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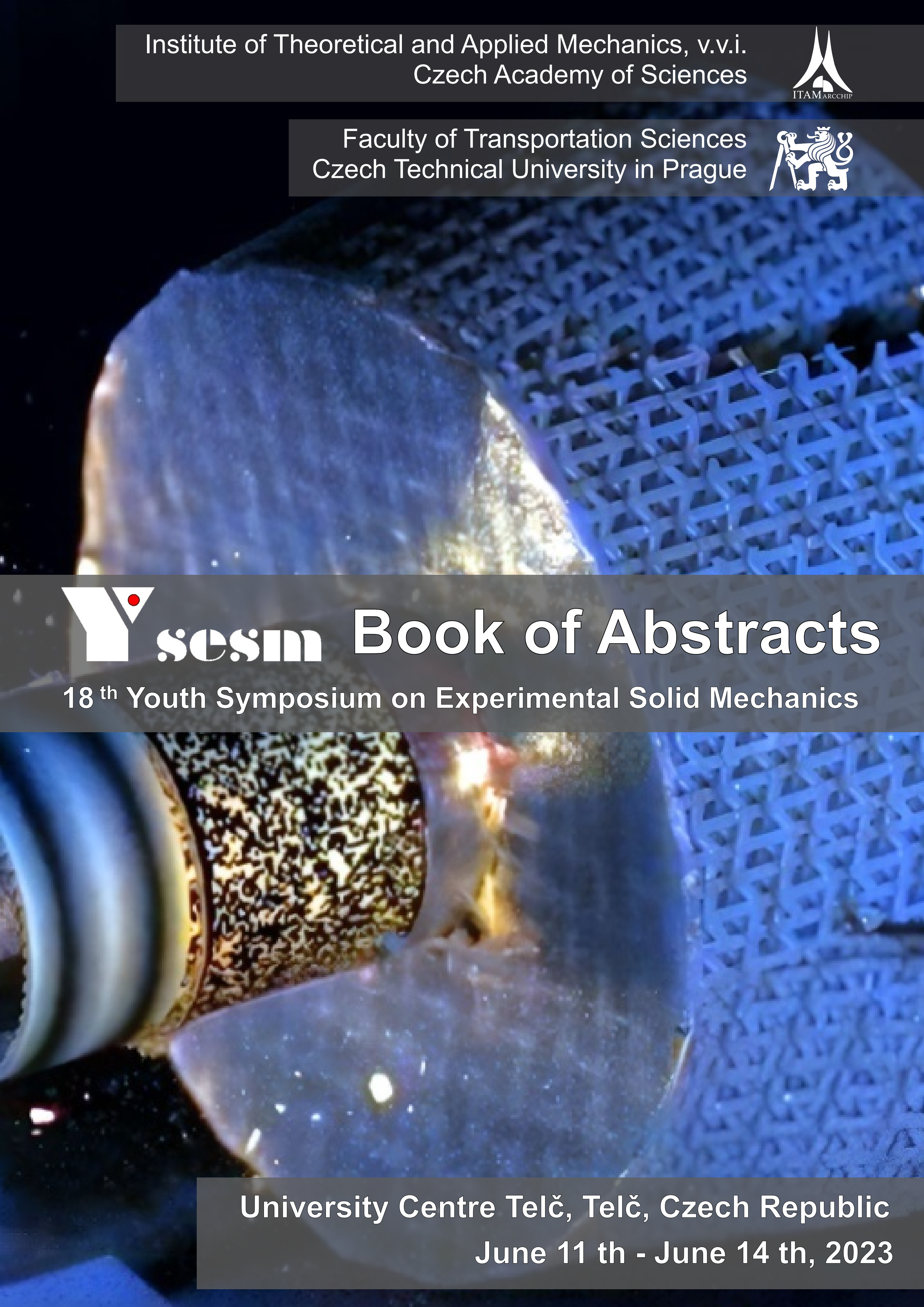

YSESM Book of Abstracts

18 th Youth Symposium on Experimental Solid Mechanics

University Centre Telč, Telč, Czech Republic

June 11 th - June 14 th, 2023

Institute of Theoretical and Applied Mechanics, v.v.i., Czech Academy of Sciences

Faculty of Transportation Sciences, Czech Technical University in Prague

Book of Abstracts

18th Youth Symposium on Experimental Solid Mechanics

University Centre Telč, Telč, Czech Republic
June, 11th - June, 14th 2023

supported by:
Czech Academy of Sciences
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About YSESM 2023

The YSESM symposium provides a forum for young researchers and engineers, PhD students and students dealing with subjects of experimental mechanics. The Symposium concentrates on current work in all areas of experimental research and its application in solid and fluid mechanics. The topic will particularly concern to:

- Conventional and Advanced Experimental Methods in Solid and Fluid Mechanics
- Non-Destructive Testing and Inspection
- Measurements in Material Science
- Computer Assisted Testing and Simulation
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- Hybrid Methods, Experimental Techniques – Numerical Simulation
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- Measurement Methods for Forensic Engineering

