1st Workshop on Experimental and Computational Mechanics "WECM'22"

+ DIACMEC Canaletto Project Kick-off Meeting

under Honorary Patronage of

His Magnificence Rector of Lublin University of Technology
(Lublin, Poland)
&
the Department of Civil and Industrial Engineering
of the University of Pisa
(Pisa, Italy)

"Truly great is the man who wants to learn something"
St. John Paul II

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Sylwester Samborski (LUT) & Paolo S. Valvo (UniPi)

Lublin, Poland, June 1st 2022

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Scope of the Workshop

The conception of the "WECM22" workshop arose in the Polish-Italian group of scientists, cooperating in the field of experimental and computational mechanics, within the framework of bilateral agreement between Lublin University of Technology (Lublin, Poland) and the University of Pisa (Pisa, Italy). Taking advantage of international cooperation of both universities, a multinational Scientific Advisory Board was established. Many of its members have experience in teaching abroad as Visiting Professors, whereas most of the workshop participants have attended the VP's lectures. This way the event enables gathering the teachers and the students all together - in one place and time, even though the "online" option is provided. The workshop should thus be found a unique possibility to deepen the knowledge and understanding for those, who study - in accordance with its motto, as well as to share ideas and results - for those, who teach. These goals are expected to be reached more effectively by dedicating "WECM22" to PhD students from the two universities - LUT and UniPi. In particular, as the red letter "W" indicates, the emphasis is on the discussion among the two sides of the stage. Hopefully, the workshop will become a cyclic event in the nearest future.

About the NAWA-Canaletto "DIACMEC" Project

The project "DIACMEC - Damage Identification in Advanced Composite Materials with Elastic Couplings" has been funded by the Ministry of Foreign Affairs under the Executive Protocol "Canaletto" for Scientific and Technological Cooperation between Italy and Poland for the years 2022-2023.

The general aim of the project is to support the mobility of scientists from the University of Pisa and Lublin University of Technology, working in the specific field of damage identification in advanced composite laminates with mechanical couplings. The research methodology includes the development of theoretical models and numerical simulations - based on the Finite Element Method supported by Computational Fracture Mechanics tools - and the execution of laboratory tests on advanced composite laminates.

The research team include Prof. Paolo S. Valvo (Italian coordinator) and Prof. Daniele Fanteria from the University of Pisa, Prof. Sylwester Samborski (Polish coordinator) and Dr. Jakub Rzeczkowski from Lublin University of Technology.

During the project, four mutual visits of the Italian and Polish members of the research team are planned:

1. Kick-off meeting in Lublin (29 May to 5 June 2022);
2. Intermediate meeting in Pisa (11 to 18 September 2022);
3. Intermediate meeting in Lublin (Spring 2023);
4. Final meeting in Pisa (Autumn 2023).

The WECM '22 was the occasion to share the news about the DIACMEC project with many other potentially interested researchers to foster the development of new scientific collaborations and international relationships.

Contents

Session 1: Computational Methods in Solid Mechanics

Keynote Lecture:

ENERGETICALLY ORTHOGONAL DECOMPOSITION OF FRACTURE MODES

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ABSTRACT

The conventional definition of the three basic fracture modes (mode I: opening; mode II: sliding; and mode III: tearing) considers a crack embedded in an infinite medium made of a homogeneous and isotropic elastic material. In this case, the applied loads can be decomposed into symmetric and antisymmetric parts (w.r.t. the crack plane), which are naturally associated with the basic fracture modes. Unfortunately, this decomposition fails when analyzing bodies of finite size or made of inhomogeneous or anisotropic materials (e.g., the laboratory specimens used to assess delamination toughness of composite laminates). The lecture will show how a more general definition of fracture modes can be obtained by decomposing the applied loads into three energetically orthogonal systems of forces.

