ICSSM 2021
Proceedings

8th International Congress of the Serbian Society of Mechanics

June 28-30, 2021
Kragujevac, Serbia

Hellenic Society for Theoretical & Applied Mechanics (HSTAM)

СРПСКО ДРУШТВО ЗА РАЧУНСКУ МЕХАНИКУ
SERBIAN SOCIETY FOR COMPUTATIONAL MECHANICS

MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL DEVELOPMENT

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The 8th International Congress of the Serbian Society of Mechanics Kragujevac, Serbia, June 28-30, 2021

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Organizers

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- **Faculty of Mechanical Engineering, University of Belgrade**
- **Faculty of Technical Science, University of Novi Sad**
- **Faculty of Mechanical Engineering, University of Niš**
- **Hellenic Society of Theoretical and Applied Mechanics**
- **Institute of Information Technology Kragujevac**
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- **Ministry of Education, Science and Technological Development**
- **Serbian Academy of Sciences and Arts**

and

- **Serbian Society of Computational Mechanics**

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Welcome Message

Dear colleagues,

It is a great pleasure for us to welcome you all at *the* ***8th International Congress of the Serbian Society of Mechanics*** in Kragujevac, Serbia Well-known for its culture, history and industrial heritage, Kragujevac was the first capital of modern Serbia and the place where the first constitution in the Balkans was proclaimed. Today, we are more than proud to say that Kragujevac is also becoming one of the scientific capitals in the region.

In this very difficult time of the COVID-19 pandemic, we decided to make this congress a hybrid event combining physical and online sessions, so that everyone interested can join us despite the obstacles we have all been facing for more than a year now.

8th International Congress of the Serbian Society of Mechanics aims to bring together leading academic scientists, researchers and research scholars to exchange and share experiences and research results on various aspects of *Theoretical and Applied Mechanics*. It will bring an interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, theories, algorithms, as well as practical challenges encountered and solutions adopted in the fields of *Classical Mechanics, Solid and Fluid Mechanics, Computational Mechanics, Biomechanics, Applied Mathematics and Physics, Structural Mechanics and Engineering.*

The Congress is organized by the Serbian Society of Mechanics (SSM) in partnership with: Faculty of Engineering, University of Kragujevac, Faculty of Mechanical Engineering, University of Belgrade, Faculty of Technical Science, University of Novi Sad, Faculty of Mechanical Engineering, University of Niš, Hellenic Society of Theoretical and Applied Mechanics, Institute of Information Technology Kragujevac, University of Kragujevac, with the support of the Serbian Ministry of Education, Science and Technological Development, Serbian Academy of Sciences and Arts and Serbian Society for Computational Mechanics.

Six distinguished plenary speakers will deliver lectures:

1. Prof. Georgios E. Stavroulakis – Technical University of Crete, Greece
2. Prof. Themis Exarchos – Ionian University, Corfu, Greece
3. Prof. Mihailo R. Jovanović – University of Southern California, USA
4. Prof. Ricardo Ruiz Baier – Monash University, School of Mathematics, Clayton, Australia
5. Dr Božidar Jovanović – MISANU, Serbia
6. Dr Marko Janev – MISANU, Serbia

The Congress encompasses six main topics: General Mechanics, Fluid Mechanics, Mechanics of Solid Bodies, Biomechanics, Control and Robotics, Interdisciplinary and Multidisciplinary Problems.

Also, there are four Mini-Symposia:

- M1: 5th Serbian-Greek Symposium on Advanced Mechanics
  Chairs: Prof. Georgios Stavroulakis, President of HSTAM, Greece; Prof. Nenad Filipović, President of SSM, Serbia
- M2: Turbulence
  Chair: Prof. Đorđe Čantrak, University of Belgrade, Serbia
- M3: Mathematical Biology and Biomechanics
  Chair: Dr. Anđelka Hedrih, MI SANU, Serbia
- M4: Nonlinear Dynamics
  Prof. Julijana Simonović, University of Niš, Serbia

Within the Congress, we are also very proud to organize the 5th Serbian-Greek Symposium on *Current and Future Trends in Mechanics*. The Symposium is organized by the Serbian Society of Mechanics (SSM) and the Hellenic Society of Theoretical and Applied Mechanics (HSTAM).

This year, *8th International Congress of the Serbian Society of Mechanics* received more than 150 high-quality research papers. Each paper was reviewed and ranked by at least 2 professors and scientists in the program and the scientific review committee. As a result of the strict review process and evaluation, the committee selected 120 research papers.

We must also say that the conference would certainly not have been so successful without the efforts of many people who were actively engaged in organization of such a major nationally and internationally recognized academic event. We give our special gratitude to the members of the program and scientific review committee as well as to all chairs, organizers and committee members for their dedication and support.

On behalf of the Organizing Committee, we wish you all a pleasant stay in Kragujevac and a productive conference.

Chairs:

Prof. Nenad Filipović, ***president of SSM, University of Kragujevac***
Prof. Miloš Kojić, ***Serbian Academy of Sciences and Arts***

Organizing Committee

Co-chairs:

- Nenad Filipović, president of SSM (University of Kragujevac)
- Miloš Kojić, (Serbian Academy of Sciences and Arts)

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Keynote Speakers

“Analysis of a New Mixed Formulation for Hyperelasticity Using Kirchhoff Stress”

Monday 28 June 2021

09:15 - 09:45

Prof. Ricardo Ruiz Baier,
Monash University, School of Mathematics,
Clayton, Australia

Abstract

Using the three-field formulation for nearly incompressible hyperelasticity introduced in [Chavan, Lamichhane, Wohlmuth, Comput. Methods Appl. Mech. Engrg. (2007), 196:4075-4086] we define a similar form valid for the fully incompressible case. We define a mixed finite element scheme and verify theoretical rates of convergence through computational tests. We also propose a new augmented Lagrangian preconditioner that improves convergence properties of iterative solvers. A few benchmark solutions are computed, and we test the formulation in models of cardiac biomechanics.

“Coronary Atherosclerosis Assessment: A New Anatomical, Functional, Morphological and Bio-mechanical Approach”

Monday 28 June 2021

15:00 - 15:30

Prof. Themis Exarchos,
Ionian University, Corfu, Greece

Abstract

Aims: To investigate and compare two different endothelial shear stress (ESS) calculation techniques, compare lesion specific smartFFR and ESS values, as well as total vessel smartFFR and ESS values, and investigate the relationship between smartFFR and ESS to stress MBF (myocardial blood flow) and MFR (myocardial flow reserve).

Methods: A total of 10 coronary vessels of 6 patients with intermediate pre-test likelihood for coronary artery disease who have undergone both CTCA and PET-MPI with 15O-water or 13N-ammonia were included in the study. Seven (7) cases had normal stress MBF and MFR values and three (3) had abnormal ones. PET was considered abnormal when > 1 contiguous segments showed both stress MBF ≤2.3mL/g/min and MFR ≤2.5 for 15O-water or <1.79 mL/g/min and ≤2.0 for 13N-ammonia, respectively. The ESS at the luminal surface of the artery was calculated as the product of viscosity and the gradient of blood velocity near the vessel wall. To calculate the smartFFR, we performed a transient simulation for each case. We used a pressure of 100 mmHg as a boundary condition at the inlet (i.e. mean human aortic pressure). At the outlet, a flow profile of 4 timesteps with a timestep duration of 0.25 sec was used. In each timestep, a volumetric flow rate of 1, 2, 3 and 4 ml/s are applied as outlet boundary conditions. The cut-off value for a pathological smartFFR is 0.83.