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Symposium Programme

	SUN June 11th	MON June 12th	TUE June 13th	WED June 14st
7:45		breakfast	breakfast	
8:00				breakfast
8:45				
8:50		opening ceremony		
9:00		invited lecture MON-IN-I	invited lecture TUE-IN-I	
9:15				
9:30		lectures MON-I	lectures TUE-I	lectures WED-I
10:30		coffee break & registration	coffee break	poster session & coffee
11:00		lectures MON-II	lectures TUE-II	closing ceremony
11:10				
12:00		poster session	poster session	
12:45				
13:00		lunch	lunch	
14:30		invited lecture MON-IN-II		
15:00		invited lecture MON-IN-III		
15:30		lectures MON-III		
16:30		poster session & coffee		
17:00	registration			
18:00	welcome drink			
19:00		dinner	dinner	

Schedule of Lectures

MON June 12th		
8:50-9:00	Opening ceremony	
9:00-9:30	MON-IN-I	Invited lecture
Isabel Duarte	MULTIFUNCTIONAL STRUCTURES BASED ON CELLULAR METALS FOR ENGINEERING APPLICATIONS	
9:30-10:30	MON-I	Contributed lectures
Sebastian Pistor	COMPARATIVE STUDY OF SIMULATED WATER-ASSISTED INJECTION MOLDED BICYCLE FRAMES AND THEIR INJECTION MOLDED COUNTERPARTS	
Theresa Rubenzucker	INVESTIGATION OF THE THEORETICAL LIMITS OF SHORT FIBER COMPOSITE PERFORMANCE BASED ON RVE SIMULATIONS	
Evrim Burkut	PRODUCTION AND VISCOELASTIC CHARACTERIZATION OF MAGNETORHEOLOGICAL PDMS FOAMS	
Barbora Kotlánová	VOLUME CHANGES MEASUREMENT OF ELASTOMERS USING 3D DIC	
11:00-12:00	MON-II	Contributed lectures
Jan Krivošej	EXPERIMENTAL VALIDATION OF MOTION SENSOR PHYSILOG®5 APPLIED TO SHOULDER JOINT	
Adam Tater	MODELLING OF TEMPERATURE FIELD DISTRIBUTION ON SINGLE ANNULAR USING HIGHER ORDER NEURAL NETWORKS	
Alexander Engel	SIMUALTION OF MODIFIED AUXETIC STRUCTURES DURING DROP WEIGHT IMPACT	
Sergej Grednev	AI-ASSISTED STUDY OF AUXETIC STRUCTURES	
Laura Lindner	SIMULATION OF THE MECHANICAL BEHAVIOR OF TRIPLY PERIODIC MINIMAL SURFACE (TPMS) BASED GYROID	
14:30-15:00	MON-IN-II	Invited lecture
Petr Koudelka	LABORATORY X-RAY IMAGING IN MATERIAL SCIENCES	
15:00-15:30	MON-IN-III	Invited lecture
Tomáš Fíla	ACTUAL CHALLENGES IN EXPERIMENTAL IMPACT DYNAMICS: PROGRESS IN STATE-OF-THE-ART INSTRUMENTATION AND HIGH SPEED X-RAY IMAGING	
15:30-16:30	MON-III	Contributed lectures
Jan Sleichrt	EXPERIMENTAL APPROACH AND HIGH SPEED X-RAY IMAGING SYSTEM FOR INVESTIGATION OF COMPLEX MODES OF DEFORMATION IN MATERIALS AT ELEVATED STRAIN RATES	
Nela Krčmářová	RESPONSE OF THE ULTRA HIGH PERFORMANCE CONCRETE UNDER DYNAMIC COMPRESSIVE LOADING	
Jan Falta	MECHANICAL PROPERTIES OF BASALT: A STUDY ON COMPRESSIVE LOADING AT DIFFERENT STRAIN RATES USING SHPB	
Veronika Drechslerová	EFFECT OF AGING ON MECHANICAL PROPERTIES OF 3D PRINTED SAMPLES USING STEREOLITHOGRAPHY	
TUE June 13th		
9:00-9:30	TUE-IN-I	Invited lecture
Nejc Novak	COMPUTATIONAL AND EXPERIMENTAL MECHANICAL CHARACTERISATION OF MODERN CELLULAR METAMATERIALS AT DIFFERENT STRAIN RATES	
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Jonathan Glinz	FAST CONTINUOUS IN-SITU XCT OF ADDITIVELY MANUFACTURED CARBON FIBER REINFORCED TENSILE TEST SPECIMENS	
Julia Maurer	INVESTIGATION OF LOCAL DEFECT FORMATION IN SHORT GLASS FIBRE REINFORCED POLYMERS BY MICRO-MECHANICAL SIMULATIONS AND INTERRUPTED IN-SITU EXPERIMENTS	
Blanka Zaloudkova	EFFECT OF THE LONG-TERM STORAGE METHODS ON THE STABILITY OF CARTILAGE BIOMECHANICAL PARAMETERS	
Rene Preuer	CONDUCTIVE OPEN-CELL SILICONE FOAM FOR MODULATABLE DAMPING AND IMPACT SENSING APPLICATIONS	
Miroslav Yosifov	SEGMENTATION OF PORES IN CARBON FIBER REINFORCED POLYMERS USING THE U-NET CONVOLUTIONAL NEURAL NETWORK	
11:00-12:00	TUE-II	Contributed lectures
Alessandra Panerai	ANALYSIS OF PEEL AND SHEAR STRAINS IN CRACKED LAP SHEAR	