Acknowledgements: Financial support by the Executive Protocol “Canaletto” under project “DIACMEC – Damage Identification in Advanced Composite Materials with Elastic Couplings” is gratefully acknowledged.

VALIDATION OF ELASTIC COUPLINGS IN A COMPRESSED LAMINATE PLATE ELEMENT

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ABSTRACT

Analytical calculations were led on carbon fiber reinforced polymer (CFRP) laminates in asymmetrical configuration. Three types of configurations were investigated where Extension-Twisting and Extension-Bending couplings were used to get elastic element. Analysis was conducted according to classical laminate theory (CLT) toward the presence of elastic couplings. Components of matrices A, B, and D, as well as the parameters Dc and Bt were obtained using the Matlab software environment. The results showed that couplings between the extension and bending, as well as between the extension and twisting, were strongly dependent on specimen plies orientation. Moreover, additional analysis was performed on the influence of layers angle on the D11, D16, D12 and the D22 terms which are components of the Bt and Dc coefficients. The results indicated that angle of laying fibers around 45^{o}-50^{o} significantly amplify the effects of elastic couplings.

Acknowledgments: The project/research was financed in the framework of 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).

MODE III DELAMINATION IN FRP LAMINATES WITH ELASTIC COUPLINGS

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ABSTRACT

Carbon fiber reinforced polymer (CFRP) laminates are widely used in many engineering applications. Nevertheless, composite laminates are susceptible to delamination which can follow according to three fracture schemes. The need for better recognition of determination the mode III fracture toughness became a swollen problem in the face of lack of commonly accepted standard. Determination of the pure mode III fracture toughness by using existing test configurations, such as the ECT or the family of the SCB approaches is not possible due to presence of contribution of different modes, in particular near free specimen edges. Results of research conducted on elastically coupled laminates revealed, that edge effects were dependent on applied boundary conditions. This suggested, to analyze influence of different boundary conditions in case of the anti-plane shear SCB tests, in such way, to find configuration that would minimalize an edge effects and allow to obtain pure mode III circumstances.

MODELLING OF DEPLOYABLE CABLE NETS FOR ACTIVE SPACE DEBRIS REMOVAL

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ABSTRACT

Space debris represent a true risk for current and future activities in the circumterrestrial space, and remediation activities must be set out to guarantee the access to space in the future. For active debris removal, the development of an effective capturing mechanism remains an open issue. Among several proposals, cable nets are light, easily packable, scalable, and versatile. Nonetheless, guidance, navigation, and control aspects are especially critical in both the capture and post-capture phases.
We present a finite element model of the deployment of a net in space. We consider a lumped mass/cable net system taking into account non-linearities arising both from large displacements and deformations, and from the different response of cables when subject to traction and compression. The problem is stated by using the nodal coordinates as Lagrangian coordinates. The nonlinear dynamic response of the system is obtained by direct integration of the equations of motion.

Session 2: Computational Methods in Fluid Mechanics

Keynote Lecture:

ADJOINT-BASED PASSIVE CONTROL OF HYDRODYNAMIC INSTABILITIES

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ABSTRACT

A large number of research papers in the literature have been dedicated to the use of adjoint-based sensitivity and global stability analyses for both characterizing and controlling instabilities in fluid mechanics. Such controls, which are mainly passive, are designed for stabilizing linearly unstable configurations. The design strategy based on global stability analysis can be rigorously applied to relatively simple flows in laminar regime. More complex configurations can also be rigorously treated, as for instance cases in which the flow to be controlled is time periodic. Moreover, a large interest exists in the application of the same methods for the control of coherent large-scale flow structures in turbulent flows as, for instance, the quasi-periodic shedding of vortices in turbulent wakes. This is possible by postulating the marginal stability of mean flows, which is shown to apply for several cases of interest. In this seminar a review of the methods based on global stability and sensitivity analyses for the design and/or analysis of passive controls will be presented. Moreover, configurations of increasing complexity will be considered, ranging from laminar steady flows to turbulent flows.

