021)*

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Member of the Scientific Council (2010-2013)

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Operational Research, Mathematical Modelling, Data Modelling, Software for Linear Programming and Related Fields, Production Planning Software, Business Process Reengineering, Information Systems, Natural Language Processing

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Casting Technology, Casting Alloys, Wear-resistant Casting Alloys

Katović, Drago, Prof. Ph.D.
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Textile Chemistry, Determination of Iron and Copper, Free Formaldehyde, Polycarboxylic Acids, Durable Press Finishing, Microwave Treatment

<table>
<tr><td></td><td>Kelemen, Tomislav, Prof. Ph.D.
Department of Electrical Engineering and Electronics
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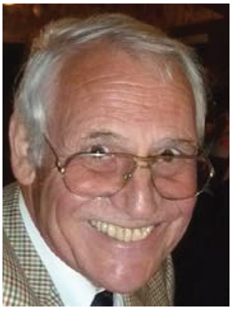
Theoretic and Applied Electrical Engineering, R/D in Power and Instrument Transformars as Products, Power and Instrument Transformers in Interaction with Networks, Development of Power and Instrument Transformers for Voltages up to 400 kV.</td></tr>
<tr><td></td><td>Kipphan, Helmut, Prof. Ph.D.
Born: 1943
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Measurement Techniques and Systems, Measurement and Automation Control, Printing Technologies, Print and Media Technologies and System Design, Theory of Color, Photography, Education and Professional Training, Cartography, Geophysics, Geography and Ethnology</td></tr>
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Information Science, Intelligent Systems, Data Science, Multimedia Systems, Complex Systems, Information Technology in Tourism</td></tr>
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BioChemical Engineering, Cell Culture Technology, Endocrine Secretion and Regulation, Science Policy, Intellectual Property Protection
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Secretary of the Department of Bioprocess Engineering (2013–2017)
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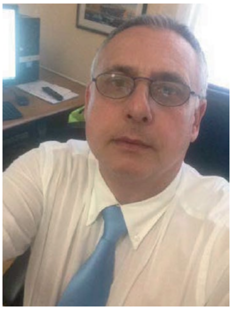	**Kos, Serđo**, Prof. Ph.D. Born: 1957 Department of Transport Full Member of the Academy (admitted 2005) B.Sc. in Marine Engineering (1978), M.Sc. in Marine Engineering (1992), Ph.D. in Marine Engineering (1994), all from the Faculty of Maritime Studies, University of Rijeka University of Rijeka, Faculty of Maritime Studies, Studentska 2, 51000 Rijeka Full member of the European Academy of Sciences and Arts (2017, Salzburg, Austria) tel: +385 51 338411, fax: +385 51 336755 e-mail: skos@pfri.hr Theory of Navigation, Terrestrial Navigation, Electronic Navigation (Satellite and inertial navigation – Space weather), Integrated and Multi-modal Transportation, Multimodal Transport Networks Activity and work of common professional meaning: Since July 2016 elected as a Full member to the European Academy of Sciences and Arts, Salzburg, Austria

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Power Systems Dynamic and Control, Renewable Energy Sources, Electric Vehicles

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Optoelectronics, Optical Communications, Radiopositioning</td></tr>
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Geodesy, Cartography, Geoinformatics, Mathematics, History of Science, Map Projections
Vice-President of the Academy (2009–2013)
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Member of the Committee for Ethics (2013–2017) and (2017–2021)
Member of the Scientific Council (2013–2017)</td></tr>
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</table>

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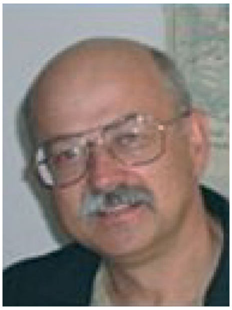

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Deputy-Secretary of the Department of Civil Engineering and Geodesy (2017–2021)
Deputy-Member of the Scientific Council (2013–2017)
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Member of the Committee for Awards (2013–2017)
Chairman of the International Relations Committee of the Academy (2009–2013)
Secretary-General of the Academy (2006–2008)
Secretary of the Department of Systems and Cybernetics (2003–2008)

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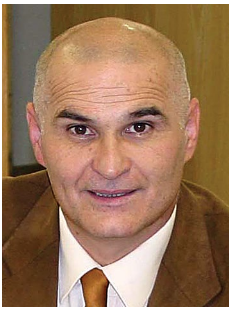

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Deputy-Secretary of the Department of Graphical Engineering (2013–2017)
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Regional Planning, Town Planning, Urban Development, Environmental Protection
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Advanced Nuclear Reactors Design, Reactor Physics, Particle Transport Theory, Radiation Shielding, Numerical Simulations of Nuclear Systems</td></tr>
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Mobile Robotics, Telerobotics, Intelligent Control and Estimation Theory
Member of the Committee for Ethics (2017 – 2021)
Member of the Scientific Council (2013 – 2017)</td></tr>
</table>