	SPECIMENS SUBJECTED TO FATIGUE LOADING USING DIGITAL IMAGE CORRELATION	
Vaclav Rada	COMPUTED TOMOGRAPHY SYSTEM WITH STRICT REAL-TIME SYNCHRONIZATION FOR IN-SITU 3D ANALYSIS OF PERIODICALLY VIBRATING OBJECTS	
Yunus Emre Yılmaz	IMPROVING STRAIN WAVE MEASUREMENT ACCURACY IN DIRECT IMPACT HOPKINSON BAR TESTS OF CELLULAR MATERIALS USING A 2 MEASURING POINTS WAVE SEPARATION TECHNIQUE	
Michal Kubínyi (Testima)	CONNECTION BETWEEN ACADEMIC RESEARCH AND X-RAY NDT DEVELOPMENT IN INDUSTRY	
Railway Research Institute (VUZ)	COMPANY PRESENTATION	
WED June 14th		
9:30-10:30	WED-I	Contributed lectures
Patrik Kovář	SCALABLE ACTIVATION FUNCTION EMPLOYMENT IN HIGHER ORDER NEURAL NETWORKS IN TASKS OF SUPERVISED LEARNING	
Tomáš Kohout	THE POSSIBILITIES OF UTILISING THE SKIDOMETER T2GO FOR FORENSIC ENGINEERING	
Radosław Grabiec	DESIGN OF THE ALGORITHM, PRINT AND ANALYSIS OF POROUS STRUCURES WITH MODIFIABLE PARAMETERS	
Yogesh Gandhi	GEOMETRY PROJECTION METHOD FOR DESIGNING AND MANUFACTURING VARIABLE-STIFFNESS COMPOSITE LAMINATE.	
Pavel Vrtal	DYNAMIC TESTS OF THE PROTECTIVE AND SECURITY BARRIER SYSTEM PROBAR	
Radim Dvořák	ASYNCHRONOUS TIME INTEGRATION WHILE ACHIEVING ZERO INTERFACE ENERGY	
11:00-11:10	Closing ceremony	

Contents

MULTIFUNCTIONAL STRUCTURES BASED ON CELLULAR METALS FOR ENGINEERING APPLICATIONS

I. Duarte [1]

Keywords: *cellular metals, filled structures, mechanical properties, energy absorption*

Abstract

Cellular metals have become the most suitable lightweight multifunctional materials, contributing to significant advances in all industrial sectors, especially for building more efficient, ecological, sustainable, comfortable, and safe buildings, cars, trains, furniture, industrial machines, and medical equipment. They are light, strong, multi-functional, recyclable and non-flammable, ideal for sustainable and environmentally friendly design. The presentation provides an overview of research activities related to the field of cellular metals. This research focuses on the design, processing, and morphological and mechanical characterizing of structures filled with various cellular metals [1, 2]: open-cell aluminium foam, closed-cell aluminium foam, advanced pore morphology (APM) foam, metallic hollow sphere structure (MHSS). The fabrication technologies for these filled structures [3] are presented. The morphology characterization of these structures is assessed by using X-ray microcomputed tomography to provide their internal cellular structures. These structures are subjected to mechanical loading in an extensive experimental testing program in which different types of loading (e.g., compression and bending) and velocity (e.g., quasi-static, dynamic) are considered. The deformation response, including the collapse mechanism of the filled structures, has been analyzed in detail. The mechanical properties, energy absorption capacity, and strain rate sensitivity are also evaluated. Results have shown that some of these filled structures offer a stable crush performance and their mechanical properties and deformation mechanism can be adjusted for specific applications.

Acknowledgment

This research has been supported by the projects: UIDB/00481/2020 (FCT, PT), UIDP/00481/2020 (FCT, PT) and CENTRO-01-0145-FEDER-022083 (Centro2020, PORTUGAL 2020).