CALIBRATED 1D MODEL OF THE PLASMA PROPERTIES IN A HALL THRUSTER FOR THE INVESTIGATION OF BREATHING MODE

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ABSTRACT

Breathing mode is an oscillatory mode which can be observed in Hall thrusters, often interpreted as a predator-prey type instability. It is commonly recognized in experiments and numerical simulations as a relatively low-frequency (10-30 kHz) longitudinal oscillation of both the discharge current and the plasma parameters. When numerically investigating breathing mode and, in general, operating regimes in Hall Thrusters, a compromise between simulation costs and modelling complexity is crucial. The present research presents a simple fully-fluid 1D model whose predictive capabilities are improved by incorporating experimental data which are usually available and easy to measure, namely the discharge current signal. In particular, the discharge current signal is used to calibrate some unknown coefficients of the plasma model by minimizing the difference between the measured and the simulated signals. The resulting calibrated model is focused on the investigation of the breathing mode. Finally, taking the calibrated model as a starting point, classical stability analysis techniques can also be applied to investigate the onset of breathing instability.

THEORETICAL AND NUMERICAL ANALYSIS OF THE BREATHING INSTABILITY IN HALL THRUSTERS

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ABSTRACT

Breathing mode is an ionization instability characterizing Hall thrusters over a wide range of operating conditions. It is observed in both experiments and simulations as a strong, relatively low frequency (10-30kHz), longitudinal and quasi-periodic fluctuation of both the discharge current and the plasma properties. Breathing instability is commonly associated to a predator-prey type instability, but other mechanisms are believed to play a crucial role. Despite several years of theoretical and experimental studies, in fact, the conditions for the onset of the instability are not fully understood, as well as the physical mechanisms controlling its growth and saturation. In this work we investigate the breathing mode by studying the stability properties and the characteristics of the limit cycle predicted by a fully-fluid, time resolved 1D model of the thruster discharge. The model is calibrated using experimental measurements of a real thruster operating in a condition of strong breathing oscillations. Then, a steady unstable solution of the model (base state) is computed by applying the Selective Frequency Damping (SFD) method. A global linear stability analysis around the base state is carried out, leading to the identification of two complex conjugated eigenvalues which are demonstrated to be responsible for the onset of the breathing mode. In particular, if the amplitude of the magnetic field is chosen as a control parameter, the analysis demonstrates that the breathing mode starts via a supercritical Hopf bifurcation of the base state. Finally, a series of numerical experiments is performed to show the existence of a feedback loop involving fluctuations around the base state of the neutral density, electron mobility and electric field.

A TRIPLE DECK ANALYSIS OF THE STEADY FLOW OVER A ROTATING DISK WITH SURFACE ROUGHNESS

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ABSTRACT

The effect of surface roughness on the steady laminar flow induced by a rotating disk submerged by fluid otherwise at rest is investigated here theoretically and numerically. A theory is proposed and described in which a triple-deck analysis is applied leading to a fast evaluation of the steady-flow modification due to the rough surface. The theory assumes that the roughness is much smaller than the boundary-layer height and is characterized by a significantly longer length scale (slender roughness). Validation of the theory is shown here against simulations performed with different roughness geometries (axisymmetric roughness, radial grooves, and localized bumps). Finally, an application of the theory is shown for predicting the statistical effects on the flow due to a random roughness distributed on the surface of a rotating disk.

Session 3: Experimental Methods in Solid Mechanics

Keynote Lecture:

DELAMINATION RESISTANCE OF COMPOSITES IN LIGHTWEIGHT STRUCTURES: EXPERIMENTAL APPROACHES

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ABSTRACT

Delaminations may affect long-fibre composite laminates largely used in safety-critical applications and they can impair the compression strength of a structure while being very difficult to detect. For this reason, delamination phenomena have been studied for a long time and specific tests have been developed to characterize the interlaminar behaviour of composite laminates. Today, standard practices exist to determine the delamination critical Energy Release Rate (ERR) for different modes.

