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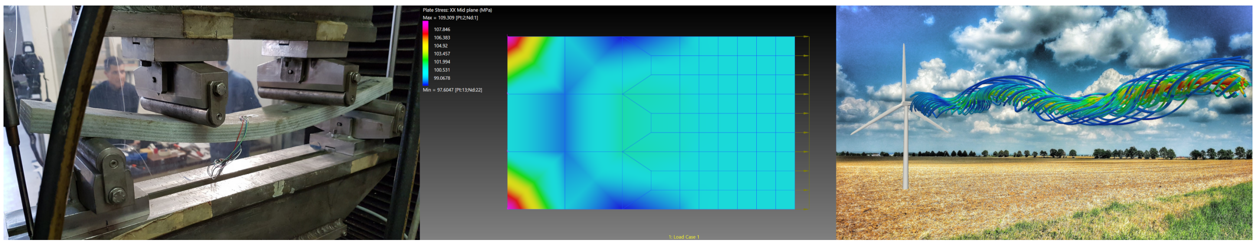

WECM'23 – 2nd Workshop on Experimental and Computational Mechanics
Book of Abstracts

Paolo S. Valvo and Sylwester Samborski (Editors)

University of Pisa, Italy, 2023

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Citation

Paolo S. Valvo, Sylwester Samborski (Editors): *WECM'23 – 2nd Workshop on Experimental and Computational Mechanics – Book of Abstracts*, University of Pisa, Italy, 2023. URL: http://wecm23.ing.unipi.it/WECM23-Book_of_Abstracts.pdf

Contents

Front matter **i**

Foreword . . . iv

Scientific Committee . . . v

Organising Committee . . . vi

Best Paper Awards . . . vii

Best Poster Award . . . vii

Websites . . . viii

WECM'23 – 2nd Workshop on Experimental and Computational Mechanics **1**

Keynote Lecture 1 **2**

T. Sadowski*, D. Pietras, E. Postek, R. Gieleta, M. Chmielewski: *Numerical modelling and experimental verification of gradual degradation of 2-phase ceramic and metal-ceramic composites under slow and high strain rates* . . . 3

Session 1A – Mechanics of Materials **4**

T. Sadowski, K. Łosiewicz*: *Comparison of two-phase ceramic composites fracture toughness obtained from nanoindentation and scratch tests* . . . 5

M. Budka*, T. Sadowski, P. Golewski: *Inclusion of a quartz sand protective layer in polymer matrix composites as a strategy to improve environmental resistance and mechanical properties* . . . 6

W. Zbyszyński*, D. Pietras, T. Sadowski, M. Pingaro: *Evaluation of the interface layer impact on fracture energy of the 3D printed multi-layered mortar composite* . . . 7

Session 1B – Technological Applications **8**

S. Kharchenko*, S. Samborski, Ł. Kłoda, F. Kharchenko: *Oscillations of perforated plates with volumetric riffles* . . . 9

S. Kharchenko, S. Samborski, F. Kharchenko*: *Factors of technological efficiency and reliability of elastic cleaners of vibrating sieves* . . . 10

S. Kapyś*, Ł. Garbacz: *Characteristic of selected properties of PHB modified by nigella oil cake* . . . 11

Ł. Garbacz*, S. Kapyś: *Characteristics of modern polymer-mineral composites made from waste materials* . . . 12

Keynote Lecture 2 **13**

J. Warmiński*: *Nonlinear phenomena in multi-stable mechanical systems* . . . 14

Session 2A – Stability and Dynamics **15**

J. Latalski*, J. Dubicka-Nowak, J. Warmiński: *Dynamics of composite beam with embedded active elements with nonlinear constitutive behaviour* . . . 16

M. Picchi Scardaoni*: *On paving the plane, plates, and origami* . . . 17

M. Coppedè*, R. Paroni, M. Picchi Scardaoni: *Energy estimates for tape spring devices* . . . 18

Session 2B – Posters **19**

M. Szala*, E. Jonda, L. Łatka, M. Walczak: *Effect of mechanical properties on cavitation erosion resistance of composite coatings manufactured via HVOF* 20

M. Kłonica*: *Comparative tests of shear strength of adhesive lap joints (316L steel) after thermal shocks* 21

M. Mohaseb Karimlou*, D. Fanteria, P.S. Valvo, S. Samborski, J. Rzeczkowski: *Mode III interlaminar fracture toughness of advanced composite materials: experimental testing and numerical modelling* 22

K. Falkowicz*, P. Różyło, H. Dębski, S. Samborski: *Experimental and numerical failure analysis of compressed thin-walled composite plate element with advanced damage models* 23

M. Gasenge*, C. Hoareau, L. Rouleau, J.-F. Deü, P.S. Valvo: *Experimental characterization and theoretical modeling of damping properties in CFRP composite structures* 24

S. Kharchenko*, S. Samborski, F. Kharchenko, I. Korzec-Strzałka: *Method for identifying the sizes and shapes of biological objects* 25

D. Kostyła*, P. Węgierek, M. Lech, A. Zielonka: *Fiber optic sensor for pressure measurement* . . . 26

O. Miroshnyk*, O. Moroz, T. Shchur, A. Chepizhyi, S. Halko: *Smart grid operation modes with electrical energy storage system* 27

P. Podolak*, P. Jakubczak, J. Bieniaś: *Numerical simulation of damage propagation in fibre metal laminates subjected to compression after impact* 28

Session 2C – Damage Mechanics **29**

S. Samborski*, J. Rzeczkowski, J. Skoczylas, J. Paśnik, I. Korzec-Strzałka: *Damage identification of composites conducted by acoustic emission technique with special emphasis on FFT and wavelet analysis* 30

I. Korzec-Strzałka*, J. Rzeczkowski, S. Samborski: *Detection of delamination in fiber reinforced polymer composites based on acoustic emission* 31

J. Rzeczkowski*, S. Samborski, D. Fanteria, P.S. Valvo: *Experimental and numerical study of delamination in composite laminates with bending-twisting elastic couplings* 32

P. Tsokanas*, L.F.M. da Silva, P. Fisicaro, P.S. Valvo: *On the conditions for pure-mode fracture* . . . 33

H. Zarei*, M. Buchignani, S. Giangrandi, M. Paggi: *Failure analysis and mechanical behavior of coupled laminates for packaging* 34

C. Santus, L. Romanelli*, T. Grossi, P. Neri: *Analysis on the determination of Chaboche and Bouc-Wen parameters for a quenched and tempered steel* 35

M. Droździel-Jurkiewicz*, P. Jakubczak, J. Bieniaś: *Influence of surface treatment on the adhesive fracture energy of titanium-based laminates using T-peel tests* 36

Keynote Lecture 3 **37**

F. Giannetti*, J. Sierra-Ausin: *Feedback mechanism of sound generation in a rounded impinging jet: tonal vs broad-band noise* 38

Session 2D – Fluid Dynamics **40**

S. Bikić*, L. Bubnjević, A. Gavrilov, R. Al Afif, M. Radojčin: *Calibration of gas leak detector* 41

P.G. Ledda*, M. Pezzulla, E. Jambon-Puillet, P.-T. Brun, F. Gallaire: *Gravity-driven coatings on three-dimensional curved substrates* 42

G. Lunghi*, S. Brusco, A. Mariotti, G. Piccardo, M.V. Salvetti: *The accelerating and decelerating flow around a square cylinder* 44

E. Luzzati*, A. Mariotti, M.V. Salvetti: *Development of an actuator line model for variable pitch vertical axis turbines* 46

Session 2E – Hemodynamics **47**

S. Garzia*, M.A. Scarpolini, B.M. Fanni, S. Celi: *Synthetic aided deep learning segmentation of 4D flow image data for CFD simulations* 48

M. Mazzoli*, M.A. Scarpolini, B.M. Fanni, S. Celi: *A combined statistical shape model and CFD simulations framework for hemodynamic investigation* 49

F. Dell'Agnello*, M.A. Scarpolini, K. Capellini, E. Vignali, E. Gasparotti, F. Cademartiri, S. Celi: *Effects of wall motion on the hemodynamics of the aorta* 51

J. Singh*, K. Capellini, B.M. Fanni, A. Mariotti, M.V. Salvetti, S. Celi: *Numerical simulations to predict the onset of atherosclerotic plaques in carotid arteries* 53

M. Morello*, M.N. Antonuccio, A. Mariotti, M.V. Salvetti, S. Celi: *CFD simulations of different grades of severity of aortic coarctations: analysis of the flow patterns and effect of outlet boundary conditions* 55

Keynote Lecture 4 **56**

A. Castellano*: *Linear and nonlinear ultrasonic techniques for mechanical characterization of materials* 57

Session 3A – Civil Engineering **59**

F. Guarracino, I. Mascolo*: *Static and dynamic buckling of rings: a critical review of classical approaches* 60

A. Castellano, A. Fraddosio*, M.D. Piccioni, T. Kundu: *Non-linear ultrasonic approach for the characterization of Mode II debonding behavior of FRCM reinforcements for masonry constructions* 61

D. Aita*, M. Bruggi: *Anti-funicular networks in masonry vaults with stereotomy, friction and strength requirements: a multi-constrained min/max problem validated through Durand-Claye's method* 62

I. Vangelisti*, P. Di Re, J. Ciambella, A. Paolone: *In situ dynamic measurements and finite element analysis of a composite steel-concrete highway girder bridge* 63

M. Assad, R. Hawileh*, G. Karaki: *Finite element modelling of RC walls under fire exposure* 64

Session 3B – Aerospace Engineering **65**

C. Guidi*, M.M. Saravia, F. Paganucci, S. Camarri: *Integrated data analysis for the experimental assessment of anomalous electron transport in Hall thrusters* 66

L. Leporini*, V. Giannetti, S. Camarri, T. Andreussi, B. Jorns: *Investigation of the plume mode in hollow cathodes via a 1D fluid model* 67

P. Fisicaro*, A. Pasini, P.S. Valvo: *Deployable cable nets for active removal of derelict rocket bodies* 68

Foreword

This book collects the 47 abstracts of the scientific works presented at the **WECM'23 – 2nd Workshop on Experimental and Computational Mechanics**, held in Pisa, Italy, from 20 to 22 September 2023. The overall programme included

- 4 Keynote Lectures;
- 34 Oral Presentations;
- 9 Posters.

All submitted abstracts were reviewed under the responsibility of the Scientific Committee.

WECM'23 was organised in the wake of the **WECM'22 – 1st Workshop on Experimental and Computational Mechanics**, held in Lublin, Poland, on 1 June 2022. Both events were organised under the ten-year Agreement of Collaboration signed between the University of Pisa and Lublin University of Technology for the years 2019–2029. **WECM'23** received the patronage of the **Department of Civil and Industrial Engineering (DICI)** of the University of Pisa, His Magnificence the Rector of **Lublin University of Technology (LUT)**, and the **Società Italiana di Scienza delle Costruzioni (SISCo)**. The event was funded by the **University of Pisa (UniPI)**. Further support was offered by the engineering company **AICE Consulting Srl**.

The aim of **WECM'23** was to gather researchers who use computational and/or experimental approaches in both Solid and Fluid Mechanics to foster mutual knowledge and promote collaboration across disciplines. **WECM'23** was specially addressed to young researchers – including MSc and PhD students – hoping to make them grow in love for scientific research. The workshop had around 70 registered participants with affiliations in Italy (around 60%) and Poland (around 30%), besides Portugal, Serbia, Ukraine, and the United Arab Emirates.

WECM'23 was also the occasion to hold the Final Meeting of the Italian-Polish project titled "Damage Identification in Advanced Composite Materials with Elastic Couplings" (DIACMEC). The **DIACMEC Project** was funded by the **Italian Ministry of Foreign Affairs and International Cooperation (MAECI)** and the **Polish National Agency for Academic Exchange (NAWA)** under the Executive Protocol "Canaletto" for Scientific and Technological Cooperation between Italy and Poland for the years 2022–2023.

Pisa, 22 September 2023.

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Best Paper Awards

Based on the evaluation carried out by a Selection Committee composed of

- Prof. Simone Camarri, University of Pisa, Italy
- Prof. Luigi Lazzeri, University of Pisa, Italy
- Prof. Jerzy Warmiński, Lublin University of Technology, Poland (Chairman)

the following awards were attributed:

- **WECM'23 Best Paper Award in Experimental Solid Mechanics**
  C. Santus, L. Romanelli*, T. Grossi, P. Neri
  Analysis on the determination of Chaboche and Bouc-Wen parameters for a quenched and tempered steel

- **WECM'23 Best Paper Award in Computational Solid Mechanics**
  M. Coppedè*, R. Paroni, M. Picchi Scardaoni
  Energy estimates for tape spring devices

- **WECM'23 Best Paper Award in Fluid Dynamics**
  J. Singh*, K. Capellini, B.M. Fanni, A. Mariotti, M.V. Salvetti, S. Celi
  Numerical simulations to predict the onset of atherosclerotic plaques in carotid arteries

Best Poster Award

Based on the preferences expressed by the participants, the **WECM'23 Best Poster Award** was attributed *ex aequo* to the following two posters presented at the workshop:

- M. Gasenge*, C. Hoareau, L. Rouleau, J.-F. Deü, P.S. Valvo
  Experimental characterization and theoretical modeling of damping properties in CFRP composite structures

- M. Szala*, E. Jonda, L. Łatka, M. Walczak
  Effect of mechanical properties on cavitation erosion resistance of composite coatings manufactured via HVOF

Websites

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WECM'23 – 2nd Workshop on Experimental and Computational Mechanics

«Fatti non foste a viver come bruti,
ma per seguir virtute e canoscenza.»

«You were not made to live like brutes,
but to follow virtue and knowledge.»