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COMPARATIVE STUDY OF SIMULATED WATER-ASSISTED INJECTION MOLDED BICYCLE FRAMES AND THEIR INJECTION MOLDED COUNTERPARTS

S. Pistor [1] , M. Wimmer [2] , U. Çakmak [1 2] , Z. Major [1]

Keywords: *Injection Molding, Material Testing, Structural Simulation, Water Assisted Injection Molding*

Abstract

This study focuses on the polymer injection molding process for manufacturing bicycle frames. [1] Specific injection molding parameters were used to produce the frames and a filling simulation based on the production data was conducted to ensure proper filling of the mold. [1] The structural values of the frames were then determined using a specially designed testing setup.

To further analyze the performance of the frames, a structural simulation was conducted based on the injection molding simulation. Afterwards the results were compared with the measured test stand data. The aim was to verify the accuracy of the simulation in predicting the mechanical properties of the frames. The objective of the study was to evaluate the consistency between the simulation and the actual injection molded bicycle frame. Overall, the study provides a comprehensive analysis of the injection molded bicycle frame and its effect on the resulting mechanical properties. The findings contribute to the improvement of the design and manufacturing of bicycle frames, leading to better performance and durability.

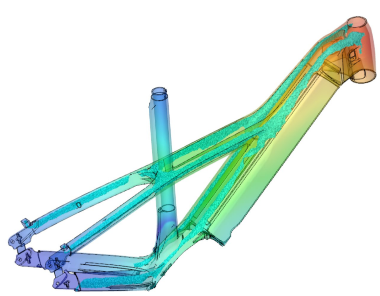

Figure 1: Water-Injection-Channel

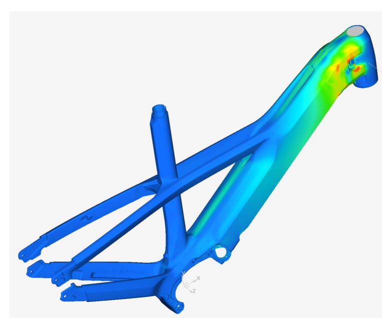

Figure 2: Finite-Element-Analysis

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INVESTIGATION OF THE THEORETICAL LIMITS OF SHORT FIBER COMPOSITE PERFORMANCE BASED ON RVE SIMULATIONS

T. Rubenzucker [1] **, A. Kapshammer** [1] **, Z. Major** [1]

Keywords: *short fiber-reinforced polymers, composites, mechanical performance, micromechanical simulations*

Abstract

Polymeric materials have gained increasing attention due to their unique mechanical properties and versatile applications in various industries like automotive, aerospace or prosthetics. This study provides a database of simulations on short fiber-reinforced polymers, which can be used for a general classification of composites based on common constituent properties and different aspect ratios. The performed simulations investigate the influence of aspect ratio and elastic modulus on the mechanical properties of a short fiber composite utilizing representative volume elements (RVE) for finite element simulations. In particular the range of elastic moduli from 10 MPa to 100000 MPa, as well as aspect ratios of 10, 50, and 100 were analyzed regarding uniaxial tension, in-plane shear and biaxial deformation. As expected the mechanical properties of polymer materials are significantly affected by both the aspect ratio and elastic modulus. A three dimensional plot was derived, providing an envelop of the theoretical limits regarding the mechanical properties of short fiber composites. The corresponding numerical simulations were based on a 3D random and an experimentally derived fiber orientation tensor. These findings provide important insights into the design and selection of the matrix and reinforcement phases of composites for specific applications, as well as opportunities for further research in the field of polymer science. Our database of simulations can serve as a valuable resource for researchers and engineers in the field of materials engineering, enabling them to explore the properties of polymer materials and develop new materials with improved mechanical performance.

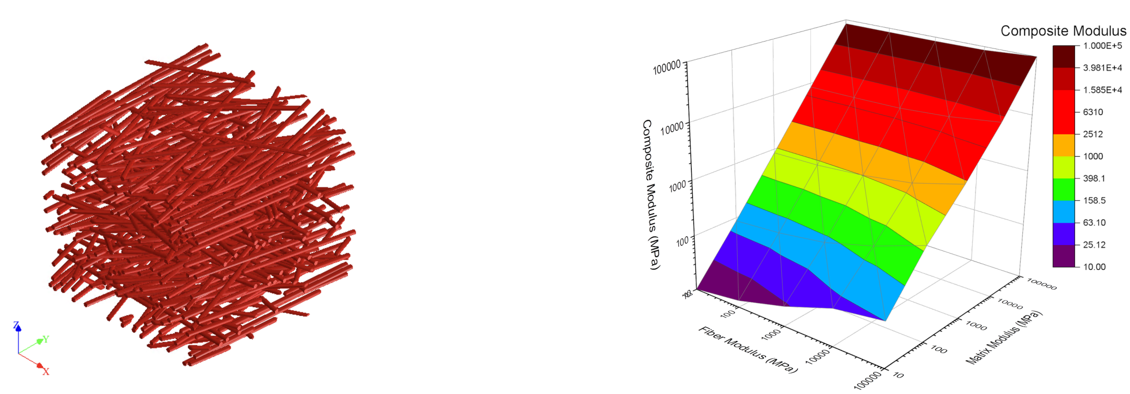

Figure 1: RVE (left) and Resulting Modulus (right)