Results: There is a difference in total vessel calculated smartFFR results compared to the corresponding values of lesion specific smartFFR (0.88 vs 0.97, p=0.01). For ESS there is a negligible difference between lesion specific and total vessel values (2.22 vs 2.74, p = 0.9). There is a moderate negative correlation between both lesion specific (r = -0.543) and total vessel smartFFR and ESS (r = -0.915). ESS values were higher in vessels where vessel smartFFR was considered abnormal (1.97 vs 5.52, p = 0.01). Total vessel length smartFFR was lower in vessels with abnormal PET-MPI compared to the normal vessels (0.75 vs 0.93, p = 0.01). ESS is higher in vessels with pathological stress MBF and CFR (5.5 vs 2.0, p = 0.02)

Conclusion: The total vessel length smartFFR and lesion ESS appear to assess the functional significance of the vessel well, when compared to the PET-MPI measurements.

“Auxetic and other Metamaterials in Dynamics”

Tuesday 29 June 2021

08:30 - 09:00

Prof. Georgios E. Stavroulakis,
Technical University of Crete, Greece

Abstract

Microstructures are in several cases reponsible for the novel mechanical behavior. Materials with negative Poisson ratio, the so-called auxetics, constitute an interesting class of mechanical metamaterials with interesting applications in statics as well as in dynamics. For example, they have enhanced damping properties. Auxetics can be produced with star-shaped microstructures and perforations. These metamaterials can serve as a first example of novel materials with nonclassical properties. Mechanical properties are mainly considered here, while in a more general setting multiphysics applications are also possible.

A short review of auxetic microstructures and optimal design of corresponding metamaterials will be presented, in view of the flexibility provided by modern additive manufacturing techniques. Applications in statics, wave propagation and dynamics will be discussed. The numerical experiments of our group will be presented together with results of current published research.

Using a classical auxetic microstructure, possible applications are studied here through numerical simulation. Finite element models are developed and dynamic analysis numerical tests are considered. First, an application related to auxetic microstructures, which are intended to be used in the core of structural panels, is presented. Then, some numerical simulation for wind turbines blades, where aluminium foam, polymeric foam and the proposed auxetic material have been considered as the core material, are taken into account. The numerical results demonstrate that the usage of auxetic microstructures results in improved dynamic response of the system in comparison to traditional, conventional materials. Further considerations of optimal design problems can be followed, either by optimizing the parameters of one given auxetic microstructure, or by using more general topology optimization tools.

Optimal design may have several goals and restrictions, depending on the application. Dynamic behaviour may be studied in frequency or time domain. In addition a complete behaviour towards the appearance of band gaps is possible. Finally, novel concepts to enhance auxeticity and control the resulting behaviour have been proposed, namely contact-activated and piezoelectric controlled microstructures. Last but not least auxetics pose challenging tasks on homogenization, especially for dynamical behaviour.

Optimal design principles, emerging research needs and technological questions will also be discussed.

“Classical Neumann System on Stiefel Manifolds: Integrability, Geometric and Algebraic Aspects, and Linearization”

Tuesday 29 June 2021

15:00 - 15:30

Dr Božidar Jovanović,
MISANU, Serbia

Abstract

The Neumann system on a sphere is one of the basic classical examples of completely integrable systems. In this talk we give a review on the results concerning natural integrable generalizations of the Neumann systems to Stiefel manifolds [1,2,3,4]. Two Lax pairs for the systems are presented. A -matrix Lax representation enables us to prove non-commutative integrabilty of the Neumann systems, while a -matrix Lax representation implies a generalization of the Chasles theorem relating the trajectories of the systems and common linear spaces tangent to confocal quadrics. Also, by applying the second Lax representation we describe algebraic geometric properties of the systems. We show that generic complex invariant manifolds are open subsets of Prym varieties on which the flow is linear.

“Noether’s Theorem for Herglotz Type Variational Problems Involving Real and Complex Order Fractional Derivatives”

Wednesday 30 June 2021

08:30 - 09:00

Dr Marko Janev,
MISANU, Serbia

Abstract

In this work a variational principle of Herglotz type with a Lagrangian that depends on fractional derivatives of both real and complex orders is formulated, and the invariance of this principle under the action of a local group of symmetries is determined. By the Noether theorem the conservation law for the corresponding fractional Euler–Lagrange equation is obtained. A sequence of approximations of a fractional Euler–Lagrange equation by systems of integer order equations is used for the construction of a sequence of conservation laws. It is proved, that under certain assumptions, weakly converge to the one for the basic Herglotz variational principle. Namely, using the expansion of fractional derivative of a function into series, we analyze the approximations of already established Euler-Lagrange equation, infitezimal criteria and Noether’s type theorem, in a weak sense within the dual pairing of corresponding topological spaces.

“Color of turbulence: Stochastic Dynamical Modeling of Turbulent Flows”

Wednesday 30 June 2021

14:00 - 14:30

Prof. Mihailo R. Jovanović,
University of Southern California, USA

Abstract

This talk describes how to account for second-order statistics of turbulent wall-bounded shear flows using low-complexity stochastic dynamical models based on the linearized Navier-Stokes equations. The complexity is quantified by the number of degrees of freedom in the linearized evolution model that are directly influenced by stochastic excitation sources. For the case where only a subset of correlations is known, we develop a framework to complete unavailable second-order statistics in a way that is consistent with linearization around turbulent mean velocity. In general, white-in-time stochastic forcing is not sufficient to explain turbulent flow statistics. We develop models for colored-in-time forcing using a maximum entropy formulation together with a regularization that serves as a proxy for rank minimization. We show that colored-in-time excitation of the Navier-Stokes equations can also be interpreted as a low-rank modification to the generator of the linearized dynamics. Our method provides a data-driven refinement of models that originate from first principles and it captures complex dynamics of turbulent flows in a way that is tractable for analysis, optimization, and control design.