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tel: +385 1 4877354, fax: +385 1 4877354; e-mail: tpusic@ttf.hr; http://www.ttf.unizg.hr/index.php?str=53&osoba=33&lang=en
Ecological Issues in Finishing and Textile Care Processes, Bioscouring, Mercerization, Electrokinetic Potential of Textile Materials, Pastel Shades – Washing Impact, Primary and Secondary Effects, Fluorescent Compounds, Detergents, Adsorption and Desorption of Surfactants, Microcapsulation: Effects and Washing Persistence, Aftertreatment of Textiles, Dry and Wet Cleaning, Dry Cleaning Solvents, Enzyms in Finishing and Textile Care, UV Protection
Deputy-Secretary of Department of Textile Technology (2017-2021)
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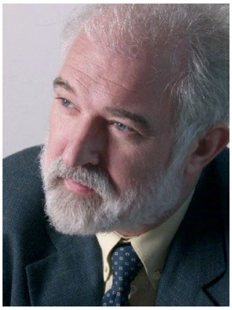
Road Planning, Road Designing



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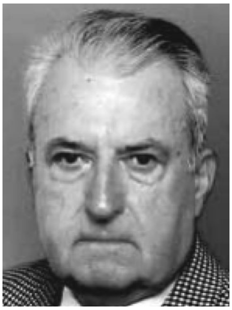
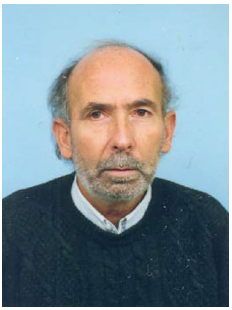
	**Rožanić, Igor**, Prof. Ph.D. Born: 1927 Honorary Member of the Academy (admitted 1998) B.Sc. in Naval Architecture (1953), Ph.D. in Naval Architecture (1973), all from the University of Rijeka, Faculty of Engineering Nova cesta 86, HR 51410 Opatija tel: +385 51 711 762, fax: +385 51 272 005 e-mail: igor.rozanic@ri.t-com.hr Naval Architecture, Offshore Engineering, Welding and Allied Processes, Testing, Measurment and Control of Welds, Science and Research Methodology
	**Rožić, Nikola**, Prof. Ph.D. Born: 1942 Department of Information Systems Emeritus of the Academy (admitted 1999) B.Sc. in Electrical Engineering (1967 and 1968), Faculty of Electrical Engineering, University of Split, M.Sc. in Electrical Engineering (1977), Ph.D. in Electrical Engineering (1981), Faculty of Electrical Engineering, University of Ljubljana University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture (FESB), R. Boškovića 32, 21000 Split tel: +385 21 305638, fax: +385 21 305655 e-mail: nikola.rozic@fesb.hr Telecommunication and Information Systems, Forecasting and Planning, Communication and Information Services and Applications, Resource Management in Wireless Systems, Multimedia Systems, Signal Processing and Coding

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Deputy-Chairman of the Committee for International Co-operation (2017–2021)
Member of the Committee for International Co-operation (2013–2017)

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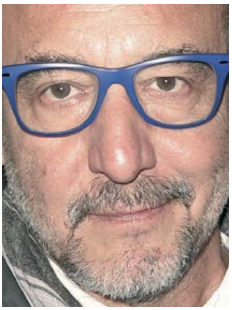
	**Sorić, Zorislav** Prof. Ph.D. Born: 1947 Department of Civil Engineering and Geodesy Emeritus of the Academy (admitted 1993) B.Sc. in Civil Engineering (1971), Faculty of Civil Engineering, University of Zagreb, M.Sc. in Civil Engineering (1982), Faculty of Civil Engineering, University of Zagreb, Ph.D. in Civil Engineering (1987), University of Colorado, Department of Civil, Environmental and Architectural Engineering, Boulder, Colorado, USA, Charles Darwin street 10, 10000 Zagreb, Croatia tel: +385 91 5767392 e-mail: soric@grad.hr Concrete Structures, Masonry Structures