Measurement techniques for interlaminar properties, proposed and standardized by the American Society for Testing and Materials (ASTM), will be illustrated and discussed with relevant examples. Double Cantilever Beam Mode I test procedure will be treated with attention to: toughness definition and calculation of G_{Ic}, effects of pre-cracking and influence of data reduction. End Notch Flexure for G_{IIc} calculation will be presented and discussed next; eventually an overview of the Mixed Mode Bending test set up to evaluate mixed mode I + II toughness will be presented. Finally options to elaborate a set of toughness properties will be discussed that enable a reliable interpolation of missing data.

ENERGY RECOVERY TECHNOLOGIES

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ABSTRACT

Production of fuel via conversion of energy crops and organic wastes would benefit society by providing a clean fuel from a renewable feedstock. and when appropriately linked to natural ecological cycles, industrial biofuels may be non-polluting and sustainable. The conversion of biomass into electrothermal energy can be achieved using a number of different routes. This study reviews potential energy generation from biomass through combustion, hydrothermal carbonization, pyrolysis, fermentation and anaerobic digestion technologies, focusing on the most relevant technologies and on the properties of the different products. The study is concluded with some comments on the future potential of these processes.

Keywords: Biomass, Thermochemical, biochemical, Bioenergy

FRACTURE TOUGHNESS ANALYSIS OF NON-CONVENTIONAL SPECIMENS: SOME KEY ISSUES

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ABSTRACT

The specimens used to characterize the interfacial fracture toughness may be grouped as *conventional* and *non-conventional*. We call conventional a specimen cut from, for example, a symmetric composite or a *similar* adhesive joint. Analyzing the fracture toughness using conventional specimens is a common practice guided by existing standards. In contrast, we call non-conventional a specimen resulting from, for instance, bi-material joints, thin laminates that need to be stiffened before testing, or laminates with an elastically coupled behavior or residual stresses. Here, we collect such cases of *peculiar* specimens and highlight issues related to the following three steps of the process of fracture toughness analysis: specimen design, testing, and data reduction. Our particular focus is on making suggestions for a proper evaluation of the fracture toughness.

Acknowledgements: Financial support from the Visiting Fellows Programme 2022 of the University of Pisa is gratefully acknowledged.

INTENSIFICATION OF TECHNOLOGICAL PROCESSES OF EQUIPMENT FOR POST-HARVEST PROCESSING OF GRAIN. STUDY OF RELIABILITY OF SIEVES WITH COMPLEX SHAPES OF HOLES

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ABSTRACT

On the basis of complex assessment and system analysis of existing approaches perspective direction increase in efficiency of vibrosieve sifting grain mixes by use of activators is reasonable. The offered concept of intensification of sifting processes on vibrosieves from different geometry of openings based on hydrodynamic analogy of movement to movement of vesiculate fluidized medium. The speeds components of vesiculate fluidized medium as functions from constructive and kinematic parameters of sieves with activators, grain mixes properties for the first time are determined by developed three-dimensional dynamic model of annular grain mixes layer at its sifting on cylindrical vibrosieves. Use of developed cylindrical vibrosieves with activators increases its productivity on 38,5...95% in comparison with basic. The developed vibrosieves with activators have passed fail-safe tests. By means of finite element method on basis of Pro/ENGINEER software product and these experimental researches dependences of equivalent tension and durability are established vibrosieve, considering parameters of activators, loadings and grain mixes properties. It is established that use of activators, at expense of reasonable innovative forms, increase durability vibrosieve on 8...24% in comparison with basic.

Keywords: sifting processes, vibrating sieves, grain mixtures, sifting intensification.