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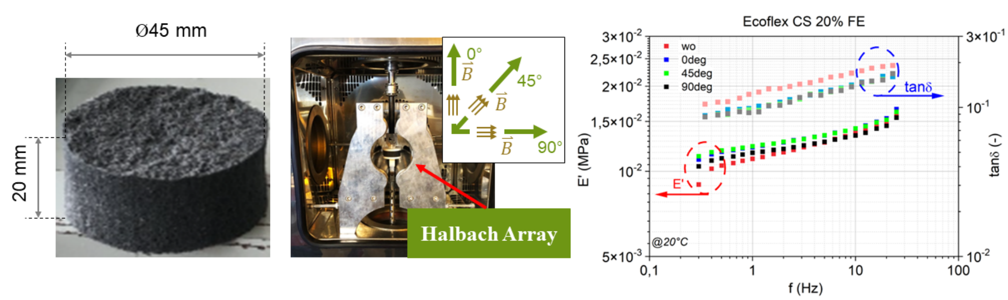
PRODUCTION AND VISCOELASTIC CHARACTERIZATION OF MAGNETORHEOLOGICAL PDMS FOAMS

E. Burkut [1], C. Emminger[1], R. Preuer [2], U. Çakmak[1], I. Graz[2], Z. Major[1]

Keywords: *Viscoelastic Characterization, DMA, Magnetorheological Foam, PDMS*

Abstract

In this research novel poly(dimethylsiloxane) (PDMS) foams filled with iron particles are investigated to gain insights of the magnetorheological (MR) effect. The cell size and the cellular architecture of the foams are controlled by mixing (coarse) cane sugar during the casting of the PDMS. After curing the sugar was dissolved in hot water and cylindrical specimens were stamped. The objective is to analyze the dependency of the MR effect on the angle of the magnetic field and the iron particle contents within the PDMS foams ranging from 20w% to 40w%. A Halbach array [1] with a flux density of 448mT was used to adjust the direction of the magnetic field. The foams were characterized by measuring their storage and loss moduli under sinusoidal compression. Above 10Hz loading frequency, the specimens response is only determined by the material behavior as well as cellular structure of the specimen. The findings of this research contribute to the understanding of silicone elastomer foam production and development of magnetorheologically active materials for various applications.



(a) (b) (c)

Figure 1: (a) Stamped specimen, (b) DMA set-up with Halbach array, (c) Results of the DMA

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VOLUME CHANGES MEASUREMENT OF ELASTOMERS USING 3D DIC

B. Kotlánová [1] , J. Javořík, S. Rusnáková, R. O. Ogunleye

Keywords: *elastomer, DIC, volume change*

Abstract

Elastomeric materials are also characterised by low compressibility and are often assumed to be incompressible. However, a change in volume under stress is also observed, although the change in shape is more significant. A suitable method for observing and quantifying volume changes is digital image correlation (DIC) [1]. DIC is a non-destructive, non-contact optical method for measuring deformations on objects of different materials and shapes [2]. The presented study aims at measuring the volume changes of elastomers using 3D DIC (stereo) and follows the author's research [3] in the field of 2D DIC (mono) measurements. The deformation measurement method in 3D DIC configuration was applied during the mechanical testing of two types of test specimens (dumbbells, cylinders) in uniaxial tension. In this configuration, two cameras were used. The test specimens were measured up to a specified strain value, and the measured data were used to obtain the strain dependence of Poisson's number and bulk modulus. The measurement results reveal that the 3D DIC method provides relatively less scattered data in the low-strain regions for dumbbell-shaped test specimens and is suitable for measuring various test specimen shapes.

Acknowledgment

This article was supported by the project IGA/FT/2023/004 TBU in Zlin.

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EXPERIMENTAL VALIDATION OF MOTION SENSOR PHYSILOG®5 APPLIED TO SHOULDER JOINT

J. Krivošej [1] , J. Garanová Krišťáková [2] , M. Daniel [3] , Z. Šika [4]

Keywords: *shoulder joint, motion sensor, wearable, experimental validation*

Abstract

The aim of this paper is to experimentally verify the deployability and accuracy of the Physilog®5 motion measurement unit when used to measure absolute position, velocity and acceleration of the shoulder joint during large movements. The Physilog®5 is well known and its applications are mainly related to walking, where the movement of human limbs can be considered as planar. However, this simplification often leads to neglecting the acceleration in the perpendicular direction to the considered plane of movement of the limb and as a result the measuring unit often gives very good and relatively accurate results. However, during large movements of the shoulder joint this simplification cannot be made, which often leads to drifting of the absolute position and other induced inaccuracies. The paper connected to this topic [1] shows validation of the motion unit during walking when mounted in a shoe.