	**Srbljić, Siniša**, Prof. Ph.D. Born: 1958 Department of Information Systems Full Member of the Academy (admitted 1998) B.Sc. in Electrical Engineering (1981), M.Sc. in Computer Engineering (1985), Ph.D. in Computer Science (1990), all from the Faculty of Electrical Engineering and Computing, University of Zagreb, Postdoc. University of Toronto, Canada (1993-1995) University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb tel: +385 1 6129954, +385 1 6129999, fax: +385 1 6129653 e-mail: sinisa.srbljic@fer.hr Advanced Conventional and Experimental Nonconventional Architectures of Computer and Information Systems, Theory of Computing, and Consumer Computing *Secretary of Department of Information Systems (1999–2004)* *Member of the Scientific Council (2010-2013)* *Member of the Committee of the Science Foundation (2017–2021)*
	**Sršen, Mate**, Prof. Ph.D. Born: 1943 Department of Civil Engineering and Geodesy Emeritus of the Academy (admitted 1993) B.Sc. in Civil Engineering (1968), M.Sc. in Civil Engineering (1981), Ph.D. in Civil Engineering (1985), all from the University of Zagreb, Faculty of Civil Engineering University of Rijeka, Faculty of Civil Engineering, 3 Radmile Matejčić Street, 51 000 Rijeka, Croatia tel: +385 51 265928, fax: +385 51 265998 e-mail: mate.srsen@gradri.uniri.hr Civil Engineering, Pavement Engineering, Design and Optimization of Pavement Structures, Road and Asset Management, Pavement Maintenance and Rehabilitation Technology, Road Traffic Safety, Teaching *Secretary of the Department of Civil Engineering and Geodesy of the Academy (1999–2009)*
	**Stipaničev, Darko**, Prof. Ph.D. Born: 1955 Department of Systems and Cybernetics Full Member of the Academy (admitted 1998) B.Sc. in Electrical Engineering (1977), M.Sc. in Electrical Engineering (1980), Ph.D. in Electrical Engineering (1987), all from the Faculty of Electrical Engineering and Computing, University of Zagreb University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boškovića bb, 21000 Split tel: +385 21 305813, fax: +385 21 563877 e-mail: dstip@fesb.hr; http://laris.fesb.hr/dstip.html *Deputy-Member of the Scientific Council (2017–2021)*

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Bioprocess Engineering, Mathematical Modeling of Bioprocesses, Malting and Brewing Technology, Wastewater Treatment, Biofuels and Biopolymer Production

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Secretary of the Department of Mechanical Engineering and Naval Architecture of the Academy (2013–2017)

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	**Šimić, Zdenko**, Prof. Ph.D. Born: 1964 Associate of the Academy (admitted 2012) B.Sc. in Electrical Engineering (1988), M.Sc. (1994) and Ph.D. in Nuclear Engineering (2001) at the University of Zagreb Faculty of Electrical Engineering and Computing European Commission Joint Research Centre Postbus 2 – 1755ZG Petten, The Netherlands tel: +31-224-565-016 e-mail: zdenko.simic@ec.europa.eu http://www.linkedin.com/in/zdenkos Reliability, Risk, Nuclear energy operating and regulatory experience, Energy resources, Renewable energy sources characterization
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Chemical Engineering Thermodynamics, Corrosion and Protection of Materials, Modeling in Chemical Engineering Thermodynamics and Corrosion
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	**Vasić-Rački, Đurđa**, Prof. Ph.D. Born: 1946 Department of Chemical Engineering Emerita of the Academy (admitted 1995) B.Sc. in Chemical Engineering (1971), M.Sc. in Chemical Engineering (1976), Ph.D. in Chemical Engineering (1981), all from the Faculty of Chemical Engineering and Technology, University of Zagreb University of Zagreb, Faculty of Chemical Engineering and Technology, Savska cesta 16, 10000 Zagreb tel: +385 1 4597104, fax: +385 1 4597133 e-mail: dvracki@fkit.hr, Djurdja.Vasic-Racki@hatz.hr Enzyme Reaction Engineering, Computer Modeling, Biochemical Engineering, Ecological Engineering *Head of the Center for Environmental Protection and Development of Sustainable Technologies (2009–2013) and (2013-2016)* *Chairwoman of the Council of the Centers (2009-2013) and (2013-2017)*

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Secretary of the Department of Architecture and Urban Planning (2017–2021)

Veža, Ivica, Prof. Ph.D.
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Industrial Engineering, Mechanical Engineering, Plant Layout, Computer Integrated Manufacturing, Modeling and Simulation, Production Management, Logistics
Secretary of the Department of Mechanical Engineering and Naval Architecture (2005–2009)

	**Virag, Zdravko**, Prof. Ph.D. Born: 1955 Department of Mechanical Engineering and Naval Architecture Full Member of the Academy (admitted 1994) B.Sc. in Mechanical Engineering (1978), M.Sc. in Mechanical Engineering (1985), Ph.D in Mechanical Engineering (1991), all from the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, 10000 Zagreb tel: +385 1 6168944/137, fax: +385 1 6156940 e-mail: zdravko.virag@fsb.hr Fluid Mechanics, Numerical Methods in Heat and Mass Transfer, Hemodynamics of the Cardiovascular System *Deputy-Member of the Scientific Council (2017–2021)* *Member of the Committee for Awards (2013–2017)* *Deputy–Secretary of the Department of Mechanical Engineering and Naval Architecture (2009–2013)*
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Structure and Properties of Textile Fibers, Objective Measurement and Evaluation, Restauration and Conservation of Textile and Clothes, Fibers and Forensics, Fiber Reinforced Composites & Textile Recycling
Secretary of the Department of Textile Technology (2017-2021)
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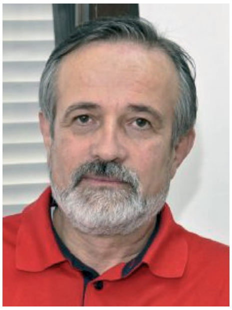

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