Program at a Glance

Monday 28 June 2021		
08:45 - 09:15	Opening Ceremony - Welcome speech: **Prof. Nenad Filipović**, President of SSM, Conference Co-Chair **Prof. Miloš Kojić**, full member of SASA, Conference Co-Chair **Nikola Dašić**, Major of Kragujevac City **Prof. Ivica Radović**, State Secretary, Ministry of Education, Science and Technological Development, Serbia **Prof. Dobrica Milovanović**, Dean of Faculty of Engineering, Kragujevac	
09:15 - 09:45	Keynote speaker: **Topic: Analysis of a New Mixed Formulation for Hyperelasticity Using Kirchhoff Stress** **Dr Ricardo Ruiz Baier,** *Monash University, School of Mathematics, Clayton, Australia*	
09:45 - 11:00	**Session M.1A** **Biomechanics (part I)**	**Session M.1B** **Mechanics of Solid Bodies (part I)**
11:00 - 11:30	Coffee Break	
11:30 - 13:00	**Session M.2A** **Interdisciplinary and Multidisciplinary Problems (part I)**	**Session M.2B** **Mechanics of Solid Bodies (part II)**
13:00 - 14:00	Buffet Lunch	
14:00 - 15:00	**Session M.3A** **Interdisciplinary and Multidisciplinary Problems (part II)**	**Session M.3B** **Mechanics of Solid Bodies (part III)**
15:00 - 15:30	Keynote speaker: **Topic: Coronary Atherosclerosis Assessment: A New Anatomical, Functional, Morphological and Bio-mechanical Approach** **Dr Themis Exarchos,** *Ionian University, Corfu, Greece*	
15:30 - 16:30	**Session M.4A** **General Mechanics (part I)**	**Session M.4B** **Mechanics of Solid Bodies (part IV)**
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17:00 - 18:30	**Session M.5** **General Mechanics (part II)**	

Tuesday 29 June 2021		
08:30 - 09:00	Keynote speaker: **Topic: Auxetic and other Metamaterials in Dynamics** **Dr Georgios E. Stavroulakis,** *Technical University of Crete, Greece*	
09:00 - 11:00	**Session T.1A** **Mini-Symposia I: 5th Serbian-Greek Symposium on Advanced Mechanics (part I)**	**Session T.1B** **Biomechanics (part II)**
11:00 - 11:30	Coffee Break	
11:30 - 13:00	**Session T.2A** **Mini-Symposia I: 5th Serbian-Greek Symposium on Advanced Mechanics (part II)**	**Session T.2B** **Biomechanics (part III)**
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14:00 - 15:00	**Session T.3A** **Mini-Symposia I: 5th Serbian-Greek Symposium on Advanced Mechanics (part III)**	**Session T.3B** **Control and Robotics**
15:00 - 15:30	Keynote speaker: **Topic: Classical Neumann System on Stiefel Manifolds: Integrability, Geometric and Algebraic Aspects, and Linearization** **Dr Božidar Jovanović,** *MISANU, Serbia*	
15:30 - 16:00	Coffee Break	
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Wednesday 30 June 2021		
08:30 - 09:00	Keynote speaker: **Topic: Noether's Theorem for Herglotz Type Variational Problems Involving Real and Complex Order Fractional Derivatives** **Dr Marko Janev,** *MISANU, Serbia*	
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10:45 - 13:00	**Session W.2A** **Fluid Mechanics**	**Session W.2B** **Mini-Symposia IV: Nonlinear Dynamics**
13:00 - 14:00	Buffet Lunch	
14:00 - 14:30	Keynote speaker: **Topic: Color of turbulence: Stochastic Dynamical Modeling of Turbulent Flows** **Dr Mihailo R. Jovanović,** *University of Southern California, USA*	
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Technical Program

Monday 28 June 2021

08:45 - 09:15	Opening Ceremony - Welcome speech: **Prof. Nenad Filipović**, President of SSM, Conference Co-Chair **Prof. Miloš Kojić**, full member of SASA, Conference Co-Chair **Nikola Dašić**, Major of Kragujevac City **Prof. Ivica Radović**, State Secretary, Ministry of Education, Science and Technological Development, Serbia **Prof. Dobrica Milovanović,** Dean of Faculty of Engineering, Kragujevac

09:15 - 09:45	Keynote speaker: Topic: **Analysis of a New Mixed Formulation for Hyperelasticity Using Kirchhoff Stress** **Prof. Ricardo Ruiz Baier**, Monash University, School of Mathematics, Clayton, Australia Chair: Hedrih A.

Session M.1A: 09:45-11:00

Biomechanics (part I)

Chairs: Kojić M., Geroski V.

M.1A.1 – Extension of our computational model for the left ventricle tissue to include hypertrophy – *Kojić M.*

M.1A.2 – Coupled Ohara-Rudy numerical model for heart electro-mechanics – *Geroski V., Milošević M., Milićević B., Simić V., Filipović N., Kojić M.*

M.1A.3 – Electromyography detection of muscle response in musculus quadriceps femoris of elite volleyball players on different exercises – *Radaković R., Peulić A., Kovač S., Simojlović M., Filipović N.*

Session M.1B: 09:45-11:00

Mechanics of Solid Bodies (part I)

Chairs: Mastilović S., Dunić V.

M.1B.1 – Remarks on discreteness of the nanoscale fragmentation mass distribution – *Mastilović S.*

M.1B.2 – Size-effect modeling of Weibull Jc cumulative distribution function based on a scaling approach – *Mastilović S., Đorđević B., Sedmak A.*

M.1B.3 – Material parameters identification of concrete damage plasticity material model – *Rakić D., Bodić A., Milivojević N., Dunić V., Živković M.*

M.1B.4 – Using of gap element for contraction joints modeling in seismic analysis of concrete arch dams – *Živković M., Jović N., Pešić M., Rakić D., Milivojević N.*

M.1B.5 – Finite element analysis of effects of multiple defects on welded joint integrity – *Aranđelović M., Sedmak S., Jovičić R., Sedmak A., Radaković Z.*

11:00 - 11:30	Coffee Break

Session M.2A: 11:30-13:00

Interdisciplinary and Multidisciplinary Problems (part I)

Chairs: Sedmak A., Nikolić D.

M.2A.1 – Noise induced dynamics of earthquake nucleation model – *Kostić S., Vasović N.*

M.2A.2 – Nonlinear landslide dynamics – *Kostić S., Vasović N.*

M.2A.3 – Computational mechanics – welding joint as a case study – *Jeremić L., Sedmak A., Sedmak S., Martić I.*

M.2A.4 – Experimental electrochemotherapy using novel design single needle device – *Cvetković A., Cvetković D., Milasinović D., Jovičić N., Miailović N., Nikolić D., Mitrović S., Filipović N.*

M.2A.5 – Cavitation diagrams for merchant ships using four blade b series propellers – *Veg M., Kalajdžić M.*

M.2A.6 – Microfluidic lab-on-chip system development for cell culture cultivation – *Milivojević N., Živanović M., Nikolić D., Jovanović Ž., Šeklić D, Nikolić M., Filipović N.*

Session M.2B: 11:30-13:00

Mechanics of Solid Bodies (part II)

Chairs: Rakić D., Obradović A.

M.2B.1 – New pipe ring tensile specimen for pipeline material fracture assessment – *Trajković I., Rakin M., Milošević M., Sedmak A., Međo B.*

M.2B.2 – Mass minimization of an AFG Timoshenko cantilever beam with a large body placed eccentrically at the beam end – *Obradović A., Mitrović Z., Zorić N.*

M.2B.3 – On concentrated surface loads and the flat punch contact problem in strain gradient elasticity – *Zisis T., Gourgiotis P., Georgiadis H.*

M.2B.4 – Geometric optimization of shaft transition zone based on stress-strain analysis of nature inspired design – *Atanasovska I., Momčilović D.*

M.2B.5 – A comparative analysis of fatigue behaviour between S355J2+N and Strenx 700 steel grade – *Živković M., Milovanović B., Dišić A., Jovičić G., Topalović M.*

M.2B.6 – Linear transient analysis of spatial curved Bernoulli – Euler beam using isogeometric approach – *Jočković M., Nefovska Danilović M.*

13:00 - 14:00	Buffet Lunch

Session M.3A: 14:00-15:00

Interdisciplinary and Multidisciplinary Problems (part II)

Chairs: Milošević M., Šušteršič T.