FRACTURE TOUGHNESS OF MULTI-DIRECTIONAL INTERFACES IN LAMINATED COMPOSITES: DESIGN AND TESTING OF FULLY UNCOUPLED DELAMINATION SPECIMENS

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ABSTRACT

No consensus exists on best test practices to study delamination in Multi-Directional (MD) specimens. Indeed, a generic MD laminate may operate in mixed-mode conditions at delamination fronts even when performing a (globally) pure mode test: this easily leads to invalid results if experimental data are treated according to standards. Fully Uncoupled Multi-Directional (FUMD) delamination specimens have been proposed by the authors to test delamination at interfaces with any orientation, while having the same thermo-mechanical response of a UD specimen. FUMD specimens, designed using superposition criteria for quasi-trivial stacking sequences, prevent undesired mechanical behaviors and avoid residual stresses caused by the curing process. The principles underlining FUMD delamination specimens and their design will be discussed and the key results of a first experimental campaign on Mode I tests presented. FUMD specimens will let standard tests, currently recommended for UD specimens, be extended to interfaces between differently oriented plies.

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Posters

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Timetable

June 1st, 2022

9.00- 9.15	**Welcome speech S. Samborski (in Polish), P.S. Valvo (in English); Opening Dean H. Dębski**	
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9.15- 9.45	P.S. Valvo (Keynote Lecture): *Energetically Orthogonal Decomposition of Fracture Modes*	
9.45-10.00	K. Falkowicz, S. Samborski, P.S. Valvo: *Validation of Elastic Couplings in a Compressed Laminate Plate Element*	
10.00-10.15	J. Rzeczkowski, S. Samborski, P.S. Valvo, J. Paśnik: *Mode III Delamination in FRP Composite Laminates with Elastic Couplings*	
10.15-10.30	P. Fisicaro*, P.S. Valvo: *Modelling of Deployable Cable Nets for Active Space Debris Removal*	
10.30-10.45	Coffee break	
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10.45-11.15	S. Camarri* (Keynote Lecture): *Adjoint-based Passive Control of Hydrodynamic Instabilities*	
11.15-11.30	M. Saravia*, L. Leporini, V. Giannetti, T. Andreussi, A. Piragino, F. Califano, S. Camarri: *Calibrated 1D Model of the Plasma Properties in a Hall Thruster for the Investigation of Breathing Model*	
11.30-11.45	L. Leporini*, V. Giannetti, M. Saravia, T. Andreussi, A. Piragino, F. Califano, S. Camarri: *Theoretical and Numerical Analysis of the Breathing Instability in Hall Thrusters*	
11.45-12.00	C. Chicchiero*, S. Camarri, A. Segalini: *A Triple Deck Analysis of the Steady Flow Over a Rotating Disk with Surface Roughness*	
12.00-12.15	Coffee break	
12.15-13.30	***Experimental Methods in Solid Mechanics***	
12.15-12.45	D. Fanteria (Keynote Lecture): *Delamination Resistance of Composites in Lightweight Structures: Experimental Approaches*	
12.45-13.00	R. Al Afif*: *Energy Conversion Technologies*	
13.00-13.15	P. Tsokanas*, P. Fisicaro, T. Loutas, P.S. Valvo: *Fracture Toughness Analysis of Non-conventional Specimens: Some Key Issues*	
13.15-13.30	S. Kharchenko, F. Kharchenko: *Intensification of Technological Processes of Equipment for Post-harvest Processing of Grain. Study of Reliability of Sieves with Complex Shapes of Holes*	
13.30-13.45	T. Garulli, D. Fanteria*, A. Catapano, E. Martin: *Fracture Toughness of Multi-Directional Interfaces in Laminated Composites: Design and Testing of Fully Uncoupled Delamination Specimens*	
13.45-14.00	Group photo in front of the FME	
14.00-16.00	Lunch	
16.00-18.00	Poster Session + Discussions in the FME main hall	DIACMEC Canaletto Project participants' meeting

*) presented online with transmission to the workshop room

Notes