The experimental setup consist of a spherical joint which is assembled for this purpose as a rotary and an universal joint arranged in a serial configuration. Where both the rotary and the universal joint are equipped with an accurate absolute position sensing. A Physilog®5 unit is subsequently mounted on this assembly.

Acknowledgment

This research was funded by the Czech Science Foundation project 23-06920S ”Functionally biomimetic exoskeleton of human upper limb for selective muscle augmentation”.

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MODELLING OF TEMPERATURE FIELD DISTRIBUTION ON SINGLE ANNULAR USING HIGHER ORDER NEURAL NETWORKS

J. Pařez [1] , P. Kovář [2] , A. Tater [3]

Keywords: *Natural Convection, Correlation, Engine Cooling, Neural Network*

Abstract

Temperature field distribution correlation in a single annular using artificial neural network is introduced. This temperature distribution is non-uniform [1] on the outer annular tube due to ongoing natural convection caused by the steady-state homogeneous heating of the inner tube, which is representing hot gases flowing through the turbine. Since the outer tube represents the case of the gas turbine this temperature is important for the electronic components placement or the overall engine deformation [2]. Presented approach allows a quick estimation of the temperature distribution with no need to perform time demanding CFD simulations that can rapidly accelerate design and development [3].

The correlation function is obtained using an extensive set of CFD simulations under different conditions and geometrical setups. A machine learning approach is applied to the CFD results and only the correlation function is obtained for a range of input variable parameters.

Acknowledgment

Authors acknowledge support from the ESIF, EU Operational Programme Research, Development and Education, and from the Center of Advanced Aerospace Technology (CZ.02.1.01/0.0/0.0/16 019/0000826), Faculty of Mechanical Engineering, Czech Technical University in Prague.

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SIMUALTION OF MODIFIED AUXETIC STRUCTURES DURING DROP WEIGHT IMPACT

A. Engel [1], **A. Jung** [2]

Keywords: *Metamaterials, auxetic, lightweight, energy absorption*

Abstract

Mechanical metamaterials is a term used to describe artificially fabricated, cellular structures with a special geometry and highly uncommon traits that cannot be found in the bulk material. Given their cellular character, most metamaterials are promising to be utilised in lightweight and energy absorbing applications [1]. In the case of auxetic structures, which is a term used to described materials with a negative Poisson's ratio, the beneficial properties also include a high indentation resistance, a higher fracture toughness and several more. This enables applications in many fields, such as aerospace and sports industries [2]. Given the potential of these materials, many studies have already been conducted. Thus the geometry of a selected auxetic re-entrant structure was optimised in order to maximise its mass-specific energy absorption for ideal usage in lightweight applications [3]. Moreover, only a singular material was used, whereas the combination of multiple materials could drastically increase the performance of such structures. Hence, in this paper the use of two different materials combined into a modified re-entrant structure is investigated via simulation. The Poisson's ratio in the linear range of deformation as well as beyond that could be improved, which leads to a much more pronounced and longer lasting auxetic effect. Further studies were carried out in order to get a similar improvement while going back to a singular material and sacrificing some of the weight optimisations done previously by thickening some of the struts and therefore massively increasing the auxetic effect, even far beyond elastic deformation. Whilst this approach also simplifies the fabrication by a huge margin, the focus shifts more from a lightweight approach towards an energy absorbing approach. This is emphasised even more by the fact, that the increase in performance is especially present beyond elastic and during plastic deformation, which will be reached during some applications of energy absorbers.

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AI-ASSISTED STUDY OF AUXETIC STRUCTURES

S. Grednev [1] , S. Bronder [2] , A. Jung [3]

Keywords: *regression, machine learning, auxetic structures*

Abstract

As a main characteristic auxetic structures posses a negative Poisson's ratio, which makes them a subclass of so called mechanical metamaterials. They show remarkable mechanical properties rendering them particularly useful for applications as crash absorbers. This aptitude stems from their high stiffness and low density combined with a plateau stress over a large deformation regime [1, 2]. The mechanical performance of auxetic structures is mainly governed by their geometry making structural optimization a study topic of paramount importance, which is typically facilitated through finite element simulations. Since those can be very time consuming given the structural complexity this work aims at utilizing a machine learning approach to circumvent the need for lengthy simulations – a strategy commonly pursued in contemporary engineering sciences.

The main focus so far has been on predicting stress-strain curves under compression and the corresponding energy absorption potential for a type of auxetic structures that was studied by Bronder et al. [3]. To this end a multitude of modeling techniques was applied and assessed with regard to their aptitude for the predictive task. The overarching objective of this work, however, is a nascent AI driven tool of constantly increasing capacity to facilitate the study of geometry-governed mechanical metamaterials.