M.3A.1 – Analysis of atherosclerotic plaque in carotid arteries by using convolutional neural networks – *Arsić B., Đorović S., Anić M., Gakovć B., Končar I., Filipović N.*

M.3A.2 – Structural condition assessment and rehabilitation of 'Karpos' system bridge – *Milošević M., Živković S., Marković Branković J., Marković M.*

M.3A.3 – Epidemiological predictive modelling of COVID-19 spread – *Šušteršič T., Blagojević A., Cvetković D., Cvetković A., Lorencin I., Baressi Šegota S., Car Z., Filipović N.*

M.3A.4 – In vitro and in silico testing of stent device – *Nikolić D., Saveljić I., Filipović N.*

Session M.3B: 14:00-15:00

Mechanics of Solid Bodies (part III)

Chairs: Dunić V., Milovanović V.

M.3B.1 – Waves in composite layer reinforced with two families of inextensible fibres – *Milosavljević D., Radaković A., Čukanović D.*

M.3B.2 – Simulation of damage evolution in metal structures – *Živković J., Dunić V., Milovanović V., Živković M.*

M.3B.3 – Analysis of Hertz contact stresses for metallic material with carbides – *Atanasovska I., Momčilović D.*

M.3B.4 – Tuning a fractionally damped piezoelectric energy harvester with attached concentrated masses – *Paunović S.*

15:00 - 15:30	Keynote speaker: Topic: **Coronary Atherosclerosis Assessment: A New Anatomical, Functional, Morphological and Bio-mechanical Approach** **Prof. Themis Exarchos**, Ionian University, Corfu, Greece Chair: Filipović N.

Session M.4A: 15:30-16:30

General Mechanics (part I)

Chairs: Rakić D.

M.4A.1 – Design and practical realization of a frame with stiffness at its ending point – *Radomirović D., Kovačić I., Gatti G.*

M.4A.2 – Problematizing the orbital mechanics' two first integrals – *Nedić S.*

M.4A.3 – Simple algorithm for computing the stiffness matrix of composite cross-section – *Lazović Radovanović M., Nikolić J., Radovanović J.*

M.4A.4 – Topological interface states in acoustic metamaterials – *Cajić M., Karličić D., Adhikari S.*

Session M.4B: 15:30-16:30

Mechanics of Solid Bodies (part IV)

Chairs: Mićunović M., Anđelić N.

M.4B.1 – Low-cycle fatigue damage modeling with hysteretic energy loss – *Perović Z., Šumarac D.*

M.4B.2 – A model for the analysis of elasto-plastic buckling of compressed columns – *Milekić N., Bendić M., Ćorić S., Perović Z.*

M.4B.3 – On diffuse instability of orthotropic viscoplastic plates – *Kudrjavčeva Lj., Mićunović M.*

M.4B.4 – One view on the optimization of thin-walled cantilever channel-section and Z-section beams – *Anđelić N., Milošević Mitić V., Petrović A., Đurđević Đ.*

16:30 - 17:00	Coffee Break

Session M.5: 17:00-18:30

General Mechanics (part II)

Chairs: Nikolić D.

M.5.1 – Determination of dynamic load factor for single element camshaft using various laws of follower motion – *Jovanović Đ., Milenković B.*

M.5.2 – Behaviour, examination and stability of the constrained mechanical system described with nonlinear equations – *Vesović M., Radulović R.*

M.5.3 – Kowalevski exponents for the Kirchhoff equations – *Dragović V., Gajić B.*

M.5.4 – Added mass method application for dam-accumulation interaction analysis – *Rakić D., Jelić L, Živković M., Milivojević N., Bojović M.*

M.5.5 – Comparative bending analysis of composite laminate and functionally graded plates based on the new shape function – *Milosavljević D., Radaković A., Čukanović D., Bogdanović G., Ivanović L.*

M.5.6 – Vehicle motion in the presence of nonholonomic constraints – *Žigić M., Grahovac N.*

Tuesday 29 June 2021

08:30 - 09:00	Keynote speaker: Topic: **Auxetic and other Metamaterials in Dynamics** **Prof. Georgios E. Stavroulakis,** *Technical University of Crete, Greece* Chair: Kojić M.

Session T.1A: 09:00-11:00

Mini-Symposia I: 5th Serbian-Greek Symposium on Advanced Mechanics (part I)

Chairs: Filipović N., Kojić M.

T.1A.1 – Rolling without slipping a heavy homogeneous rigid ball on a torus – *Hedrih Stevanović K.*

T.1A.2 – Exact augmented perpetual manifolds: a corollary for their uniqeness – *Georgiades F.*

T.1A.3 – Effect of chiral materials on presence of band gaps – *Koutsianitis P., Tairidis G., Kougkolos A., Stavroulakis G.*

T.1A.4 – Viscoelastic fillers in cellular shear wall panels: behavior under dynamic loads – *Syrimi P., Papathanasiou S., Tsopelas P.*

T.1A.5 – Mathematical modelling of electro-elastic dislocations in piezoelectric materials and the J-integral – *Agiasofitou E., Lazar M.*

T.1A.6 – Free vibration of axially functionally graded Timoshenko cantilever beam with a large rigid body attached at its free end – *Obradović A., Šalinić S., Tomović A.*

T.1A.7 – A study of rectangular plates under colinear point load with both approximate and exact solution – *Tsiatas G., Pavlović M.*

T.1A.8 – Bullet penetration in auxetic star-shape armor plates – *Ntintakis I., Stavroulakis G.*

Session T.1B: 09:00-11:00

Biomechanics (part II)

Chairs: Kojić M., Marković Z.

T.1B.1 – Torsional oscillations of a tree trunk with branches through a biomechanical oscillatory model in the form of a complex cantilever – *Hedrih A., Hedrih Stevanović K.*

T.1B.2 – Inhibitory effect of coumarin derivate on vitamin K epoxide reductases (VKOR) responsible for anticoagulation effect – *Milanović Ž., Avdović E., Milenković D., Marković Z.*

T.1B.3 – Substituent effect on the binding mode and toxicity of selected 1,4-benzodiazepin-2-one – *Milanović Ž., Dimić D., Kesić A., Milenković D.*

T.1B.4 – Entresto (Sacubitril/Valsartan): molecular docking simulations with Neprilysin and Angiotensin II receptor – *Antonijević M., Marković Z., Filipović N., Đorović Jovanović J.*

T.1B.5 – Inhibitory effect of the 4-Hydroxy-(E)-N'-(1-(2,4-Dioxochroman-3-YL)Ethyl)-Benzohydrazide on the α-Glucosidase – *Antonijević M., Simijonović D., Avdović E., Đorović Jovanović J.*

T.1B.6 – Left ventricle model generated from echocardiographic data – *Milićević B., Milošević M., Geroski V., Simić V., Trifunović D., Filipović N., Kojić M.*

T.1B.7 – Fluid-electro-mechanical parametric model of the left ventricle – *Simić V., Milošević M., Milićević B., Geroski V., Filipović N., Kojić M.*

T.1B.8 – Numerical analysis of blood flow through the cerebral aneurysm – *Milovanović A., Saveljić I., Jovanikić O., Filipović N.*

11:00 - 11:30	Coffee Break

Session T.2A: 11:30-13:00

Mini-Symposia I: 5th Serbian-Greek Symposium on Advanced Mechanics (part II)

Chairs: Kojić M., Vulović A.