Dante Alighieri
(Inferno, XXVI, 119–120)

Keynote Lecture 1

Wednesday 20 September 2023, 14:30 – 15:15

Numerical modelling and experimental verification of gradual degradation of 2-phase ceramic and metal-ceramic composites under slow and high strain rates

Tomasz Sadowski[1,*], Daniel Pietras[1], Eligiusz Postek[2], Roman Gieleta[3], Marcin Chmielewski[4]

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Keywords: 2-phase composites, damage modelling, experimental tests.

Gradual degradation of brittle composites exhibits different mechanical responses under uniaxial tension and uniaxial compression. In this paper, we analysed cracking processes and failure under quasi-static loading of 2-phase ceramic (Al_2O_3/ZrO_2) or Al_2O_3/SiC, subjected to tension and compression. Constitutive modelling of 2-phase ceramic composites obeys the description of (1) elastic deformations of initially porous material, (2) limited plasticity and (3) cracks initiation and propagation.

Modelling of polycrystalline ceramics at a mesoscopic level under mechanical loading is related to the analysis of a set of grains, i.e. Representative Volume Element (RVE). The basic elements of the defect structure inside polycrystals are micro- and meso-cracks, kinked and wing cracks. To get a macroscopic response of the material one can calculate averaged values of stress and strain over the RSE with the application of an analytical approach.

A high strain rate degradation process was illustrated for Al_2O_3/ZrO_2 and Al_2O_3/SiC composites, which were subjected to short compressive impulses. The pulse duration was 10^{-7} s. In the proposed more advanced finite elements formulation it was necessary to take into account the following data and phenomena appearing inside of the RVE: (1) spatial distribution of the composite constituents, (2) system of grain boundaries/binder interfaces modelled by interface elements, (3) rotation of brittle grains. The gradual degradation of the Al_2O_3 composite response due to pulse loading is presented in Fig. 1.

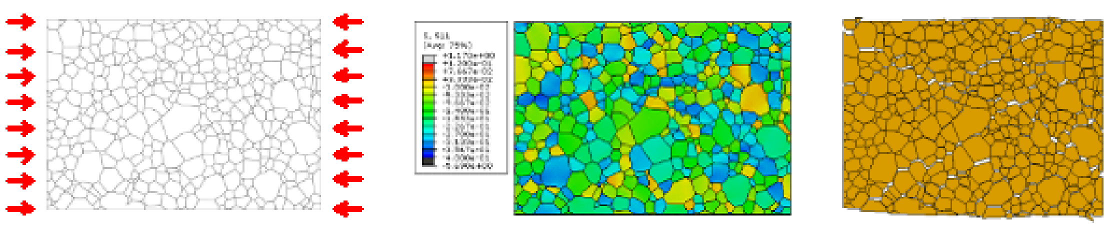

Figure 1: High strain rate degradation process of the Al_2O_3 composite.

Acknowledgements: The results presented in this paper were obtained within the framework of research grant No. UMO/2016/21/B/ST8/01027 and UMO 2019/33/B/ST8/01263 financed by the National Science Centre, Poland.

Session 1A – Mechanics of Materials

Wednesday 20 September 2023, 15:15 – 16:00

Comparison of two-phase ceramic composites fracture toughness obtained from nanoindentation and scratch tests

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Keywords: nanoindentation, scratch test, ceramic composites.

Fracture toughness is a parameter that corresponds to material's resistance to crack propagation. This characteristic can be calculated in laboratory tests, e.g. bending of notched bars or indentation test [1].

The objective of this study is to compare less frequently used scratch test to conventional methods mentioned above.

This paper shows results of scratch tests with a use of Rockwell tip. Five types of ceramic composites with composition ratios of 20, 40, 60, 80 wt% of Al_2O_3 content were tested. To estimate the fracture toughness a linear correlation to hardness and its changing trend along the scratch length was analysed.

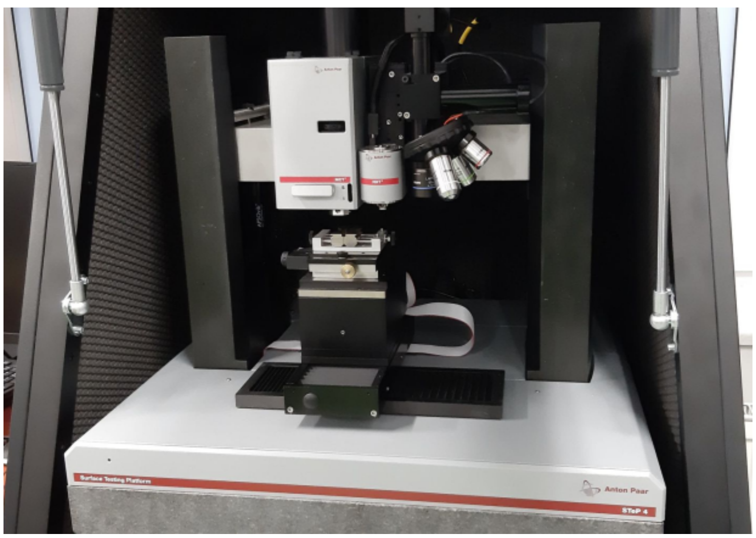

Figure 1: NHT^3 combined nanoindenter and scratch tester.

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[1] Sadowski, T.; Łosiewicz, K.: Pop-in phenomenon at nanoindentation and fracture toughness of two-phase ceramic composites, *Mater. Today: Proc.*, 78 (2), 270–273 (2023). DOI: 10.1016/j.matpr.2022.11.413

Inclusion of a quartz sand protective layer in polymer matrix composites as a strategy to improve environmental resistance and mechanical properties

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Keywords: polymer composites, protective layer, inclusion.

Fibre-reinforced composites with a polymer matrix due to low weight and high strength parameters has found applications in many engineering fields i.a. in civil engineering, automotive, aerospace engineering. However, sensitivity to environmental factors pose challenges for long-term usability [1]. In this study, we propose an innovative strategy to enhance the mechanical resistance of polymer composites by including a protective quartz sand layer [2]. The inclusion method was employed to introduce fine-grained quartz into the polymer composite matrix. The inclusion process was developed under laboratory conditions in to achieve an even distribution of sand in the polymer matrix during the epoxy resin matrix infusion process.

The results revealed that the inclusion of a protective sand layer have altered the material properties of the composite. Microstructural analysis showed the distribution of sand in the composite matrix. Mechanical corrosion test was also conducted on the composite with a protective layer of quartz sand (Fig. 1). The addition of quartz layer in the structure of the composite led to changes in tensile strength.

The presented findings represent a significant step towards the development of more durable and resilient polymer composites. The results of the research will help in the development and design of new protection systems.

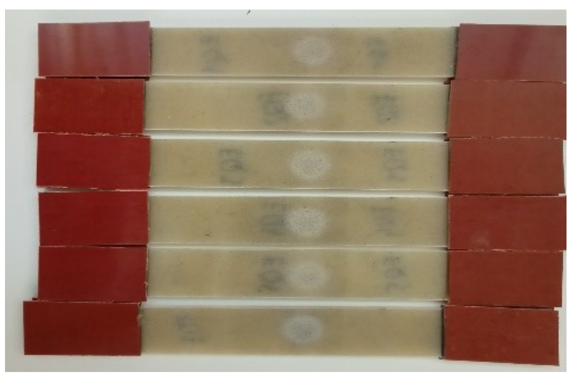

Figure 1: Samples after mechanical erosion test.

Acknowledgements: This research was funded by the National Centre for Research and Development of Poland grant number LIDER XIII 0135/L-13/2022.

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[2] Golewski, P.; Sadowski, T.: Technological and Strength Aspects of Layers Made of Different Powders Laminated on a Polymer Matrix Composite Substrate, *Molecules*, 27 (4), 1168 (2022). DOI: 10.3390/molecules27041168

Evaluation of the interface layer impact on fracture energy of the 3D printed multi-layered mortar composite

Wojciech Zbyszyński[1,*], Daniel Pietras[1], Tomasz Sadowski[1], Marco Pingaro[2]

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Keywords: 3D printing, mortar, mechanics.

Dynamic development of a 3D Printing (3DP) technology creates new type of structural materials. The most popular technology of 3DP used in civil engineering involves layer-by-layer deposition for structure creation. Structures manufactured in this technology behave as multi-layered composites with an additional cohesive layer between printed layers of the material (Fig. 1). The cohesive layer, commonly known as an interface, behaves differently than the material used for printing, thus changes the composite's behaviour. This leads to modifications of its characteristics, which in itself generates new scientific problems. One of which is the behaviour during failure process [1].

The aim of this experimental study is the evaluation of interface layer impact on the fracture energy of the multi-layered mortar composite created in a 3DP technology. The evaluation consists of comparison of the results acquired for the 3DP composite and the material used for its creation in form of classical specimens with dimensions similar to the 3DP specimens and varying levels of compaction. The specimens were subjected to 3-point bending under the condition of Loading-Unloading-Reloading. Digital Image Correlation (DIC) was used instead of the traditional clip-on extensometer for Crack Mouth Opening Displacement (CMOD) measurements. The DIC method avoids introduction of the external damaging tensile forces which lead to accelerated failure of the material. The achieved results indicate the difference between values of fracture energy acquired with forces applied perpendicular and parallel to layers' stacking direction. Moreover the acquired data can be directly used for numerical description of the composite.

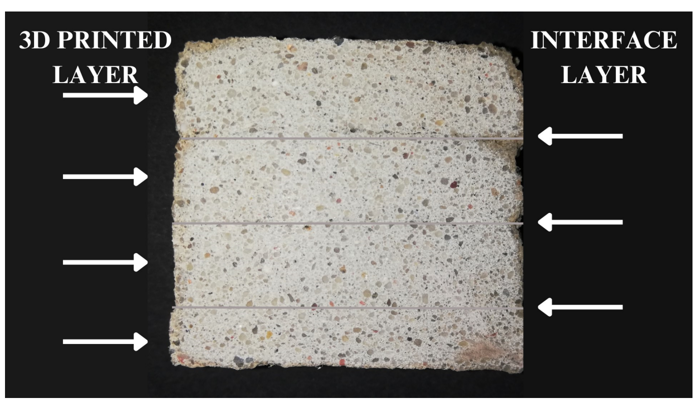

Figure 1: The cross-section of the 3DP composite.

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Session 1B – Technological Applications

Wednesday 20 September 2023, 16:30 – 17:30

Oscillations of perforated plates with volumetric riffles

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Keywords: finite element method, natural frequencies, perforated surface with riffles.

Oscillation of plates are present during the execution of technological processes in many machines and equipment. One of the common options is the use of perforated surfaces for sifting loose mediums, when vibration is additionally used. Entering into resonance can lead to damages, such as cracks occurring between the holes. This leads to a disruption in the sifting process of loose medium components and a decrease in the reliability of the structure. The use of sieves with volumetric riffles, which are extruded from the metal between the holes, has shown to significantly increase the technological efficiency of sifting by orienting the components of loose mediums into the holes [1]. Such a riffles serve as structural stiffeners and influence the oscillation of the perforated surface and its reliability. Experimental identification was carried out on the laser scanning vibrometer PSV-500 $w = 68.44 \ldots 698.12$ Hz.

Obtained values of the natural oscillation describe the surface with defined hole and riffle parameters. The development of reliability studies of perforated surfaces with riffles will be continued in the finite element modeling, which will be based on these results. This will allow a detailed study and obtaining dependencies of the frequency of oscillation of perforated surfaces on the riffle and hole parameters.

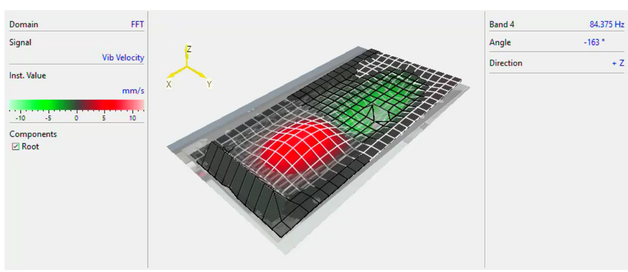

Figure 1: Experimental identification of oscillations of a perforated surface with riffles.

Acknowledgements: The authors acknowledge the financial support of the National Science Centre in Krakow to the research project funded in the "POLONEZ BIS 2" call No. 2022/45/P/ST8/02312 entitled Numerical-experimental analysis of a sieve holes' shape and arrangement effect on the degree. POLONEZ BIS is operated by the Centre on the basis of the Grant Agreement No. 945339 concluded with the European Research Executive Agency.

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Factors of technological efficiency and reliability of elastic cleaners of vibrating sieves

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Keywords: finite element method, natural frequencies, perforated surface with riffles.

Sieve sifting processes of loose medium occupy a significant place in many technological processes of construction, mining, chemical, pharmaceutical, agricultural, food and other industries [1]. The efficiency of sifting of loose medium particles depends on the timely cleaning of the vibrating surface holes, mainly by means of impact impulses from oscillating elastic cleaning balls [2]. As a result of preliminary research and analysis, the factors of technological efficiency and reliability of elastic cleaners have been formed: 1) Parameters and material properties of cleaners. Holes cleaning condition, which are based on the ratio of the adhesion force between the biological objects (BO) and the holes edge and the wedging force initiated by the kinetic energy of the cleaner impact. The ratio of these forces determines not only the intensity of hole cleaning, but also leads to the BO and elastic cleaner damage. 2) Structural and kinematic parameters of perforated surfaces that determine the efficiency of sieve sifting of the BO. 3) Parameters of the reflective device (bumper) to give impulse to the cleaner with minimisation of non-working (non-cleaned) areas of the perforated surfaces; 4) Parameters and properties of the BO with minimization of damage level from impact cleaners. 5) Minimization of the maximum permissible concentration of wear particles of elastic cleaners and, as a result, physical and chemical contamination of final sifting products.

Prospective research directions:

- development of the optimal design of the bumper, weight, dimensions of elastic cleaners according to the criterion of maximum sifting of perforated surfaces;
- minimization of the BO damage and contamination of the final sifting products;
- minimization of forced vibrations of the perforated surface caused by the impacts of cleaners;
- optimization of the properties of the cleaner based on criteria of elasticity and durability of operation.