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SIMULATION OF THE MECHANICAL BEHAVIOR OF TRIPLY PERIODIC MINIMAL SURFACE (TPMS) BASED GYROID

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Keywords: *multiaxial loading, TPMS Gyroid, FEM*

Abstract

New advances in the field of additive manufacturing are constantly. As a result, the multitude of applications for additive manufactured structures, such as cellular metamaterials, is increasing. This includes mathematically controlled surface-based triple periodic minimal surface (TPMS) structures, which have received much attention recently. Their mathematical definition makes them easy to adapt for specific applications. Additionally, the geometric and mechanical properties can be influenced separately [1].
The quasi-static and dynamic material behaviour under uniaxial loading has been investigated for different TPMS structures [2]. Thus, the elastic and plastic behavior is known for many TPMS lattice structures, but for an industrial application, knowledge of the yield behavior under multiaxial 3D loading is mandatory. Therefore, the aim of this work is to investigate the mechanical properties of TPMS based Schoen Gyroid under multiaxial loading.
To that end, finite element simulations are performed with an explicit solver in LS-DYNA™. TPMS Gyroid with dimensions 40 x 20 x 20 mm and a relative density of 11.6 % is used. The boundary conditions were chosen so as to allow for their application in experimental investigations. Of particular importance in the mechanical characterisation are the energy absorption and the yield points.

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LABORATORY X-RAY IMAGING IN MATERIAL SCIENCES

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Keywords: *X-ray imaging, material characterization, mechanical properties*

Abstract

In recent decades, X-ray imaging and computed (micro)tomography (XCT) in particular have become common tools for volumetric inspection, visualization, and analysis of internal structure in materials from various fields [1]. In this lecture, we will explore various applications of laboratory X-ray imaging chains utilizing the combination of tomographical imaging with mechanical, thermal, or chemical loading of the irradiated sample in a so-called time-resolved imaging allowing for unprecedented insight into different phenomena driving fundamental processes encountered in various fields of material science. We will show that failure processes in engineering or geological materials [2] can be thoroughly studied by synergy of information from radiographical imaging and other methods including acoustic emission detection and optical measurements via high-speed visible-spectrum and thermal-imaging cameras, where the radiography provides important spatial information regarding deformation processes evolving within the tested samples that could not be obtained otherwise. The state-of-the-art the laboratory based imaging chains for investigation of dynamic response of materials under loading will be also discussed including high speed X-ray radiography utilizing a powerful X-ray source during high velocity impact as an approach suitable for inspection of an impacted sample. As an alternative to both conventional high-power sources and accelerator facilities, capabilities of a flash X-ray system developed primarily for in-situ ballistics research providing very short bursts of an extremely powerful intermittent X-ray radiation with a typical duration of dozens of nanoseconds will be shown.

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ACTUAL CHALLENGES IN EXPERIMENTAL IMPACT DYNAMICS: PROGRESS IN STATE-OF-THE-ART INSTRUMENTATION AND HIGH SPEED X-RAY IMAGING

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Keywords: *impact dynamics, split Hopkinson bar, complex materials, additive manufacturing, high speed X-ray imaging*

Abstract

Mechanical properties of materials as well as their deformation behavior and failure modes at intermediate and high strain rates are crucial parameters in many engineering fields, including, for instance, crash zones of vehicles, impact and ballistic protection, manufacturing processes, vibration control, shock absorbers and dampers. Over years, several experimental techniques for investigation of materials at high strain rates have been developed, e.g., drop-weight tower, servo-hydraulic machines, split Hopkinson bars or Taylor anvil. Although these techniques can provide relevant results for conventional specimens, it is very challenging to implement them for testing of complex materials such as foams, additively manufactured constructs, lattices, heterogeneous materials, and, especially, full-scale components (panels etc.) subjected to complex modes of dynamic loading. This topic represents an important and progressively developing research field crucial for application of specific engineering solutions optimized for operation under high strain rates. Recently, innovative techniques introducing instrumentation of the impacting projectile [1], in-situ high speed X-ray imaging [2] as well as post-impact computed tomography analysis [3] have been presented. In the contribution, we overview current state-of-the-art instrumentation for experimental investigation of materials under high strain rates, including measurement of impact forces during dynamic penetration of panels, in-situ high speed X-ray imaging of the internal processes in the materials during impact, and precise control of the impact to allow for relevant representation of the experiment through inverse numerical simulation. Actual limitations of the techniques and insight into improvements in near future are discussed as well.