T.2A.1 – Analysis of freight wagons for transporting of bulk materials – *Vulović S., Pavlović D., Živković M., Vujanac R., Topalović M.*

T.2A.2 – Physics-informed neural networks for elastic plate problems – *Muradova A., Stavroulakis G.*

T.2A.3 – Crack analyses in a sandwich specimen under flexural loading – *Theotokoglou E., Tourlomousis I.*

T.2A.4 – Stochastic response of nonlinear energy sinks subjected to gaussian white noise base excitation – *Karatzia D., Tsiatas G.*

T.2A.5 – Ageing of equilibrium contact angle in capillary flows – *Lazaridis K., Wu Y., Muniyal Krishna S., Yu C., Krivilyov M., Sekulić D., Mesarović S.*

T.2A.6 – Calculation of femoral cortical bone elasticity modulus from computed tomography scans – *Vulović A., Filipović N.*

Session T.2B: 11:30-13:00

Biomechanics (part III)

Chairs: Milošević M., Đorović S.

T.2B.1 – Blood flow in arterial bifurcation calculated by turbulent finite element model – *Nikolić A., Topalović M., Simić V., Blagojević M.*

T.2B.2 – Analytical model: calculation of fractional flow reserve – *Starčević S., Savić S., Filipović N.*

T.2B.3 – Computational model for polymeric bioresorbable Poly-L-Lactic acid (PLLA) stents – *Milošević M., Anić M., Geroski V., Nikolić D., Isailović V., Filipović N., Kojić M.*

T.2B.4 – Computational modeling of tumor cell circulation in capillary with platelets – *Nikolić A., Simić V., Milošević M., Ziemys A., Yokoi K., Kojić M.*

T.2B.5 – Alterations of human articular cartilage due to osteoarthritis in terms of real and complex-conjugate derivatives – *Žigić M., Mikulić Gutman S., Grahovac N., Mitić I., Spasić D.*

T.2B.6 – Numerical analysis of knee joint at maximum power tennis serve – *Jovičić G., Vulović A., Đorović S., Vukićević A., Vulović R., Radaković R., Filipović N.*

13:00 - 14:00	Buffet Lunch

Session T.3A: 14:00-15:00

Mini-Symposia I: 5th Serbian-Greek Symposium on Advanced Mechanics (part III)

Chairs: Car Z., Simić V.

T.3A.1 – On inelasticity of damaged quasi rate independent orthotropic materials – *Mićunović M., Kudrjavčeva Lj.*

T.3A.2 – Artificial intelligence approach to parameter learning in nonlinear control systems – *Nestorović T., Pal A., Oveisi A.*

T.3A.3 – Determining inverse kinematics of a serial robotic manipulator through the use of genetic

programming – *Car Z., Baressi Šegota S., Anđelić N., Lorencin I., Musulin J., Štifanić D., Mrzljak V.*

T.3A.4 – Biomechanics of left ventricle and in silico drug testing – *Filipović N., Milićević B., Milošević M., Simić V., Georski V., Kojić M.*

Session T.3B: 14:00-15:00 **Control and Robotics** Chairs: Lazarević M., Obradović A.

T.3B.1 – H∞ proportional-integral control of a turbofan engine – *Zorić N., Jazarević V., Obradović A.*

T.3B.2 – PI velocity control of a mechanical system – *Živanović M.*

T.3B.3 – Robust constrained state space ILC for 3DOF robot manipulator – *Dubonjac A., Lazarević M.*

T.3B.4 – Adaptive iterative learning control of robotic system based on particle swarm optimization – *Živković N., Lazarević M., Petrović M.*

T.3B.5 – Open closed-loop PD\mu/PD type ILC control of neuroarm robotic system – *Cvetković B., Lazarević M., Mandić P., Šekara T., Lino P.*

15:00 - 15:30	Keynote speaker: Topic: **Classical Neumann System on Stiefel Manifolds: Integrability, Geometric and Algebraic Aspects, and Linearization** **Dr Božidar Jovanović,** *MISANU, Serbia* Chair: Lazarević M.

15:30 - 16:00	Coffee Break

16:00 - 18:00	**SSM Annual Meeting and Assembly 2021**

20:00 - 23:00	Gala Dinner - Restoran Di Trevi

Wednesday 30 June 2021

08:30 - 09:00	Keynote speaker: Topic: **Noether's Theorem for Herglotz Type Variational Problems Involving Real and Complex Order Fractional Derivatives** **Dr Marko Janev,** *MISANU, Serbia* Chair: Mađarević D.

Session W.1: 09:00-10:15

Mini-Symposia III: Mathematical Biology and Biomechanics

Chairs: Hedrih A., Simonović J.

W.1.1 – Volume optimization of the worm gear using biologically inspired algorithm – *Milenković B., Jovanović Đ.*

W.1.2 – Generalized function of fractional type dissipation energy in double DNA helix chain – *Hedrih Stevanović K.*

W.1.3 – Bone regenerative potential driven by periodic excitation: deterministic and stochastic mathematical models – *Simonović J., Woolley T.*

W.1.4 – Modelling the influence of externally induced cholesterol pulses on hypothalamic-pituitary-adrenal axis perturbed with ethanol – *Stanojević A., Anđelković M., Čupić Ž., Kolar Anić Lj.*

W.1.5 – Rotation transformation matrix of the joint coordinate system with the application to the knee joint – *Rosić N.*

10:15 - 10:45	Coffee Break

Session W.2A: 10:45-13:00

Fluid Mechanics

Chairs: Saveljić I., Topalović M.

W.2A.1 – Influence of second order effects on pressure distribution in microtubes – *Guranov I., Milićev S., Stevanović N.*

W.2A.2 – Simulating fluid flow within coronary arteries using parallelized sparse lattice Boltzmann method – *Đukić T., Filipović N.*

W.2A.3 – Saffman-Taylor instability - History and application – *Cvetković I., Milićev S., Pihler Puzović D.*

W.2A.4 – Multi-component mixture of Euler fluids - continuum/kinetic closure – *Pavić Čolić M., Mađarević D., Simić S.*

W.2A.5 – Multi-component mixture of Euler fluids - shock structure analysis – *Mađarević D., Pavić Čolić M., Simić S.*

W.2A.6 – FSI analysis of hydrofoils using FEM and SPH methods – *Topalović M., Nikolić A., Vulović S., Milovanović V.*

W.2A.7 – Natural convection due to lower plate temperature nonuniformity – *Jovanović M., Milanović S., Spasić Ž.*

W.2A.8 – Numerical simulation of laminar flow in periodical grooved channel – *Lečić L., Stevanović*

V.