Acknowledgements: The authors acknowledge the financial support of the National Science Centre in Krakow to the research project funded in the "POLONEZ BIS 2" call No. 2022/45/P/ST8/02312 entitled Numerical-experimental analysis of a sieve holes' shape and arrangement effect on the degree. POLONEZ BIS is operated by the Centre on the basis of the Grant Agreement No. 945339 concluded with the European Research Executive Agency.

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Characteristic of selected properties of PHB modified by nigella oil cake

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Keywords: biocomposites, polyhydroxybutyrate, nigella oil cake.

Plastic pollution is a significant environmental problem that is caused by the accumulation of plastic waste in the environment [1]. Most of them are polymers based on fossil fuels, that does not degrade in the natural environment and pollute it, what affects marine and terrestrial ecosystems, whilst also posing serious risks to people by finding their way into human food chain [2]. Polyhydroxbutyrate (PHB) is a PHA, a polymer belonging to the polyesters class produced by bacteria under the nutrient imbalance condition. It is a fully biodegradable biopolymer and it decomposes into water, carbon dioxide and biomass under favorable conditions to microbial growth. PHB is a good candidate to replace petroleum-based polymers like polypropylene (PP) or polyethylene (PE) but its exploitation is limited due to its high stiffness, brittleness, narrow processability window and cost [3]. Nigella oil cake is a by-product of the manufacture of oil from nigella oilseeds. After extraction oil cake still contains oil, that can be used as a plasticizers to reduce brittleness and improve processability of PHB [4]. In research selected mechanical properties of Biomer ® P304 filled with nargella oil cake were determined: tensile strength, bending strength, Charpyimpact strength and hardness. Samples were prepared in injection modling process. The comparative analysis of the properties of PHB and PHB biocomposite with 10, 20, 30 % filler content was carried out.

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Characteristics of modern polymer-mineral composites made from waste materials

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Keywords: waste plastic, composites, mechanical properties.

Polymer-mineral composites are an innovative solution in the field of reusability of post-production waste polymer plastics. The advantage of this type of method is not only the possibility of solving the problem of waste management, but also the possibility of reducing the cost of producing the composite in comparison with, for example, metals or ceramics, and the possibility of obtaining a lighter and more durable product. Both thermoplastic and thermosetting plastics can serve as the composite matrix, but the use of a thermosetting polymer is preferred. Thermosetting plastics allow for excellent properties such as increased mechanical strength, good weather resistance and chemical resistance. Mineral fillers are increasingly successfully used as modifiers of polymeric materials, providing a good alternative to glass or aramid fibers, among others.They make it possible to reduce the cost of the final product, but are also responsible for improving parameters such as mechanical strength, thermal stability and fire resistance. Mineral fillers for thermoplastics include mineral sedimentary rocks such as silica, zeolites, but also clay minerals with bilayer and trilayer structures. Mineral fillers can be applied directly or after prior surface treatment.

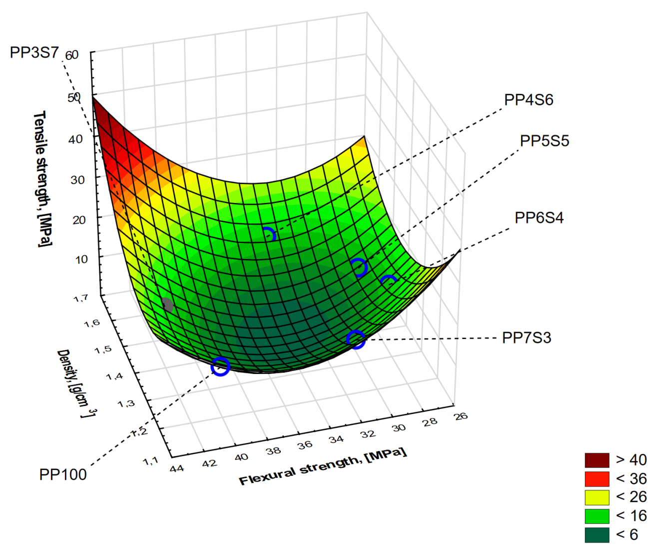

Figure 1: Obtained values of mechanical properties and densities for highly filled polymer-mineral composites.

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Keynote Lecture 2

Thursday 21 September 2023, 9:00 – 9:45

Nonlinear phenomena in multi-stable mechanical systems

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Keywords: nonlinear vibrations, multi-stable systems, snap-through.

Multi-stability is one of the main futures of nonlinear systems. A typical example of Duffing oscillator demonstrates three different solutions which may exist for the same set of parameters. As presented in [1], even for the one degree of freedom system and properly tuned parametric and external excitations a number of solutions may increase up to five.

In a classical Duffing type equation with positive linear stiffness the potential function has just one minimum and then equilibrium is stable. However, in structural mechanics also multi-stable structures may exists. Multi-equilibria occur in a natural way or can be designed to get this phenomenon for specific purposes, as presented in papers [2, 3].

The composite technology offers new possibilities in creating multi-stable structures. The bi-stability, with an associated snap-through effect defined as a rapid jump from one to another equilibrium is attractive for a design of efficient energy harvesters [4, 5]. A laminate shell with an asymmetric configuration has been proposed in [4] where several equilibria have been detected. The number of layers and the layout have been proposed to get a multi-stable shell with the snap-through effect. The analytical models and numerical solutions of the studied structure show a softening effect of the resonance curves for in-well dynamics. For large amplitude of excitation the period doubling and the snap-through are observed leading to chaotic global dynamics.

Acknowledgments: The work is financially supported by grant 2021/41/B/ST8/03190 from the National Science Centre, Poland.

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Session 2A – Stability and Dynamics

Thursday 21 September 2023, 9:45 – 10:30

Dynamics of composite beam with embedded active elements with nonlinear constitutive behaviour

Jarosław Latalski[1,*], Joanna Dubicka-Nowak[1], Jerzy Warmiński[1]

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Keywords: smart structure, piezoelectric transducer, nonlinear constitutive behaviour.

The presented research discusses the mathematical modelling of composite thin-walled beams with embedded active elements made of piezoceramic materials. In the studied design the piezoceramic actuation of the bending load to the hosting beam is achieved by means of d_{31} piezoelectric effect. The mathematical model of the structure is formulated within geometrically linear framework. However, the nonlinear constitutive behaviour of the piezoceramic material is considered based on experimental results and on the data published in literature. It is shown that accounting for these nonlinear effects is crucial to properly capture the behaviour of the transducer in near-resonant operating conditions.

The analytical model of system dynamics is formulated by means of the extended Hamilton's principle and a system of mutually coupled partial differential governing equations is obtained. These represent rich dynamics of the structure resulting from its complex deformation modes involving transverse and in-plane shearable bending, torsion and axial deformations. Next, the derived system of partial differential equations is transformed into a set of ordinary differential ones by the Galerkin discretization method. The results of performed numerical studies show the importance of non-linear terms for accurate prediction of systems dynamic properties; in particular one can observe the softening phenomenon near the resonance zone due to the nonlinear characteristics of the PZT layers and electrostrictive effect.

Acknowledgements: The research is financially supported by grant 2021/41/B/ST8/03190 National Science Centre, Poland.

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On paving the plane, plates, and origami

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Keywords: plates, origami, microstructure.

In this talk we introduce and consider thin tiled plates having exactly one degree of freedom. The plate is realized as a tessellation composed by rigid tiles hinged to each other along the sides, and it can deform in just one way, that is, into a predetermined surface. The microstructure of these plates has been inspired by Graphene [2] and can be seen as infinitesimal origami. In particular, such plates can approximate surfaces with positive, negative, and null Gaussian curvatures, also including auxetic behaviors [3] and a fine texture at finer scales. We characterize the one degree of freedom requirement in terms of the tiles geometry, and we introduce some noteworthy families of tessellations [1, 4] that fulfill intrinsically the one degree of freedom requirement. The proposed architecture is highly scalable and easily manufacturable, and it can find applications not only for civil and aerospace engineering purposes, but also for bio-mechanical scaffolds, energy harvesters, and wearable devices.

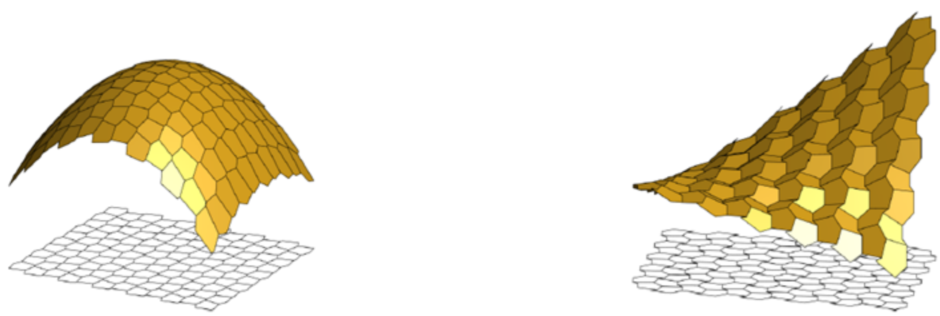

Figure 1: Tessellated plates.

Acknowledgements: MPS is supported by the Project PRIN 2017 20177TTP3S and acknowledges the Italian National Group of Mathematical Physics INdAM–GNFM. The talk is based on ongoing joint work with F. A. dos Santos, A. Favata, A. Micheletti, R. Paroni [4].

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Energy estimates for tape spring devices

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Keywords: tape spring, shallow shell, instability.

Tape spring devices are thin structures with transverse curvature (shells) used in many fields of engineering. These tapes can be used as real deployment organs, thanks to their ability to form localized elastic hinges. A peculiar feature of these devices is continuity: although there are no mechanical hinges or bending devices, they can be bent elastically [1].

Considering the case of pure bending of the tape spring device, subjecting the ends to rotations ϕ, the diagram of the moment-rotation relationship is strongly nonlinear, and can be divided into a precritical and a postcritical regime astride the fold occurrence.

To obtain an 1D analytical model for tape spring devices we started from a non-linear elastic model of the shell [5]. In the calculations it is considered that the section is perfectly circular, before and during the deformation. From the one-dimensional beam model it was possible to determine the expression of the elastic strain energy, and the differential equations for the functions θ, bending angle, and β^e, opening angle of the cross-section ruling the overall deformation. Besides, it is possible also to obtain estimates of the energy.

The pre-critical regime refers to the case in which the device deforms prior to the formation of the elastic fold (small rotations applied to the ends). Through appropriate kinematic hypotheses, the expressions of the angles θ and β^e were obtained using the previously calculated differential equations.

The post-critical regime refers to the case in which the device deforms after the formation of the elastic fold. In this case it is possible to identify three regions in the deformed configuration of the tape: a zone in which the tape is almost undeformed, a transition zone of length L_t (gradual flattening of the cross section), and a zone of the fold of length L_p (perfectly flat).

The problem has also been solved with the finite element method, considering one-dimensional Lagrange finite elements. For the validation of the analytical model, a 2D FEM analysis was made, solving via an arc length method.

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Session 2B – Posters

Thursday 21 September 2023, 10:30 – 10:48

Effect of mechanical properties on cavitation erosion resistance of composite coatings manufactured via HVOF

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Keywords: mechanical properties, cavitation erosion, cermet coatings.

In this study, effect of the mechanical properties on cavitation erosion resistance of high velocity oxy-fuel (HVOF) sprayed composite (cermet) coatings was carried out. The mechanical properties of coatings, such as Vickers hardness, the instrumental indentation hardness, the instrumental elastic modulus (EIT), and the fracture toughness, were combined with the microstructure of the sprayed coatings. A piezoelectric-driven apparatus generated cavitation, test conformed to the ASTM G-32 standard. The WC-Co-Cr and WC-Co samples exhibited higher hardness and higher values of Young's modulus than the WC-Cr_3C_2-Ni one. The generated stresses with lower values of hardness and Young's modulus for the WC-Cr_3C_2-Ni sample. The harder samples exhibited higher stiffness (WC-Co-Cr and WC-Co). The cavitation erosion mechanism of different types of cermet coatings has been reviewed. Cavitation tests indicated that in the initial stages of erosion, the WC-Co-Cr sample had a slightly higher resistance than the WC-Cr_3C_2-Ni and far better resistance than the WC-Co coating. In the further stages of erosion, the Ni-containing coating delaminated due to its lower fracture resistance and surface nonuniformities, such as pores and ceramic-metallic phase interfaces. Deposition of the composite (cermet) coatings effectively protected the metallic substrate from cavitation erosion.

Acknowledgements: The research was financed in the framework of Individual Grant no. FD-20/IM-5/116 funded by Scientific Board Discipline of Mechanical Engineering, Lublin University of Technology, Poland.

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Comparative tests of shear strength of adhesive lap joints (316L steel) after thermal shocks

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Keywords: adhesive joint, surface layer, 316L steel.

Adhesive compositions based on epoxy resins are one of the most popular materials used in adhesive processes. Adhesive joints are frequently used in many modern sectors of industry, especially in aerospace, automotive, and machine engineering. Adhesives and adhesive processes are utilised not only for bonding components of machines, but also to seal and encapsulate mechanical constructions. This is related to the many advantages provided by adhesives and adhesive joints. How good the adhesive bond is depends largely on the process of pretreating the faces of the materials to be joined [1, 2, 3]. As a rule of thumb, the adhesive processes are intended to "develop" the interface geometrically and provide an optimum energy state of the faces of the joined components [4]. This work presents the results of comparative tests for the determination of Young's modulus and the static shear strength of adhesive lap joints, based on grade 316L steel. The paper shows the test results for the surface free energy and selected surface roughness parameters, including photographs of the test specimens after destructive testing. The tests were comparative and performed on adhesive joints, with and without exposure to thermal cycling. The scope of the testing included a relatively short thermal cycling run of 500 cycles with a temperature variation of -40°C to +60°C. An analysis was carried out of the results from testing the static shear resistance of specimens manufactured using various methods of adhesive joint seasoning. The experimental test results were statistically processed in compliance with good research practice.

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Mode III interlaminar fracture toughness of advanced composite materials: experimental testing and numerical modelling

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Keywords: composite materials, mode III fracture, experimental testing.

The objective of this study is to experimentally investigate and numerically model damage phenomena in fibre-reinforced advanced composite materials with a focus on interlaminar fracture toughness. Standard test procedures have been established for fracture modes I and II using the Double Cantilever Beam (DCB) [1] and End-Notched Flexure (ENF) [2] tests, respectively. For Mode III, there is no standard procedure yet, but the Edged Crack Torsion (ECT) test is widely used [3, 4] (Fig. 1a). As an alternative, the Split Cantilever Beam (SCB) [5] has also been proposed (Fig. 1b). The SCB test can be performed with a simpler test set-up than that required for the ECT, but whether the Mode III interlaminar fracture toughness results obtained from the ECT and SCB tests are comparable is still an open question.

The final aim is to compare the two test setups for Mode III interlaminar fracture toughness characterisation by conducting both experimental tests and numerical simulations.

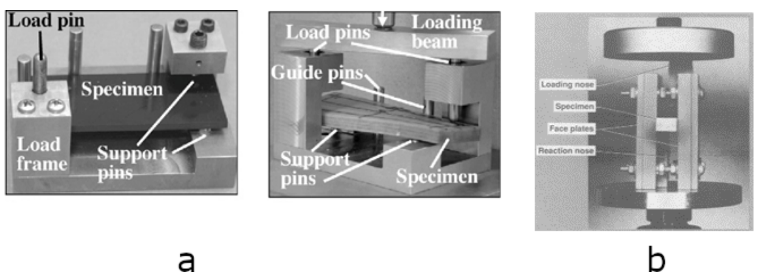

Figure 1: Mode III interlaminar fracture tests: a) ECT; b) SCB [4, 5].

Acknowledgements: Financial support is gratefully acknowledged from the "Canaletto" project "DIACMEC – Damage Identification in Advanced Composite Materials with Elastic Couplings".

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Experimental and numerical failure analysis of compressed thin-walled composite plate element with advanced damage models

Katarzyna Falkowicz[1,*], Patryk Różyło[1], Hubert Dębski[1], Sylwester Samborski[1]

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Keywords: composite structures, mechanical couplings, progressive failure analysis.

The paper analyzes the stability and failure phenomenon of compressed thin-walled composite plate element weakened by cut-out. Tested elements were made of carbon fiber reinforced polymer (CFRP) composite material (using the autoclave technique). An experimental study on actual structures and numerical calculations on computational models using the finite element method was performed. During the experimental study, post-critical equilibrium paths were registered with acoustic emission signals, in order to register the damage phenomenon. Simultaneously to the experimental tests, numerical simulations were performed using progressive failure analysis (PFA) and cohesive zone model (CZM). A significant effect of conducted numerical calculations was the simulation of the failure phenomenon of thin-walled composite structures, in terms of loss of load-carrying capacity, using three independent damage models (model PFA, CZM and xFEM). The above constitutes a novelty, with respect to current papers from the subject literature. The use of the above-mentioned techniques of experimental research and numerical simulations made it possible to conduct a comprehensive analysis of the damage state of the composite material. The obtained results of the numerical tests demonstrated very high agreement with the results of the experimental studies.

Acknowledgements: The research has been conducted under Project No. UMO 2022/47/B/ST8/00600 financed by the National Science Centre, Poland.

Experimental characterization and theoretical modeling of damping properties in CFRP composite structures

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Keywords: damping models, CFRP composites, finite element method.

The increased use of composite materials in modern engineering requires accurate prediction of their dynamic behavior. In particular, damping is a major design constraint in composite structures subject to cyclic loads. While the effects caused by damping are well known, the underlying microscopic mechanisms are still unclear on a quantitative basis. Experimental testing of these phenomena requires some difficulties to be overcome, like the contribution of spurious sources. Besides, several theoretical models of damping have been proposed with different degrees of accuracy.

We consider two of such models representative of the correspondence principle group [1] and the viscoelastic theory group [2], respectively. The first class of models have a simpler theoretical infrastructure with a blunt relation with the underlying physics. Instead, the viscoelastic models are based on the dominance of the viscoelastic behavior of the composite matrix on the dynamic response. Such models lead to a non-linear complex eigenvalue problem that can be computationally heavy to solve.

A modification to the strain energy method is proposed to improve the accuracy to computational load ratio. A testing campaign was conducted on carbon fiber-reinforced polymer (CFRP) composite plates to evaluate the prediction efficacy of the selected models. The following quantities were compared: the frequency response function (FRF), the eigenfrequencies, the mode shapes, and the modal damping. Predictions compare well with experimental results for the simpler stacking sequences (Fig. 1), while some discrepancies arise for the more complex ones. The accuracy significantly increases just at higher frequencies, when computationally heavier methods are employed.

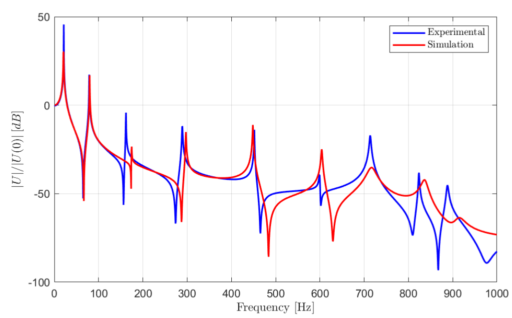

Figure 1: Comparison of the experimental and numeric FRF for the [0°] plate.

Acknowledgements: Federica Daghia from the ENS Paris-Saclay also contributed to this work.

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Method for identifying the sizes and shapes of biological objects

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Keywords: optical-electronic method, sizes, identification.

The efficiency of various technological processes depends on the parameters of biological objects, which determine the productivity and quality of machine operations. The shape and size are significant factors in the processes of sieve separation [1]. The analysis of identification methods, considering the criteria of accuracy and speed of determination, has revealed the prospects of using optical-electronic approaches [2]. The developed methodology for determining the sizes and shapes of objects is based on the following stages: preliminary analysis, obtaining an image of the object, setting boundary conditions, automatic image processing, analysis and extraction of desired object parameters, and consolidation of values. The implementation of the proposed method is based on scanning a group of particles and subsequent processing of the selected object using the developed software. The adequacy of the proposed methodology was verified by comparing it with microscopy (Opta-tech x 2000 microscope) of various biological objects. For data analysis, a universal algorithm has been created, which allows for the identification of object parameters with complex geometric shapes. Approbation of the developed method was carried out for biological objects of common agricultural crop seeds, their dimensional parameters and shape coefficients were obtained. The obtained values allow to increase the accuracy of mathematical modeling of dynamical processes of similar particles in different technologies. The proposed methodology gives an understanding of particle shape and size in the shortest time, which is a necessary condition for effective sifting of biological objects on vibrating sieves.

Acknowledgements: The authors acknowledge the financial support of the National Science Centre in Krakow to the research project funded in the "POLONEZ BIS 2" call No. 2022/45/P/ST8/02312 entitled Numerical-experimental analysis of a sieve holes' shape and arrangement effect on the degree. POLONEZ BIS is operated by the Centre on the basis of the Grant Agreement No. 945339 concluded with the European Research Executive Agency.

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Fiber optic sensor for pressure measurement

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Keywords: vacuum measurement, on-line measurement, fiber optics technology.

Pressure sensors are key components in industrial manufacturing, as pressure is one of the most fundamental features for condition monitoring and safety assessment in modern industry and engineering applications [1, 2]. Traditional pressure sensors are subject to technical limitations, such as single-point measurement, poor resistance to electromagnetic interference and lack of remote transmission and online monitoring of measurement signals [3, 4]. The test bench is shown in Fig. 1.

The design and measurement work carried out and the empirical tests conducted led to the development of a pressure level sensor using a mechanical elastic element and fibre optic technology to determine the pressure prevailing in the system in the range from 5 to 10^5 Pa.

Figure 1: Test bench.

Acknowledgements: This work was supported by The National Centre for Research and Developmentand co-financed from the European Union funds under the Smart Growth Operational Programme (grant POIR.01.01.01-00-0451/21).

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Smart grid operation modes with electrical energy storage system

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Keywords: electricity storage system, distribution network, smart grid.

The paper considers the issues of maintaining the equality of flows of generated and consumed electric energy in an electric network incorporating an electric power storage system. An analysis of ways to equalize the energy and power balance was carried out, and the advantages of using electricity storage systems in electrical networks were assessed [1]. From simulations carried out using the Power Factory program, we noted that after switching on the load, a transient process occurs, characterized by a jump in active power. This jump is caused by the time needed to initiate the electric energy storage system (ESS), but immediately after, the process of issuing the accumulated energy to the electrical network and compensating for energy consumption began. Moreover, when the load was disconnected, there is at first a certain dip in the active power curve and a further increase in consumption [2]. This was found to be due to the transition of the electricity storage system to the mode of energy storage and battery charging. As a result of the simulation, data on the charging and discharging time of the electricity storage system were obtained. Conducted studies show that the use of electricity storage systems in electrical networks allows for stable operation of all main generators and thus increases the safety and reliability of the entire system. The comparative analysis of two methods of maintaining the equality of the generated and consumed power of electric flows in the energy system makes it possible to clearly determine the advantage in favor of battery ESS, as these evidently ensure the stable operation of all main generators in the network and thereby increase the safety and reliability of the entire system. The considered principles of construction and management of an electrical system with a battery ESS allow us to move to the experimental stage of creating and testing the operation of a new type of Smart Grid electrical network. Compared to the hydroaccumulating ESS, battery ESS has significantly reduced capital costs in construction, since neither water basins occupying a large area nor dams are needed here. In any case, operating costs will be significantly lower, since battery ESS can be managed remotely, without service personnel.

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Numerical simulation of damage propagation in fibre metal laminates subjected to compression after impact

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Keywords: fibre metal laminates, compression after impact, finite element analysis.

Fibre reinforced polymers (FRP) are built as laminar structures, what allows to adjust in-plane properties of the laminate. Nevertheless, the out-of-plane forces – e.g. low velocity impact (LVI) – are devastating in terms of delaminations [1]. Fibre metal laminates (FML) were created primarily to increase the fatigue properties of metals used in aviation. However, the presence of metal layers stacked alternately with FRP layers increased the impact resistance too – and thus, delaminations size was also reduced [2]. The study made for compression after impact (CAI) of FRP showed a strength decreased by 60% [3]. For FMLs, a reduction up to 40% was noted. The research team observed a drop in range of 2%-17% [4, 5]. Also, the fact that damage propagation from post-impact delaminations is the most intensive right before critical failure of FML (above 92.5% of max. force) due to CAI, was proven. The research team also validated if the damage propagates from impact point by preparation of numerical model of FML. Results of LVI simulations were imported to CAI analysis to keep the damage state of each FML layer and interface. A metal behaviour was predicted by Johnson-Cook model. A response of composite layers was controlled by Hashin 3D VUMAT subroutine. A cohesive surface interactions were given between each pair of adjacent layers to recreate delaminations. ABAQUS/Explicit solver was used for computations. The analysis proved, that damage propagation takes place mainly in the impact area and grows perpendicularly to load direction. The peak forces were predicted with satisfactory accuracy, but displacement at failure was significantly lower upon comparing to experiment.

Acknowledgements: This conference paper was supported by NAWA STER Programme Internationalization of the Doctoral School of Lublin University of Technology – IDeaS of LUT).

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Session 2C – Damage Mechanics

Thursday 21 September 2023, 11:15 – 13:00

Damage identification of composites conducted by acoustic emission technique with special emphasis on FFT and wavelet analysis

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Keywords: acoustic emission, fast Fourier transform, wavelet transform.

The aim of the work is to present possible applications of acoustic emission (AE) as a non-destructive technique widely used for failure detection and health monitoring of engineering materials, including fiber-reinforced polymer (FRP) composites. There are some typical forms of damage occurred such as matrix cracking, debonding, fiber failure, fiber pull out, fiber bridging, delamination. However, the latter one is the most common. Delamination is caused by cleavage after reaching the critical mechanical load which is related to material property defined as a fracture toughness. Acoustic emission is based on registration of elastic waves parameters emitted inside material during loading and propagation of delamination. This method let to indicate damage onset just while the propagation initiates, even without any effects visible by a human eye. Furthermore, the different ranges of AE parameters may be correlated with specific damage type, e.g. frequencies of 60–150 kHz, 200–300 kHz and 400–500 kHz could be referred to matrix cracking, delamination and fiber cracking, respectively [1, 2]. Apart from frequency there are other useful elastic waves parameters such as number of hits and counts, energy or amplitude. Moreover, modern tools for signal analysis: the fast Fourier transform (FFT) and the wavelet transform (WT) can be applied to analyze the raw AE signal. WT has some advantages over FFT and let to localize the results not only in frequency domain but also in time. WT coefficients of measurement points based on their diverse intensity indicated by colors help to draw 2D and 3D maps to visualize the results. Then the respective FFT plots can be simply corresponded to wavelet contour diagrams. Above described methods were applied by the authors in numerous scientific works concerning comprehensive analyses of the registered damage-induced elastic waves of various engineering materials i.e. composite laminates with elastic couplings, hybrid composites, cured epoxy resins.

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Detection of delamination in fiber reinforced polymer composites based on acoustic emission

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Keywords: acoustic emission, fiber-reinforeced polymer (FRP) composite, damage identification.