W.2A.9 – Numerical modeling the motion of otoconia particles in the semicircular canal under whole body vibration – *Saveljić I., Mačužić Saveljić S., Nikolić D., Đukić T., Đorović S., Lukić J., Filipović N.*

Session W.2B: 10:45-13:00

Mini-Symposia IV: Nonlinear Dynamics

Chairs: Hedrih Stevanović K., Simonović J.

W.2B.1 – Schools of asymptotic methods on nonlinear mechanics Krilov-Bogolyubov-Mitropolsky and scientific research in Serbia – *Hedrih Stevanović K.*

W.2B.2 – Tracking of periodic signal through the orthogonal lattice of nonlinear chains by synchronisation – *Simonović J.*

W.2B.3 – Forced vibration of the nano-system composed from elastically connected nano-plate and nano-shell with influence of different parameters – *Stamenković Atanasov M., Pavlović I., Jovanović D.*

W.2B.4 – Exact augmented perpetual manifolds: corollary about linear and nonlinear perpetual mechanical systems – *Georgiades F.*

W.2B.5 – Nonlinear vibration of fractional viscoelastic beam on nonlinear layer – *Nešić N., Cajić M., Karličić D., Jović S., Simonović J.*

W.2B.6 – Analysis of evolution equations of a nonstationary axisymmetric body in a nonstationary central gravitational field – *Minglibayev M., Prokopenya A., Bizhanova S.*

W.2B.7 – Vibration suppression and energy harvesting application of an axially moving beam – *Karličić D., Cajić M., Adhikari S.*

W.2B.8 – Motion of two coupled bodies on a rough horizontal plane with variable coefficient of friction – *Prokopenya A.*

W.2B.9 – Finite-time stability of neutral fractional-order time-varying delay systems with nonlinear parameter uncertainties and perturbations – *Lazarević M., Radojević D., Maione G., Pisl S.*

13:00 - 14:00	Buffet Lunch

14:00 - 14:30	Keynote speaker: Topic: **Color of turbulence: Stochastic Dynamical Modeling of Turbulent Flows** **Prof. Mihailo R. Jovanović,** *University of Southern California, USA* Chair: Čantrak Đ.

Session W.3: 14:30-17:30

Mini-Symposia II: Turbulence

Chairs: Čantrak Đ.

W.3.1 – High efficiency optimization of a multistage centrifugal pump based on combination of modified BA and CFD – *Wang W., Pei J., Osman M.*

W.3.2 – Challenges to accurate computation of propeller performances at low angular velocities – *Svorcan J.*

W.3.3 – Energy harvesting from the hot water transportation pipelines – *Sonawat A., Kim J.*

W.3.4 – Experimentally determined response of impinging turbulent axisyimmetric air jet modified by low-amplitude sound modulation – *Cvetinović D., Erić A., Škobalj P., Milutinović N., Tihon J., Nakabe K., Tatsumi K.*

W.3.5 – Convolutional neural networks for flow sensing in wall turbulence – *Cuellar Martín A., Güemes A., Discetti S., Ianiro A.*

W.3.6 – TSI Presentation – *Sponsor presentation*

W.3.7 – Model-based design of riblets for turbulent drag reduction – *Jovanović M., Ran W., Zare A.*

W.3.8 – Sizing valve regulating element – *Savić Lj., Janković N., Čantrak Đ., Ilić D.*

W.3.9 – Simulating transitional and turbulent flow around airfoils at medium angles-of-attack – *Svorcan J., Hasan M., Tanović D., Popović L.*

W.3.10 – Five hole fast response probe for measurements of 3D velocity and pressure fields – *Bojović D., Čantrak Đ., Janković N., Nedeljković M.*

W.3.11 – Numerical investigation of reynolds number effects on rotor aerodynamic performances in hover – *Svorcan J., Kovačević A., Ivanov T., Jovanović M.*

W.3.12 – Forced vortex in turbulent swirling flow – *Čantrak Đ., Janković N., Lečić L.*

17:30 - 18:00	Closing Ceremony

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SIMULATION OF DAMAGE EVOLUTION IN METAL STRUCTURES

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Abstract (150 - 450 words):

Phase-field damage models (PFDM) are recently used in finite element method (FEM) software combined with plasticity to simulate damage initiation and evolution in structures. The fracture of structures results from damage that influences the degradation of material's stiffness, so the proper prediction of damage evolution is valuable. The authors proposed modifications of hardening function and coupling variable to provide more control on the material parameters identification process and more accurate qualitative and quantitative prediction of the metal structures behavior. The staggered iterative scheme is employed for the implementation into the FEM software. The simulation results are compared to the experimental tensile tests. The comparison of force-displacement response is given and an excellent result is obtained. Additionally, the equivalent plastic strain and damage field are presented at the end of the loading process. In engineering practice, the proposed modification of PFDM will provide a better understanding of the steel structure's fracture.

Key words: phase-field model, plasticity, metal structures, damage evolution, fracture

1. Introduction

The safety of steel structures is unavoidable demand in structural design. During the exploitation period, unexpected loading conditions can be noticed due to various reasons. The damage mechanism can occur, and damage evolution leads to the structure's failure. A phase-field damage model (PFDM) was recently used for the numerical simulations of damage initiation and evolution. Many authors [1-6] implemented PFDM in finite element method (FEM) software for efficient use in the structure design. The metal plasticity and phase-field theory are employed by using the staggered algorithm for stress integration. The damage phase-field is related to damage of the material and the stiffness degradation, while the plasticity is responsible for the development of inelastic strains. In literature Ambati et al. [2,3], a coupling variable was suggested to define the influence of plastic strain on crack propagation. This paper presents the application of PFDM – plasticity for damage evolution simulation in steel structures [6]. We have modified the coupling variable to consider the damage influence as the results of plastic strains. Also, a two-interval yield function is proposed to simulate the stress plateau at the beginning of the yielding process. The stress integration algorithm is verified by comparing the simulation

results to the experimental investigation results of S355 specimens. An excellent qualitative and quantitative results are obtained.

2. Phase-field damage and plasticity model

A phase-field damage variable d along the coordinate x of the bar in Fig 1 can be formulated as an exponential function of the bar length in the form [2-6]:

$$d = \mathrm{e}^{-|x|/l_c}, \tag{1}$$

where l_c is a characteristic length parameter.