Acoustic emission (AE) is a non-destructive testing technique which involves the detection and analysis of stress waves generated by the release of energy in a material. AE can provide valuable information about the internal state and structural integrity of various materials, including metals, composites and so one. Several factors influence the generation and characterization of AE signals, understanding these factors is critical for effective AE-based monitoring. The analysis and interpretation of AE signals require advanced signal processing techniques. Signal parameters such as amplitude, duration, rise time, energy, frequency content, and waveforms can provide valuable insights into the nature and progression of damage. Signal analysis methods, including feature extraction, pattern recognition, and classification algorithms, are employed to identify specific AE patterns related to defects or damage mechanisms. For instance, in the case of delaminations, AE signals exhibit distinct patterns corresponding to the initiation and propagation of the delamination front. The amplitudes and frequency content of these signals change as the delamination grows, providing valuable insights into the extent and severity of the damage. Similarly, matrix cracks and fiber breakages are characterized by specific AE signatures, allowing for their identification and localization within the laminate structure. The experimental investigation involved the fabrication of FRP specimens in accordance with ASTM D5034 standard. The specimens were subjected to mechanical loading conditions that induce delamination growth. Acoustic emission sensors were strategically placed on the surface of the specimens to capture the emitted stress waves during the loading process. This paper presents a study focused on utilizing Acoustic Emission (AE) techniques to detect and characterize delamination fronts in FRP specimens.

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Experimental and numerical study of delamination in composite laminates with bending-twisting elastic couplings

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Keywords: double cantilever beam (DCB) test, elastic couplings, finite element analysis.

The objective of this study is to characterize, both experimentally and numerically, the delamination process in multidirectional carbon/epoxy composite laminates with stacking sequences exhibiting bending-twisting elastic couplings. Laboratory specimens with artificial delamination were tested in Mode I using a Double Cantilever Beam (DCB) set up according to ASTM D5528. Critical Energy Release Rate (ERR) values were determined using three different data reduction schemes: modified beam theory, compliance calibration method and modified compliance calibration method. Delamination initiation was detected in two ways: by visual observation of the crack tip using a high-resolution camera and by acoustic emission.

Numerical analyses were performed using SIMULIA ABAQUS Finite Element (FE) software. The FE model consisted of SC8R continuum shell elements and the Virtual Crack Closure Technique (VCCT) was used to evaluate the energy release rate. The experimental results showed extensive fiber bridging (Fig. 1), which significantly affected the propagation values of ERR and the load-displacement curves. Nevertheless, the numerical results obtained by the VCCT at the initial stage of delamination were in good agreement with the experimental results.

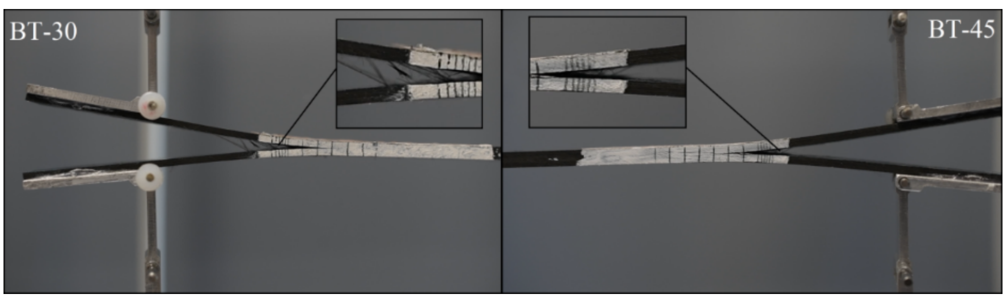

Figure 1: Experimental DCB tests conducted on elastically coupled composite laminates.

Acknowledgements: This research was conducted within the project Lublin University of Technology – Regional Excellence Initiative, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19). Financial support from the "Canaletto" project "DIACMEC – Damage Identification in Advanced Composite Materials with Elastic Couplings" is also gratefully acknowledged.

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On the conditions for pure-mode fracture

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Keywords: pure-mode fracture, fracture mode decoupling, energetic orthogonality.

In a *symmetrically* cracked planar body, fracture modes I and II are respectively associated to systems of symmetric and antisymmetric forces w.r.t. the crack plane. These forces respectively produce only normal stresses and relative transverse displacements or only shear stresses and relative tangential displacements on the crack plane. The same pure-mode conditions do not apply in general for *asymmetrically* cracked bodies.

Williams [1] proposed the following pure-mode conditions for an asymmetrically cracked isotropic beam: (i) pure mode I, if the moments of the two sub-beams at the crack-tip cross-section are equal and opposite; (ii) pure-mode II, if the curvatures of the two sub-beams at the crack-tip cross-section are equal. Although questioned [2], Williams' conditions have been used by several authors [3].

Valvo [4] proved that the standard virtual crack closure technique (VCCT) may be inappropriate for analysing problems with highly asymmetric cracks since negative values for either mode I or mode II contribution to the energy release rate (ERR) may be calculated. To remedy this shortcoming, he suggested the following pure-mode conditions: (i) pure mode I, if the tangential crack-tip force is zero; (ii) pure mode II, if the crack-tip opening displacement is zero. Later, Valvo [5] proposed the following conditions instead: (i) pure mode I, if the crack-tip sliding displacement is zero; (ii) pure mode II, if the normal crack-tip force is zero. In both the above proposals, the two pure modes are associated to energetically orthogonal systems of forces, so always non-negative modal contributions to the ERR are obtained. This revised VCCT was then adapted to generally layered beams [6]. Wang and Harvey [7] independently proposed the same energetically orthogonal pure-mode conditions.

This presentation will discuss the various pure-mode conditions proposed, also with reference to experimental tests existing in the literature or to be specifically designed, aiming to clarify which theoretical proposals for pure modes (or mode partitioning) are to be preferred.

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Failure analysis and mechanical behavior of coupled laminates for packaging

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Keywords: micromechanical characterization, damage mechanisms, coupled materials.

This study investigates the failure analysis and the mechanical behavior of thin coupled laminates particularly focusing on paper-aluminum (paper-Al) laminates, which are gaining increasing interest in various packaging applications as a potentially more sustainable alternative to conventional bi- and multi-layer materials. An innovative experimental campaign employing uniaxial loading on coupled samples is presented. The experimental setup comprises a micro-mechanical tensile stage (DEBEN) positioned beneath a confocal microscope (Leica DCM3D), enabling in-situ visualization of sample deformation throughout the loading process, while simultaneously recording force-displacement data. A comprehensive series of tests was conducted to understand the microscopical mechanisms influencing the overall mechanical response of paper-Al laminates both in the machine direction (MD) and in the cross direction (CD), and their performance was compared with aluminum-polyethylene (Al-PE) laminates. Findings contribute to a better understanding the key factors affecting the overall mechanical behavior of paper-Al coupled materials, enabling the design of more effective and sustainable laminates for the packaging industry. Results indicate that increasing the laminate thickness is advantageous for the MD direction, while it has a negligible effect on the CD direction. Moreover, the mechanical behavior of paper-Al laminates is compared to that of Al-PE laminates, highlighting the potential of paper-based materials as an environmentally friendly alternative. This research enhances knowledge regarding the performance of coupled laminates, addressing a crucial aspect of packaging design and providing insights for future developments regarding modelling and simulation.

Acknowledgements: The authors would like to acknowledge the support provided by Regione Toscana (Bando Assegni di Ricerca anno 2021) to the project NEXTPAPER4.0 "Next Generation Paper and Packaging" (CUP D63D21005360008).

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Analysis on the determination of Chaboche and Bouc-Wen parameters for a quenched and tempered steel

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Keywords: cyclic plasticity, closed-form expressions, nonlinear hysteretic behaviour.

High-strength metal alloys usually have a purely elastic behaviour during high-cycle fatigue regime. Nevertheless, some materials such as low alloy steels undergo plasticity even in high-cycle fatigue, and thus just considering a purely elastic behaviour significant prediction errors can be obtained. The Chaboche Isotropic-Kinematic Hardening (CIKH) [1, 2] model provides a versatile and realistic description of the material stress-strain behaviour under general multiaxial cyclic loadings. In this work, the global properties of the experimental cycles are introduced for the calibration. The imposed conditions are: the hysteresis areas, the peak stress values and the tangent slopes at the extreme points of the stabilized cycles, which represent the most significant loading parameters for the majority of the fatigue life loadings. The data just mentioned are taken from strain-controlled tests on plain specimens manufactured in steel 42CrMo4+QT. One linear and two non-linear backstress components of the kinematic hardening model are introduced. Two stabilized cycles are required to identify the main kinematic parameters whereas the asymptotic ratcheting rate, obtained from stress-controlled tests, is then used to determine the rate parameter of the slightly nonlinear backstress component. Finally, a fourth backstress component is added to improve the prediction near the elastic limit of the stabilized cycle of the strain-controlled test. Once the kinematic parameters are obtained, isotropic hardening laws can also be identified, by considering the evolution of the extreme points of the strain-controlled cycles before stabilization. Alternatively, the Bouc-Wen model [3, 4] can provide a reliable representation of nonlinear hysteretic phenomena, and a classic nonlinear least squares approach, based on the Levenberg-Marquardt algorithm, is employed to calculate the values of its constants. The performances of the two proposed techniques are compared, and a final discussion is provided.

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Influence of surface treatment on the adhesive fracture energy of titanium-based laminates using T-peel tests

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Keywords: impact, fibre metal laminates, failure analysis.

Fibre metal laminates are hybrid structures consisting of metal and composite layers and are the answer to the aerospace industry's need for lightweight, high-performance materials with high damage tolerance [1]. They are characterized by high impact resistance, fatigue strength, low density, and high resistance to environmental conditions [2]. However, the predominant failure mechanism in these structures remains delamination, at an early stage of loading resulting directly from ineffective preparation of the metal surface and low strength at the metal-composite interface.

The designing of the metal-composite interface in fibre metal laminates remains an extremely important issue, as it plays a pivotal role in the stress transfer between the metal and composite layers [3]. The selection of an appropriate metal surface modification process makes it possible to obtain an appropriate surface topography and morphology, as well as physicochemical properties that can enhance the strength and durability of the bonding at the metal-composite interface. Particularly with titanium-based laminates, metal surface treatment remains a problem because there is no single method that improves adhesion to the composite layer [4].

The work evaluates the influence of the different metal surface treatments on the adhesive fracture energy of titanium-carbon based fibre metal laminates measured by the peel test. The T-peel tests were performed based on ASTM D1876 standard to determine the adhesive fracture energy in mode I. The tested fibre metal laminates consisted of titanium layers and a carbon fibre-reinforced polymer composite. Titanium surface was modified using different surface treatment methods including mechanical and chemical methods. Moreover, the application of the intermediate layers like sol-gel or primer was also evaluated. The influence of the different metal surface treatment on the failure at the micro-scale was evaluated with a particular focus on the failure at the metal-composite interface.

The adhesive fracture energy was found to be strongly correlated with the surface topography, and morphology, as well as physicochemical properties. It was observed that the increase in the adhesion strength at the metal-composite interface in fiber metal laminates can be achieved by the application of sol-gel interlayers. It was noted that the interlaminar fracture toughness was closely correlated with the type of failure mechanism.

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Keynote Lecture 3

Thursday 21 September 2023, 14:30 – 15:15

Feedback mechanism of sound generation in a rounded impinging jet: tonal vs broad-band noise

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Keywords: long-range instabilities, tonal noise, impinging jet.

It is well known that impinging jets, under particular conditions, may radiate intense tonal noise [1]. In some cases, the sound generation is underpinned by the presence of a self excited instability originated by a feedback loop between two kind of waves: a downstream-travelling KH wave, which is excited at the nozzle lip and propagates around the jet core position, and an upstream-travelling wave generated by the impingement of disturbances on the plate and propagates backward inside/outside the jet core. The non-local constructive interaction of such waves gives rise to a series of self-sustained global in time instabilities whose interactions, in some circumstances, are able to radiate an intense tonal acoustic field. In the presentation we will review the characteristics of the self-sustained mechanism and its noise radiation by using both a global and a local stability analysis that will precisely identify the components of the feedback loop. In order to better understand the fundamental physical mechanism leading to tonal (or broadband) sound emission, we propose a novel acoustic-hydrodynamic decomposition of the structural sensitivity tensor (originally developed for spatially localized instabilities) [2], which serves to precisely localize the active regions of the long-range feedback loop (i.e. where the conversion between the two kind of waves takes place) and which is also suited to study other kind of long-range instabilities such as thermo-acoustic, hydro-acoustic or thermo-diffusive instabilities. As an example, figures below show the results obtained by the proposed decomposition for a high subsonic case. Motivated by the results of such analysis, we then propose a minimal reduced model that faithfully represents the fundamental properties of the sound emission. More precisely, by applying equivariant bifurcation theory [3], we derive a reduced order model based on a resonant interaction of a series of unstable Hopf bifurcations which qualitatively predicts the characteristics of the sound emission. Possible applications to other problems (cavity flow, flow through apertures and flow past airfoils) and extension to turbulent regime will be briefly discussed.

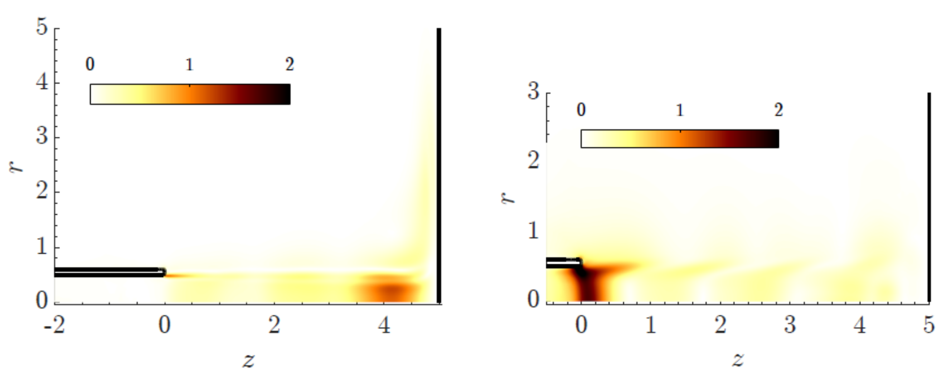

Figure 1: Examples of decomposed Structural Sensitivity for a $M_{inf} = 0.6$ jet : (left) $S_{u,s}^{(hyd,ac)}$, (right) $S_{u,s}^{(ac,hyd)}$.

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Session 2D – Fluid Dynamics

Thursday 21 September 2023, 15:15 – 16:15

Calibration of gas leak detector

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Keywords: gas leak, methane, natural gas.

Universal gas leak detection devices are often used to detect natural gas leaks. These are devices that have built-in different types of sensors such as infrared, semiconductor or electrochemical sensors. As a result, the devices can detect leaks of different types of gases such as: methane CH_4, oxygen O_2, carbon dioxide CO_2, carbon monoxide CO and hydrogen sulfide H_2. To detect natural gas leaks, the device uses sensors to detect the presence of CH_4 methane. The device measures concentration of methane in air. For lower concentration values it uses a semiconductor type of sensor, while for higher concentration values it uses an infrared sensor. The gas leak detector cannot determine the exact value of the methane concentration. The idea is to use a gas leak device to locate the place where the gas leak occurs. For example according to the German regulation DVGW G 465-3 (Classification criteria for leaks in buried and not buried pipework in gas distribution systems) the place of a gas leak can be classified into one of four leak classes: AI, AII, B and C [1]. According to the class of gas leakage, a decision is made on the measures that need to be implemented in order to eliminate the potential danger. Both semiconductor and infrared type of sensor measure methane concentration indirectly by measuring electrical signals [2]. The work confirmed importance of the following checks: methane concentrations and vacuum pump that performs gas sampling in the device. The gas leak device must be periodically checked at the check station with known concentrations of methane CH_4 in synthetic air.

Acknowledgements: This paper has been supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through project no. 451-03-68/2020-14/200156: Innovative scientific and artistic research from the Faculty of Technical Sciences, Novi Sad, Serbia, activity domain.

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Gravity-driven coatings on three-dimensional curved substrates

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Keywords: differential geometry, coating, asymptotic expansion.

Drainage and spreading processes of thin liquid films on substrates have received growing attention during the past decades owing to the large number of applications in engineering [1] and geophysical [2] problems. However, the analysis of slow coating flows on surfaces is limited to flat [3] and axisymmetric [4] substrates. We leverage differential geometry to investigate the intricate drainage and spreading processes of thin films on generic three-dimensional curved substrates. Through the lubrication approximation, we initially investigate the drainage and spreading on spheroidal substrates via an asymptotic expansion in the vicinity of the pole, finding that the thickness distribution is set by a balance between the substrate metric and tangential gravity force components. Spheroids with a large (small) ratio between height and equatorial radius are characterized by an increasing (decreasing) thickness moving away from the pole. The non-symmetric coating on a toroidal substrate shows that larger thicknesses and a faster spreading are attained on the inner region than on the outer region of the torus. An ellipsoid with three different axes is chosen as an example of three-dimensional drainage and spreading. Modulations of the drainage solution along the azimuthal direction are observed, with a variation of the thickness along both axes. We derive an analytical three-dimensional solution which well agrees with numerical results. These modulations along the principal axes are related to the different local ratio between height and equatorial radius. By imposing the conservation of mass, an analytical solution for the average spreading front is obtained. The analytical and numerical results are in good agreement. The resulting drainage solutions show also a favourable agreement with experimental measurements obtained from the coating of a curing polymer on diverse substrates (see Fig. 1).

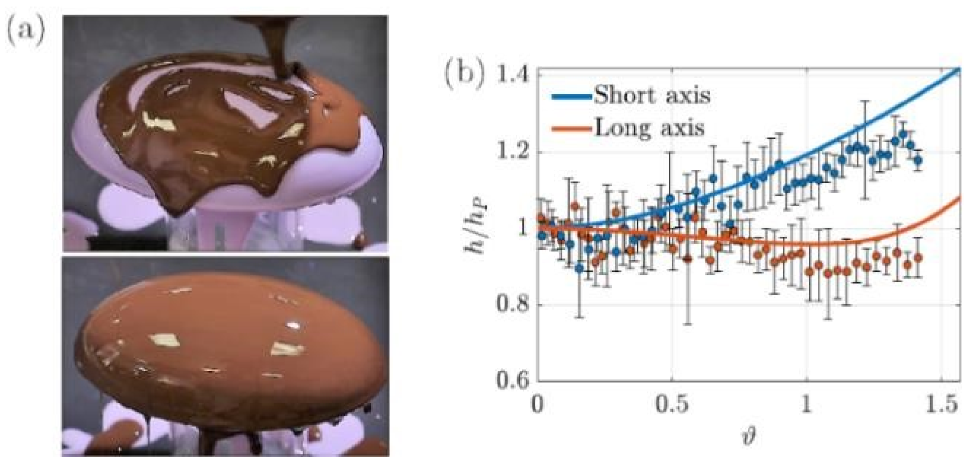

Figure 1: (a) Coating of an ellipsoid of vertical semiaxis of 30 mm and horizontal semiaxes of 24 and 48 mm. (b) Drainage analytical solution (solid lines) and experimental measurements (dots).

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The accelerating and decelerating flow around a square cylinder

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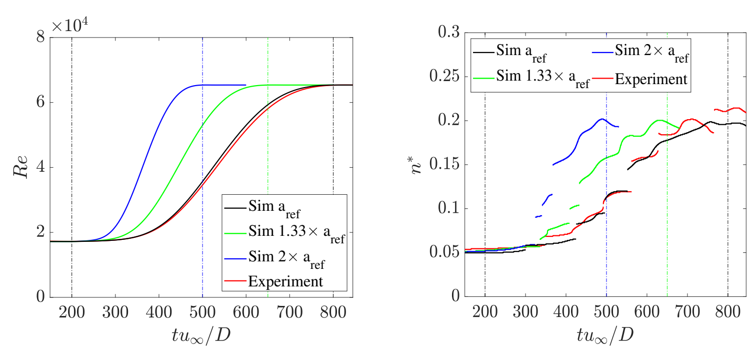
Keywords: square cylinder, accelerating flow, large-eddy simulations.

We numerically investigate the high-Reynolds-number accelerating and decelerating flows around a square cylinder, which is a paradigmatic configuration of interest for civil engineering applications, e.g., high-rise buildings and skyscrapers. The shear layers separate from the upstream edges and undergo Kelvin-Helmholtz instability, but they do not lose coherence until they form the von Karman vortex street in the wake. This flow has been well characterized in steady conditions in the range $10^3 \leq Re \leq 10^6$; however, less is known when the inflow is accelerating or decelerating, as it happens, e.g., during thunderstorms. We perform high-fidelity Large-Eddy Simulations (LES) to investigate the vortex shedding from a square cylinder subjected to transient flows and the related forces. We analyze the vortex-shedding frequency through a time-frequency analysis based on the wavelet transform. This information may be interesting for predicting the possible aeroelastic phenomena due to vortex shedding during the varying flow conditions typical of thunderstorm outflows. LES simulations are carried out by using the same numerical set-up described for rectangular cylinders in [1], and the same Gaussian-type inflow accelerations and decelerations experimentally investigated in [2] are reproduced in the Reynolds range $Re = 1.720 \times 10^4 - 6.536 \times 10^4$ (shown, e.g., in Fig. 1a for the accelerations). Simulation results are validated against the experiments in [2], and an excellent agreement is found, with discrete changes in the vortex-shedding frequency (shown in Fig. 1b for the accelerations). In addition, we perform a parametric study on the intensity of the accelerations and decelerations. In each case, time cells having constant vortex-shedding frequency shorten with the increasing velocity variation. Further details on the force coefficients, the pressure distributions, and the behavior between the vortex-shedding Strouhal number and the Reynolds number will be provided in the final presentation.



(a) (b)

Figure 1: Time behavior of (a) the inflow Reynolds number and (b) the vortex-shedding frequency.

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Development of an actuator line model for variable pitch vertical axis turbines

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Keywords: vertical axis wind turbine, dynamic stall, pitch control.

The present research aims at developing a numerical tool to reduce the computational cost needed to investigate the performance of variable-pitch vertical-axis wind turbines while still modelling the main physical processes involved. An Actuator Line Model [1] was modified and a variable pitch module was implemented. The model was then validated against experimental data for high and intermediate blade solidity at $Re_C \approx 105$, with fixed pitch configuration [2]. This model integrates blade element theory and Navier-Stokes simulations into an OpenFOAM routine to calculate the blade forces and wake characteristics. In the present work, the ALM was tested using Reynolds-averaged Navier-Stokes turbulence models in Open-FOAM, along with the sub-modules implementing dynamic stall, flow curvature and added mass effects due to both rotor and blade rotation in the case of a variable pitch turbine. The accuracy of the model in approximating turbine performance is assessed, and wake results are compared against experimental data [3] with a reasonable agreement in resolving the main flow features and performance characteristics. This is a substantial improvement over the conventional low-fidelity vortex line and actuator disc models at roughly the same computational cost [4].

Special attention is given to the assessment and calibration of the dynamic stall module, comprising its validation against experiments for stall prediction and real-time stall delay estimation. The dynamic stall model is implemented starting from the work made in [5] and the resulting stall delay characteristics are compared with the experimental results of [6].

The validated model, given its relative accuracy and speed, can be coupled to a genetic algorithm optimiser to perform an investigation on the optimal pitch control law maximising the turbine performance, and to evaluate the resulting angle of attach at the onset of dynamic stall conditions of the blade profiles.

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Session 2E – Hemodynamics

Thursday 21 September 2023, 16:45 – 18:00

Synthetic aided deep learning segmentation of 4D flow image data for CFD simulations

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Keywords: synthetic data, 4D flow, deep learning.

3D Phase contrast magnetic resonance imaging (4D flow) is a non-ionizing imaging technique that supports computational modelling setup. However, the segmentation of 4D flow images is complex and time-consuming. Previous studies have used neural networks (NN) for segmentation with large image datasets [1] but limited availability of data results in low accuracy. This study explores the feasibility of synthetic data augmentation to improve NN accuracy, even with a small real dataset of thoracic aorta 4D flow. A statistical shape model [2] generated 250 synthetic geometries, and transient CFD simulations computed relative fluid dynamic velocity maps using patient-specific boundary conditions. Applying a fast Fourier transform and signal elaboration techniques [3], low-resolution images were obtained. The phase contrast magnetic resonance angiography (PC-MRA) formula was employed to obtain final volumes. A 3D U-Net was trained with various combinations of real and synthetic data, and the Dice score (DS) was assessed using a test set of 10 real PC-MRA images. Results showed significant improvement in segmentation accuracy and standard deviation through synthetic data augmentation. The synthetic augmented experiment achieved a DS value of 0.83, surpassing the DS of 0.65 when using only real data (No_Synth). These findings highlight the effectiveness of employing synthetic data augmentation for the 3D U-Net to enhance segmentation accuracy.

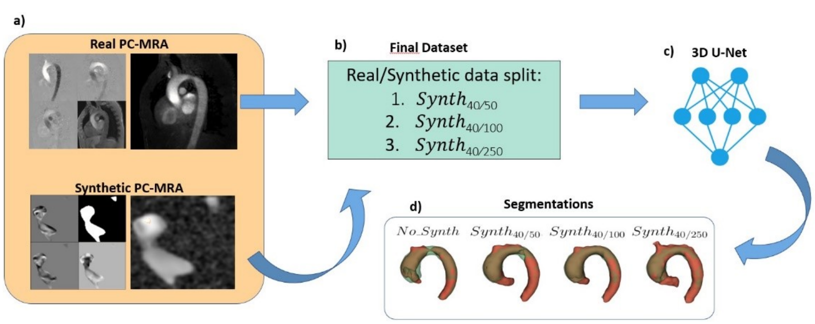

Figure 1: General workflow: Real and synthetic PC-MRA (a), combined in 40/50, 40/100, and 40/250 splits respectively (b), used to train 3D U-Net (c). Final segmentation improvement (d).

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A combined statistical shape model and CFD simulations framework for hemodynamic investigation

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Keywords: statistical shape models, computational fluid dynamics (CFD).

Statistical Shape Models (SSMs) are well-established tools for assessing the variability of vascular geometries. Several studies have been presented, mainly focused on the aorta without the supra-aortic branches [1]. To overcome this limitation, also reflected in the subsequent Computational Fluid Dynamics (CFD) clustering studies, we developed a non-rigid registration algorithm. We applied it also to a different great vessel, the pulmonary artery, to demonstrate its potentiality. A total of 21 segmented pulmonary arteries and 28 aortas were considered, originated from MRI and CT images respectively. Starting from [2], the in-house algorithm for the non-rigid registration was based on (i) a modified second order gradient descent approach, (ii) a loss function based on the minimization of Chamfer distance and (iii) four steps of remeshing. To achieve the dimensionality reduction to few meaningful geometric features we applied the Principal Component Analysis. The first principal components were used to reconstruct 5 new geometries, used to assess the effects of morphological variability on the correspondent CFD models. Simulations were carried out using ANSYS Fluent, considering the fluid as Newtonian and a laminar flow. For the hemodynamic analysis the wall shear stress, its related indexes (i.e. OSI, TAWS) and the flow split (only for the pulmonary arteries) were evaluated. A correlation was performed between the morphological and the hemodynamic features to derive a relationship between shape, fluid dynamics and pathology. Although most of the target geometries presented very peculiar shapes, a maximum error of 0.7 mm in the registrations was observed. Moreover, significant correlations between the variation of the first mode, and hemodynamical parameters were discovered (example on OSI variation reported in Fig. 1).