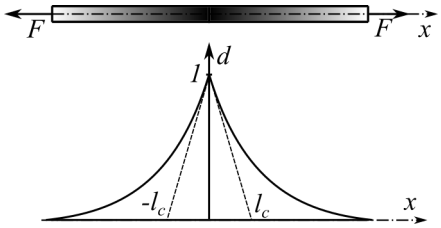

Fig. 1. A damage phase-field for bar loaded by forces F on both sides [2-6]

By following Miehe et al. [4,5], a crack surface density function γ per unit volume for multi-dimensional problems is defined as [1-6]:

$$\gamma = \frac{1}{2l_c}\left(d^2 + l_c^2 \left|\nabla d\right|^2\right). \tag{2}$$

The complete derivation of the internal and external potential energy equilibrium is given in [6] as:

$$\begin{aligned}
&\int_V \Big\{ -\Big[g'(d)\psi + G_V \Big[d - l_c^2 \nabla^2 d \Big] \Big] \delta d - \Big[Div\big[\boldsymbol{\sigma}\big] + \mathbf{b} \Big] \cdot \delta \mathbf{u} + \\
&+ \left(-g(d)\boldsymbol{\sigma}_0 : \frac{\partial \boldsymbol{\varepsilon}_P}{\partial \bar{\varepsilon}_P} + g(d)\left(\sigma_{y0,\infty} - \sigma_{yv}\right)\left(1 - e^{-n\bar{\varepsilon}_P}\right) + g(d) H \bar{\varepsilon}_P + g(d)\sigma_{yv} \right) \delta \bar{\varepsilon}_P \Big\} dV \,, \\
&+ \int_A \big\{ \big[\boldsymbol{\sigma} \cdot \mathbf{n} - \mathbf{h} \big] \cdot \delta \mathbf{u} \big\} dA + \int_A \Big\{ \Big[G_V l_c^2 \nabla d \cdot \mathbf{n} \Big] \delta d \Big\} dA = 0
\end{aligned} \tag{3}$$

where $g(d)$ is the degradation function, ψ is the internal potential energy density, G_V is the critical fracture energy release rate per unit volume, ∇ is the gradient operator, $\mathbf{b}$ is the body force field per unit volume, $\mathbf{u}$ is the nodal displacements vector, $\boldsymbol{\sigma}_0$ is the "undamaged" Cauchy stress, $\boldsymbol{\varepsilon}_P$ is the plastic strain, $\bar{\varepsilon}_P$ is the equivalent plastic strain, $\sigma_{y0,\infty}$ is the saturation hardening stress, σ_{yv} is the initial yield stress, H is the hardening modulus, $\mathbf{n}$ is the unit outer normal to the surface A, and $\mathbf{h}$ is the boundary traction per unit area. The governing balance equations of the coupled PFDM - plasticity problem can be obtained as [6]:

$$Div\big[\boldsymbol{\sigma}\big] + \mathbf{b} = 0, \tag{4}$$

$$G_V \Big[d - l_c^2 \nabla^2 d \Big] + g'(d)\psi = 0, \tag{5}$$

$$\bar{\sigma}_{eq} - \sigma_{yv} - \left(\sigma_{y0,\infty} - \sigma_{yv}\right)\left(1 - e^{-n\bar{\varepsilon}_P}\right) - H\bar{\varepsilon}_P = 0\,. \tag{6}$$

The degradation function $g(d)$ is proposed by Ambati et al. [2,3] for the phase-field damage modeling of ductile fracture as:

$$g(d) = (1-d)^{2p}\,. \tag{7}$$

The coupling variable p [2,3], graphically presented in Fig. 2, can be defined to depend on the critical value of the equivalent plastic strain $\bar{\varepsilon}_P^{crit}$ and the value of the critical equivalent plastic strain as [6]:

$$p = \begin{cases} 0 & ;\dfrac{\bar{\varepsilon}_P}{\bar{\varepsilon}_P^{crit}} < 1 \\ \dfrac{\bar{\varepsilon}_P}{\bar{\varepsilon}_P^{crit}} - 1 & ;\dfrac{\bar{\varepsilon}_P}{\bar{\varepsilon}_P^{crit}} \geq 1 \end{cases}, \tag{8}$$

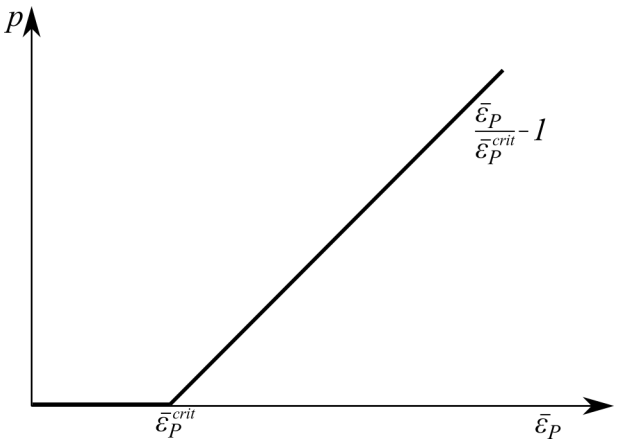

Fig. 2. Coupling variable with respect to equivalent plastic strain

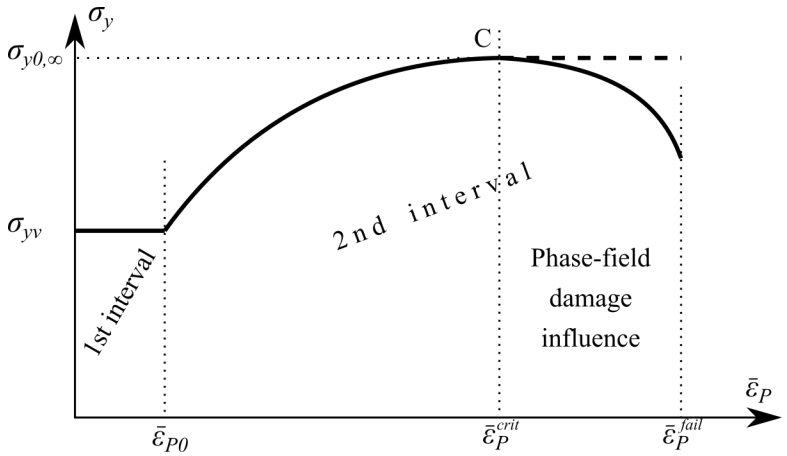

Fig. 3. A two-interval hardening function for metallic materials which exhibits plateau after yielding

The material is damaged as the result of the plastic strain accumulation (Fig. 3). For the simulation of the metallic material's behavior, which exhibits stress plateau after yielding (1st interval), the two-interval hardening function can be used to reproduce the idealized response given in Fig. 3. The complete two-interval hardening function can be defined by the following equation:

$$f_y = \begin{cases} \bar{\sigma}_{eq} - \sigma_{yv} & ;\bar{\varepsilon}_P < \bar{\varepsilon}_{P0} \\ \bar{\sigma}_{eq} - \left[\sigma_{yv} + \left(\sigma_{y0,\infty} - \sigma_{yv} \right) \left(1 - e^{-n\left(\bar{\varepsilon}_P - \bar{\varepsilon}_{P0} \right)} \right) + H\left(\bar{\varepsilon}_P - \bar{\varepsilon}_{P0} \right) \right] & ;\bar{\varepsilon}_P \geq \bar{\varepsilon}_{P0} \end{cases} . \quad (9)$$

The detailed algorithm of the von Mises plasticity for large strain problems coupled with PFDM is given in the authors paper [6].

3. Experimental Investigation and FEM Simulation of S355 Specimens

Steel S355 is a specific type of material which exhibits constant stress plateau after yielding point, so it will be used for a verification purpose. Three standard flat specimens are investigated by uniaxial tensile tests at room temperature for strain rate 10^{-3} s^{-1}. Fig. 4 shows the size and the shape of one of the investigated specimens.