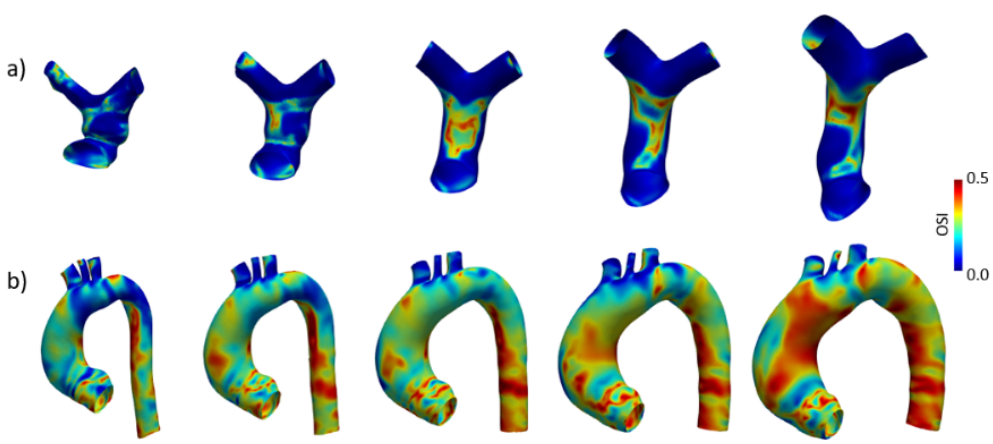

Figure 1: OSI values on geometries generated by the variation of the first mode from -2 (left) to +2 (right) standard deviation for pulmonary vessel (a) and aorta (b).

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Effects of wall motion on the hemodynamics of the aorta

Francesca Dell'Agnello[1,2,*], Martino A. Scarpolini[1,3], Katia Capellini[1], Emanuele Vignali[1], Emanuele Gasparotti[1], Filippo Cademartiri[3], Simona Celi[1]

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Keywords: aorta, computational fluid dynamics, wall motion.

Computational Fluid Dynamics (CFDs) is a valuable technique to study the hemodynamics of the thoracic aorta (TA) and associated diseases [1, 2]. Nevertheless, standard CFD simulations have limitations due to the rigid-wall assumption, while Fluid-Structure Interaction (FSI) simulations are computationally expensive and require difficult-to-define information on vessel wall. Recent studies employed mesh morphing techniques to cope with the aortic wall motion [1, 3]. However, they were restricted to the ascending aorta and featured some intrinsic discontinuities.

This works aims to develop and implement a new procedure to simulate the actual motion of the entire TA during the cardiac cycle, starting from ECG-gated CT images. For five patients, we segmented 10 3D models of the TA, each corresponding to a specific phase of the cardiac cycle. We applied an in-house non-rigid registration algorithm and a spline interpolation to respectively morph the baseline mesh (0% phase) on the geometries of the other phases and reconstruct the displacement of the wall. Then, we included the motion of TA boundaries in the set-up of the CFD simulation (CFD_{morph}). Additionally, to compare hemodynamic outcomes, a standard CFD simulation (CFD_0) was performed on the baseline mesh. The developed procedure allowed to cope with the aortic patient-specific morphological changes, maintaining mesh quality. The two simulation strategies highlighted differences in the wall shear stress (WSS) (Fig. 1) and velocity distributions. The CFD_{morph} approach also showed a time delay between the descending aorta flow rate waveform and the inlet flow profile. These findings emphasize the need to consider the geometrical variation of the entire aorta into CFD simulations and label the proposed method as a powerful tool to study the hemodynamics of the TA, overcoming the main limitations of CFD and FSI approaches.

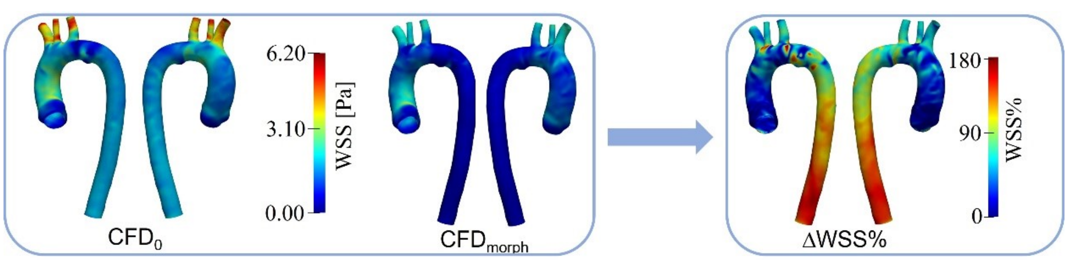

Figure 1: WSS and node-by-node percentage difference of WSS (ΔWSS%) between CFD_0 and CFD_{morph} at the maximum acceleration time.

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Numerical simulations to predict the onset of atherosclerotic plaques in carotid arteries

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Keywords: hemodynamic simulations, atherosclerotic plaque, carotid arteries.

Atherosclerosis is an inflammatory cardiovascular disease that leads to a gradual narrowing of blood vessels due to the formation of plaques inside the artery. The plaques result from the accumulation of lipidic substances over years and could obstruct the blood flow to downstream vessels and organs. Atherosclerosis is one of the major causes of death in Western countries, so efforts are devoted to understanding the main risk factors associated with this pathology. The purpose of the present work is to predict through Computational Fluid-Dynamics (CFD) simulations of the possible onset of plaques in human carotid arteries and to analyze the influence of hemodynamic and geometric parameters on the early stages of the disease. We combine CFD simulations with two different plaque growth models for this study: the first model, generally called Wall Shear Stress (WSS) model [1], correlates the thickening of the innermost intimal layer of the arterial vessel, Δe, to the CFD-computed wall shear stress τ exerted on the wall through a linear algebraic relation; the second model, indicated as Low-Density Lipoprotein (LDL) model [2], is more complex and takes into account the first phases of the inflammation process of the pathology, in which ordinary differential equations describe the plaque growth, Δe, linked to τ and to the concentration of LDL in the intima. For both cases, the thickening of the intima normal to the wall towards the arterial lumen is taken into account through a morphing procedure. We consider a clinical dataset including the 3D segmentated geometries of left and right carotids and the flow rate waveforms in Common Carotid Artery (CCA), External Carotid Artery (ECA), and Internal Carotid Artery (ICA). We compare the numerical results with the in-vivo data. We find that both plaque-growth models accurately predict the onset region of the disease and that LDL-model better estimates the plaque growth rate in the early stages of the pathology. In addition, we carry out a sensitivity analysis to the LDL-model parameters, viz. the LDL concentration in the blood, c_{bl}, and the initial thickness of the intimal layer, e_0. The locations of the onset of the plaque in the left and right carotids do not change, but their growth rate increase with the increasing c_{bl}. On the other hand, a negligible effect of e_0 is found. Since we found out that both models are sensitive to the geometry of the carotids, further analysis will be aimed to single out the effect of the different geometrical parameters.

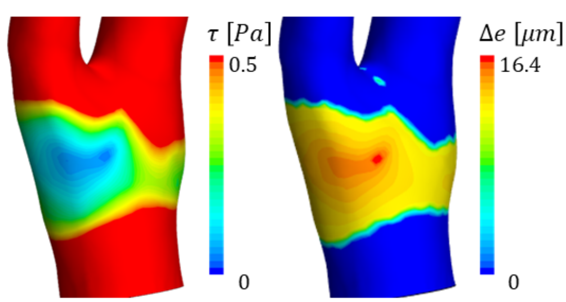

Figure 1: WSS distribution (left) and plaque growth Δe after one year (right). Results for the right carotid.

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CFD simulations of different grades of severity of aortic coarctations: analysis of the flow patterns and effect of outlet boundary conditions

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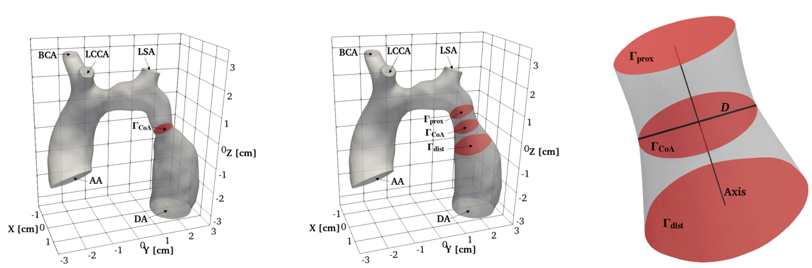
Keywords: thoracic aortic coarctation, hemodynamic simulations, stochastic sensitivity analysis.

We perform Computational Fluid Dynamics (CFD) simulations of the blood flow inside a patient-specific coarctated aorta (see Fig. 1a). Simulations allow the calculation of different hemodynamic quantities with high temporal and spatial resolution, but the reliability of the numerical simulations strongly depends on the accuracy of patient-specific geometry, wall-property modeling, and inlet/outlet boundary conditions. Different grades of severity of the coarctation are obtained by constructing parametric geometries that are characterized by a circular coarctation section with different diameter values, D (see Fig. 1b and Fig. 1c). The impact of a fine-tuning of the Windkessel model resistances, used to impose boundary conditions at each outlet, is also investigated. Indeed, Antonuccio et al. [1] recently proposed a calibration parameter, α, of the model resistances to better deal with the pressure drop caused by the coarctated section. A stochastic approach based on the generalized Polynomial Chaos (gPC) is used for the present sensitivity analysis. It allows continuous response surfaces of the quantities of interest in the parameter space to be obtained from a limited number of simulations. Two parameters are selected: the vessel diameter, D, at the coarctation plane and the non-dimensional parameter, α, through which it is possible to calibrate the resistance offered by organs and vessels downstream the thoracic aorta. The results, in terms of pressure and flow rate waveforms and spatial distributions of the velocity magnitude and of the wall shear stresses, highlight how the dominant parameter is D, and the more the value of the coarctation diameter increases, the more the effect of α weakens. This means that as the degree of severity of the coarctation decreases, it becomes less important to perform a fine calibration of the Windkessel resistances in order to match the patient-specific pressure waveform.



(a) (b) (c)

Figure 1: Sketch of: (a) patient-specific geometry, (b) parametric geometry, and (c) zoom of the parametric region.

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Keynote Lecture 4

Friday 22 September 2023, 9:00 – 9:45

Linear and nonlinear ultrasonic techniques for mechanical characterization of materials

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Keywords: ultrasonic test, damage, monitoring.

Ultrasonic tests, based on the propagation of mechanical waves, are usually considered as non-destructive methods for qualitatively assessing the "structural health" state of materials, e.g., by detecting the presence of damages like cracks and delamination. Actually, it is possible to profitably exploit the propagation features of waves specific for each material to obtain quantitative information on their mechanical properties [1]. In particular, it is possible to employ ultrasonic tests for the mechanical characterization of materials instead of classical testing techniques, by one to determining material parameters, whose value if often practically inaccessible, in a more easy and effective way.

However, depending on the aims of the test to be carried out, a crucial aspect is represented by the mechanical model assumed for interpreting test data. Actually, the propagation of ultrasonic waves in solids can be described either by simpler linear models or, when more subtle aspects have to be investigated, by more complex nonlinear models.

For this reason the lecture will address both models in order to suitably delimit their specific ranges of application. Specifically, Linear ultrasonic approaches, based on the linear elastodynamic theory, focus on the ultrasonic wave propagation viewed as small perturbations of the reference state in solid media. In this case, linear acoustic parameters – such as, e.g., ultrasonic wave velocities – are taken into account to characterize the mechanical behavior of materials. For instance, it is possible to ultrasonically identify the direction of symmetry of the material response ("classification problem") and – once known the class of material symmetry – it is possible to ultrasonically determine the elastic moduli required to describe elastic behavior ("representation problem"). Specific acoustic representations like the "slowness surfaces" are very useful for studying the constitutive and/or damage-induced material anisotropy [2].

From the experimental point of view, the need to examine propagation properties in different directions for the mechanical characterization of anisotropic materials, fosters the use of goniometric ultrasonic techniques. They are based on suitable experimental devices aimed at rotating the ultrasonic probes and/or the specimen. Goniometric ultrasonic tests are preferentially performed without a direct coupling between the ultrasonic probes and the specimen, that is, by experimental setups based on immersion techniques [2, 3], laser ultrasonic, or air-coupled ultrasonic.

Conversely, there is a large family of ultrasonic techniques based on the analysis of "nonlinear effects" in ultrasonic wave propagation. From a theoretical point of view, finite amplitude kinematic models and/or nonlinear constitutive equations are required [4]. Nonlinear ultrasonic approaches are particularly apt to identify small defects like fatigue cracks, fiber debonding, and delamination, and assessing the damage's onset at a very early stage. Moreover, a very interesting application is the quantitative evaluation of residual and/or applied stresses by studying the acousto-elastic effect.

There are several possible approaches for performing nonlinear ultrasonic tests, such as, e.g.: Higher Harmonic Technique; Nonlinear Wave Modulation Spectroscopy (NWMS); Sideband Peak Counts (SPC) Technique. Particularly this last one is considered as a representative example, since it turns out to be very effective for monitoring the stress-induced damage in non-linear materials such as concrete [5], and for determining the adhesion properties of reinforcement systems for concrete and/or masonry structures.

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Session 3A – Civil Engineering

Friday 22 September 2023, 9:45 – 11:00

Static and dynamic buckling of rings: a critical review of classical approaches

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Keywords: circular rings, buckling, nonlinear dynamics.

The buckling of circular rings is a widespread instability issue that arises in numerous engineering fields. It refers to the sudden collapse or deformation of a ring under different kinds of compressive loads, due to the sudden loss of its original shape. This phenomenon, which is among the most studied in the stability field, can lead to catastrophic failures in structural, nuclear and offshore engineering applications [1].

The significance of this issue has grown since the middle of the 20th century, but, rather surprisingly, there are still certain unknowns and potential misunderstandings that the present contribution seeks to clarify [1, 2, 3]. The work critically reviews the classical formulation of elastic ring buckling and discusses the limitations of the usually adopted approaches, emphasizing the need to incorporate correctly the extensibility conditions into the analysis in order to capture the buckling phenomenon.