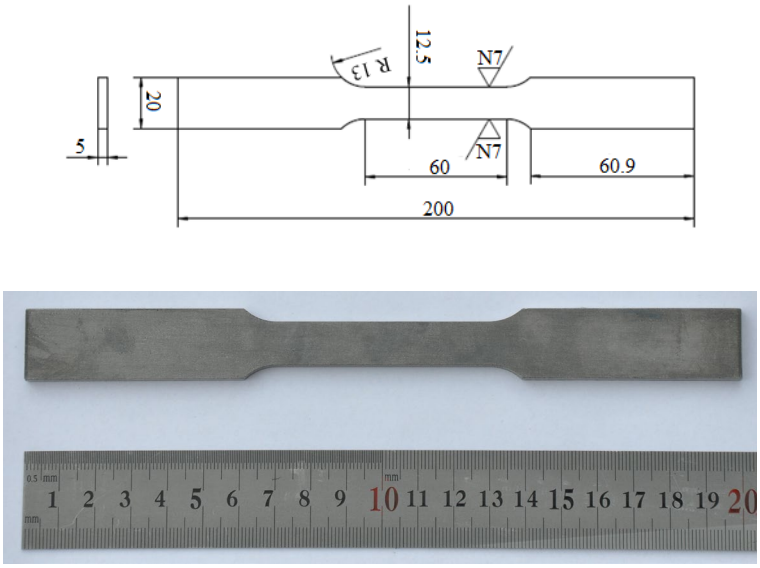

Fig. 4. Size and shape of the investigated flat S355 specimens

The Finite Element (FE) model (25 × 6.25 × 2.5 mm) is prepared along the straight part of the specimen. The loading is applied on the one side of the specimen by displacement increment of 0.02 mm for 450 steps. Experimentally obtained results for one of the investigated specimens were selected for calibration of material parameters. The material parameters used for simulations are given in Table 1.

E [MPa]	ν [–]	σ_{yv} [MPa]	$\sigma_{y0,\infty}$ [MPa]	H [MPa]	n [–]	G_V [MPa]	l_c [mm]	$\bar{e}_P^{crit}$ [–]	$\bar{e}_{P0}$ [–]
190080	0.30	382.86	642.74	0.00001	15.9	9.61	0.01	0.211	0.0051

Table 1. Material parameters used for phase-field damage model simulation

The equivalent plastic strain field as well as damage field are localized in a fracture zone of the specimen (Fig. 5). One can notice that there is a strong relation between the damage and the

equivalent plastic strain so the conclusion is that damage is a responsible for the fracture of the specimen. The comparison of the force-displacement relationship between experimental and simulation results is given in Fig. 6.

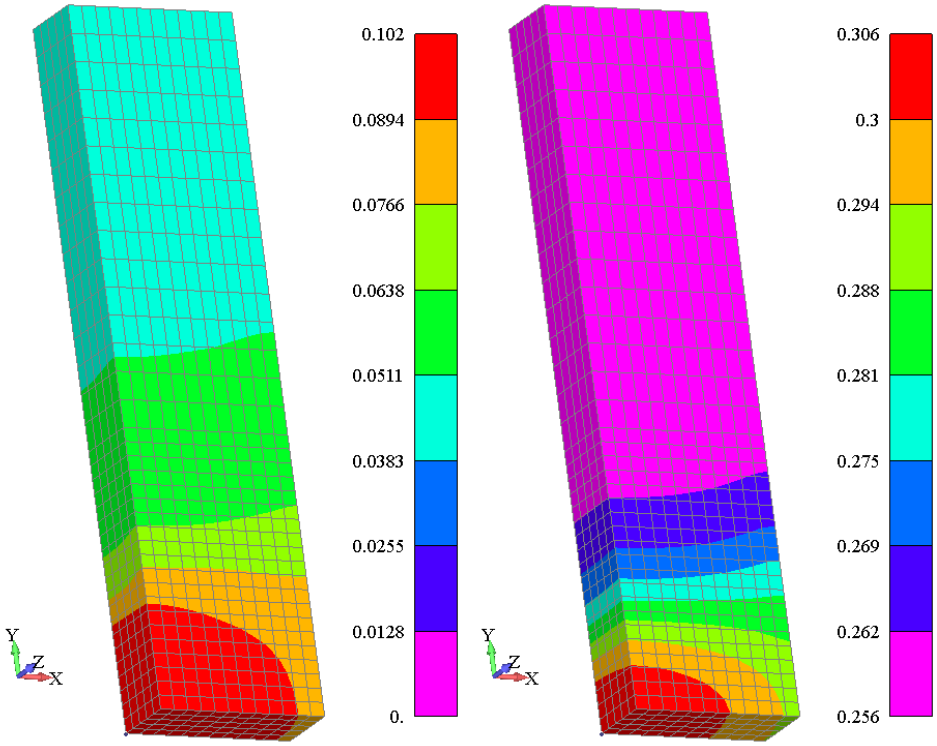

Fig 5. Damage field (left) and effective plastic strain field (right) at the displacement in y-axis of 15.36 mm

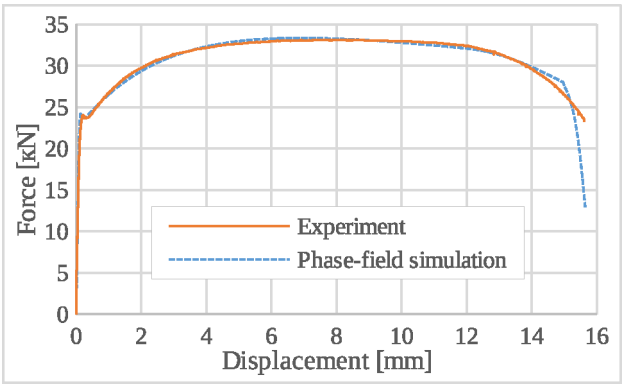

Fig. 6. Force–displacement response of experiment and phase-field simulation for S355 steel specimens.

4. Conclusions

The PFDM for the simulation fracture in engineering structures is an emerging method in computational mechanics. The proposed two-intervals hardening function extends the use for metallic materials which exhibit stress plateau after yielding occurs. The coupling variable is determined to increase after the critical value of the equivalent plastic strain is achieved. That proposes the possibility to control the onset of the damage evolution and crack propagation. The

FEM implementation in in-house software PAK for structural analysis has been verified by comparing the experimental results of S355 test specimen. The equivalent plastic strain field and the damage phase field are shown. The modifications allows the possibility to simulate various types of metallic materials in engineering practice.

Acknowledgments: This research was funded by project TR32036 of Ministry of Educations, Science and Technological Development, Republic of Serbia.

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[1] Wu, J.,Y., Nguyen, V.,P., Nguyen, C.,T., Sutula, D., Sinaie, S., Bordas, S., *Chapter One—Phase-field modeling of fracture, in Advances in Applied Mechanics*, Bordas, S., Balint, D., Eds., Elsevier: Amsterdam, The Netherlands, 53, 1–183, 2020.

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