Implications in the dynamic buckling of circular rings is also addressed, since, research concerning the nonlinear dynamics of rings still suffers from the inherent difficulties associated with different possible analytical formulations of post-buckling dynamics.

The present paper also shows some unexpected inconsistencies in the numerical modelling by means of industry standard simulation codes.

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Non-linear ultrasonic approach for the characterization of Mode II debonding behavior of FRCM reinforcements for masonry constructions

Anna Castellano[1], Aguinaldo Fraddosio[1,*], Mario Daniele Piccioni[1], Tribikram Kundu[2]

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Keywords: nonlinear ultrasonic, adhesion defects, fiber-reinforced cementitious matrix (FRCM) composites.

Fabric Reinforced Cementitious Matrix (FRCM) composites have emerged as reliable strengthening materials especially for historical masonry constructions. Their strengthening effectiveness strongly depends on the bond at the matrix–fibers interface and at the matrix–substrate interface; thus, the analysis of FRCM bond behavior is of crucial relevance [1]. To this aim, we propose an innovative nonlinear ultrasonic approach based on the Side-band Peak Count (SPC) technique [2, 3]. The Side-band Peak Count technique reprocesses the results of the ultrasonic guided wave tests on FRCM reinforced specimens during Single-Lap Tests (SLT), in order to correlate the nonlinear ultrasonic results to the shear stress distribution at reinforcement-masonry interface for long bond length. So, the bond behavior between FRCM composites, made of basalt textile embedded in a lime-based mortar matrix (B-FRCM) and masonry tuff supports was ultrasonically analyzed. Moreover, a new nonlinear ultrasonic parameter, the SPC index (SPC-I) is introduced. By means of the SPC index it was possible to monitor the evolution of the shear stress-slip law at the reinforcement-masonry interface. The non-linear ultrasonic results were compared with the results obtained during the SLT debonding test by means of electrical strain gauges positioned in suitable areas of the reinforced samples. The effectiveness of the proposed approach is investigated and discussed.

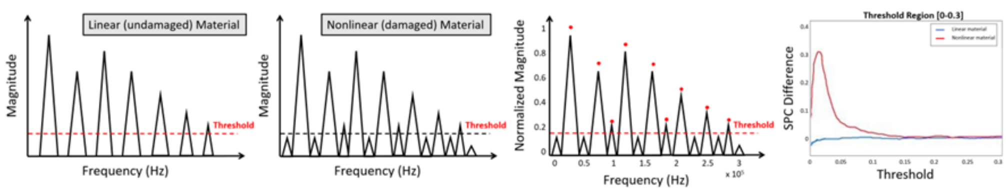

Figure 1: Generation of sideband peaks in a nonlinear material and illustration of the "Sideband Peak Count (SPC) technique".

Acknowledgements: Authors gratefully acknowledge the research project Italian Ministry for University and Research (MUR) – 2020 PRIN (Research Projects of National Interest) Program – Research project no. 20209F3A37: "Sustainable modelling of materials, structures and urban spaces including economic-legal implications".

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Anti-funicular networks in masonry vaults with stereotomy, friction and strength requirements: a multi-constrained min/max problem validated through Durand-Claye's method

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Keywords: funicular analysis, masonry vaults, stability area.

This contribution, framed within the theoretical background of limit analysis, aims at assessing the equilibrium of masonry arches and domes.

Anti-funicular networks are searched accounting for both the stereotomy of the voussoirs and the mechanical properties of masonry, by assuming a nil tensile strength, a limited compressive strength and a limited friction coefficient.

A computational approach based on the constrained force density method [1] is implemented in order to handle the equilibrium of the loaded nodes, by considering networks with a fixed plan geometry [2]. At the interfaces between the voussoirs, a suitable set of local constraints is formulated to take into account the moment and shear capacity at the cross-sectional level [3, 4]. Then, a multi-constrained minimization/maximization problem is stated, which is solved by means of a sequential convex programming.

The results obtained via the numerical method described above are validated by means of a modern re-visitation of Durand-Claye's stability area method [5, 6], which allows for determining the complete set of admissible solutions respecting both equilibrium and strength/friction requirements. Some significant case studies of masonry arches and domes with a non-conventional stereotomy are examined; moreover, critical issues related to the non-standard plastic behaviour of the material, arising from the hypothesis of a limited friction coefficient, are discussed.

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In situ dynamic measurements and finite element analysis of a composite steel-concrete highway girder bridge

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Keywords: composite bridge, dynamic measurement, finite element analysis.

Given the high economic demand of new structures, maintaining existing bridges is a significant concern for public administrations and the scientific community. Thus, the definition of efficient control strategies [1] to monitor degradation levels and prevent the occurrence of critical conditions is essential. In this framework, a useful approach, nowadays requested by several technical codes, consists in conducting in situ investigations of the bridge and laboratory tests to characterize its static and dynamic response under possible critical actions and create a digital twin model that reflects the current state of the structures [2].

This works applies this approach to a composite steel-concrete girder bridge of the Italian highway network. A comprehensive experimental campaign is conducted that involves in situ tests to characterize the structure dynamic response under potential wind or seismic excitations. The data obtained from these tests are then used to calibrate a Finite Element model of the bridge, to permits the accurate description of its dynamic behavior [3].

Finally, sensitivity analyses are conducted to study the response of the structure under the passage of heavy vehicles with different transit speed.

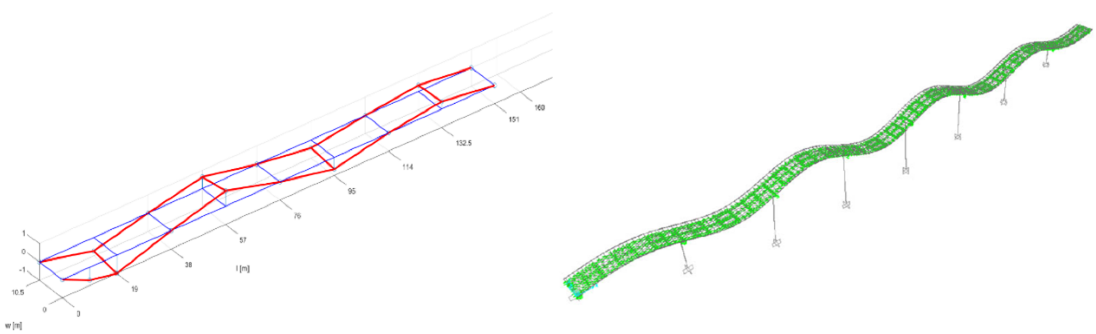

Figure 1: First flexural vibration mode shape of the bridge: experiment (left) and numerical (right).

Acknowledgements: P. Di Re acknowledges the research grant SEED PNR 2021-000048 21 SEED DI RE – CUP B89J21032850001 (Sapienza University of Rome).

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Finite element modelling of RC walls under fire exposure

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Keywords: finite element analysis, concrete, fire.

Fire represents a critical hazard that poses significant threats to building performance. As global populations grow and life becomes increasingly complex, the construction of fire-resistant structures and structural elements becomes an urgent priority. Therefore, studying the fire resistance of reinforced concrete (RC) members is of paramount importance. This research paper presents the development of a three-dimensional (3D) finite element (FE) model aimed at predicting the behaviour of experimentally tested walls documented in existing literature. The numerical model incorporates temperature-dependent properties of the constituent materials, thus enhancing its accuracy and reliability. The outcomes reveal the successful prediction capability of the developed 3D FE model for the response of RC walls under standard fire conditions. The FE model could be utilized to investigate the influence of various factors on the fire response of RC walls. This will lead to a deeper understanding of the structural behaviour of RC walls under fire conditions, thereby contributing to safer and more resilient built environments.

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Session 3B – Aerospace Engineering

Friday 22 September 2023, 11:30 – 12:15

Integrated data analysis for the experimental assessment of anomalous electron transport in Hall thrusters

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Keywords: Hall thruster, anomalous transport, integrated data analysis.

Hall thrusters are among the most efficient propulsion systems for space application. Using an ExB cross-field configuration, Hall thrusters ionize and accelerate a flow of propellant to generate a thrust [1]. The magnetic field intensity is tuned to magnetize the electrons while the ions remain unmagnetized. Unsteady oscillatory modes affect the plasma in the thruster and they differ depending on channel geometry, magnetic field, and operating conditions [2]. Experimental evidence shows that classical theories fail to justify the observed amount of cross-field electron transport, as it is several orders of magnitude bigger than how much the classical theory of collisions predicts [5]. Simplified fluid models typically deal with anomalous transport considering it as an additional ad-hoc term to the total electron collision frequency, which already accounts for collisions with heavy species and for interactions with the walls. The aim of this work is to study the anomalous electron diffusivity using Integrated Data Analysis techniques [3], which rely on Bayesian modelling methodologies to combine a fluid computational model of the plasma discharge in a Hall thruster with experimental measurements of different type. The integration of different diagnostics allows to formalize error analysis, experimental data include thruster discharge current, thrust balance and potential and temperature profiles. The problem has been formulated as a Bayesian inference problem where the free parameters are represented as distribution functions. During the implementation the posterior probability has been studied with Nested Sampler Implementation, the likelihood for the discharge current has been expressed using a Time-Lagged Phase Portrait (TLPP) [4], where the comparison between the distributions has been represented through the Wesserstein metric. For the thrust data a normal distribution has been used to express the likelihood. A numerical investigation has been carried out applying the developed methodology to an SPT100-like thruster based on the LANDMARK benchmark. The reference solution has been created as synthetic data, regarding the discharge current and the average of the thrust. Despite the simplified code it has been able to approximate in accurate manner the coefficients of the problem and to give convergent solution. The combination of physics-based method with probabilistic techniques allows us to manage this phenomenon overcoming the complexity of the problem and the weakness of fluid models, then it permits to handle the problem in a consistent and robust manner.

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Investigation of the plume mode in hollow cathodes via a 1D fluid model

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Keywords: hollow cathodes, plasma physics, numerical simulations.

Hollow cathodes are plasma devices commonly used as source of electrons for electric propulsion devices such as Hall thrusters (HT) and Gridded ion thrusters (GIT). During ideal operation, the plasma produced in these devices is relatively quiescent and stable, and visually characterized by a small, bright, 'spot' of plasma close to the cathode exit section. This operating condition takes the name of 'spot mode'. However, at the confluence of low flow rate and high extracted current, a more pronounced and diffused 'plume' of plasma appears. This operating regime, which is called 'plume mode', is ubiquitously observed in hollow cathodes of different sizes, geometries, and materials. It is characterized by the presence of large amplitude ($\approx 100\%$ of the background) plasma oscillations, and it is associated to the generation of high energy ions that increase the erosion of the external surfaces of the cathode, limiting their lifetime [1]. Despite decades of research on this subject, the nature of these oscillations is still poorly understood. It is usually believed to be an ionization-related phenomenon, which interacts with the smaller scale Ion Acoustic Turbulence (IAT) [1], whose presence in the plume of the hollow cathodes has been firstly theoretically hypothesized [2] and then demonstrated experimentally [3]. The presence of IAT increases the plasma resistivity in a non-classical fashion, representing the main challenge in the modeling and understanding of the physics of these devices.

In this work, a one-dimensional, fluid model of the plume of the hollow cathodes has been developed, in order to investigate the origin of the plume mode instability. The model considers a conical expansion for both the plasma and the neutrals. The effect of the IAT on the macroscopic dynamics has been taken into account by introducing an anomalous resistivity in the Ohm's law, by means of an idealized closure model. The model has been calibrated on a set of experimental data, consisting in time-averaged measurements of the plasma properties along the center-line in the plume of a cathode operating in plume mode. The results suggest that a momentum transfer from the electrons to the ions through the IAT is necessary to explain the large potential increase that is observed in the experiments. Despite the relatively good agreement between the computed and the measured time-averaged profiles, the model, as it is formulated, is not able to recover unstable solutions. Possible reasons and potential improvements are finally discussed.

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Deployable cable nets for active removal of derelict rocket bodies

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Keywords: active debris removal, deployable net, nonlinear dynamics.

Spent rockets and defunct satellites represent most of the mass of the current space debris population. Such objects constitute the main sources of small-size debris, that are produced mostly because of break-ups and collisions. Enabling the technology for their capture is one of the steps needed towards the development of an effective active debris removal (ADR) mission.

Tethered nets has been considered for the capture of derelict non-cooperative vehicles, since their employment would simplify the approaching manoeuvres to the target. Besides, cable nets are light, easily packable, scalable, and versatile, even though modelling their behaviour in the capture and post-capture phases is not a trivial task.

Two main mechanical models have been proposed to describe the deployment and capture processes by using cable nets. In the first approach, the net is considered as a system of concentrated masses connected to each others by spring-dampers. Springs react only in tension and infinitesimal strains are considered [1, 2]. Alternatively, a finite element model of a cable net can be developed according to the absolute nodal coordinate formulation (ANCF). In this case, finite strains are considered through the Green-Lagrange strain tensor and a weak flexural behaviour for the cable can be included [3].

We developed a new finite element model for the cable net, adopting the nodal positions as the main unknowns of the problem in line with the displacement-based finite element formulation (DFEF) [4]. Large displacements and finite deformations are considered through the Green-Lagrange strain tensor. Cable elements are assumed to react only in tension according to a hyper-elastic constitutive law [5]. Global damping is introduced into the model according to Rayleigh's hypothesis. The governing equations for the dynamical problem are solved numerically by means of the Newmark method.

As an illustrative example, we present the simulation of the three-dimensional deployment of a planar, square-mesh net. The proposed approach turns out to be computationally effective and accurate.

Acknowledgements: The support by the National Group of Mathematical Physics (INdAM–GNFM) is thankfully acknowledged.

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