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EXPERIMENTAL APPROACH AND HIGH SPEED X-RAY IMAGING SYSTEM FOR INVESTIGATION OF COMPLEX MODES OF DEFORMATION IN MATERIALS AT ELEVATED STRAIN RATES

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Keywords: *dynamic penetration, split Hopkinson bar, additive manufacturing, high speed X-ray imaging*

Abstract

Relevant mechanical analysis of materials subjected to complex modes of deformation at intermediate and high strain rates requires different approach than standard testing using established methods. State-of-the-art instrumentation and innovative imaging techniques are necessary for an in-depth analysis of the deformation and failure processes. In this paper, we introduce methods that allow for an experimental analysis of large specimens (such as panels) at intermediate strain rates with an extensive amount of measured information including actual force and velocity histories at the impact side of the object or in-situ imaging during the impact. Capabilities and performance of experimental setups with a two-sided (input and output) instrumentation as well as methods for characterization of internal failure (including its visualization) are presented. Innovative approach including post-impact investigation through X-ray analysis and future prospects of the technique to be utilized continuously during the intermediate strain rate experiments are discussed. In the paper, results of case studies aimed at instrumented dynamic indentation into additively manufactured structures and a high velocity X-ray imaging using a system with a high power X-ray tube, scintillation panel and high speed camera are summarized. Although the results are presented as two de-coupled experimental campaigns, they are employed in a manner to clearly define basis for future combination of dynamic experiments with an in-situ X-ray imaging while the expected performance, image quality and character of the image information are presented in the paper.

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RESPONSE OF THE ULTRA HIGH PERFORMANCE CONCRETE UNDER DYNAMIC COMPRESSIVE LOADING

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Keywords: *UHPC, dynamic loading, SHPB, digital image correlation*

Abstract

Ultra high performance concrete (UHPC) is a modern cementitious material which exhibits excellent mechanical properties. This assumption leads to the use of this material in wide range of applications from civil engineering to special applications such as marine structures, underground spaces, nuclear waste container, protection of critical infrastructure, mobile car barrier and national defence and military facilities. UHPC is usually used for describing a fibre reinforced, superplasticized, silica fume- cement mixture with a very low water to cement ratio, characterized by the presence of a very fine quartz sand, instead of ordinary aggregate [1]. The cemetitious matrix of the material was in this case reinforced by steel fibres which were $12\,\mathrm{mm}$ long with diameter of $0.2\,\mathrm{mm}$.

UHPC was introduced in the mid-1990s [2], [3]. But the standardisation for this material doesn't exist. And for this standardisation process it is necessary to describe mechanical properties in various modes of deformation and different strain rates.

In this study the material was subjected to compressive loading in quasi- static and dynamic conditions using split Hopkinson pressure bar (SHPB). In the dynamic condition was used advanced instrumentation for the evaluation of the results and in the quasi- static condition was used digital image correlation for the evaluation.

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MECHANICAL PROPERTIES OF BASALT: A STUDY ON COMPRESSIVE LOADING AT DIFFERENT STRAIN RATES USING SHPB

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Keywords: *basalt, dynamic loading, SHPB, digital image correlation*

Abstract

This article focuses on the mechanical properties of basalt in compressive loading at different strain rates, using split Hopkinson pressure bar (SHPB) in quasi-static and dynamic conditions. The study employs advanced instrumentation for the evaluation of the results in dynamic conditions, while standard uniaxial loading device and digital image correlation is used for evaluation in quasi-static conditions. Basalt is an igneous rock that is highly versatile in a range of applications from civil engineering to special applications. Basalt's high strength and non-corrosive properties make it a suitable material for reinforced concrete structures in specific environments [1]. Additionally, products derived from basalt can effectively contribute to the construction of bridges, highways, as well as residential and industrial buildings. Basalt fibers can be also used as a reinforcing material in composites for various industrial applications [2].

Understanding the mechanical properties of basalt can provide insights for engineers and designers in creating structures that are durable and able to withstand different loading conditions. The findings of this study can have implications for a wide range of industries, including aerospace, automotive, and construction, among others.

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EFFECT OF AGING ON MECHANICAL PROPERTIES OF 3D PRINTED SAMPLES USING STEREOLITHOGRAPHY

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Keywords: *stereolithography, aging, mechanical properties*

Abstract

The continuous development of additive manufacturing and its technologies has benefited various industries, while application of the technology for production of materials with high industry standard and reliable properties is currently a key topic of further development. For this reason detailed testing and complex understanding the mechanical properties of the newly developed materials is essential. This paper focuses on stereolithography (an additive manufacturing technology working on the principle of curing liquid resins layer by layer using ultraviolet radiation) and a complex analysis of effect of aging on the mechanical properties of the material and printed samples. As part of the research, sets of samples were printed and subjected to different aging methods and subjected to quasi-static and dynamic uni-axial load tests. Effect of aging was investigated on the samples exposed to different ambient conditions: i) minimized external effects (no external light, dark chamber, stable temperature), ii) standard external effects (specimens subjected to sunlight, temperature cycles), iii) extreme conditions (specimens subjected to extreme X-ray irradiation). The study is designed as fully comparative, while the individual effects can be directly evaluated. From the obtained data basic material characterization were evaluated and compared. The aim of the paper is to assess the different aging effects on material properties and deformation characteristics.

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COMPUTATIONAL AND EXPERIMENTAL MECHANICAL CHARACTERISATION OF MODERN CELLULAR METAMATERIALS AT DIFFERENT STRAIN RATES

N. Novak [1] , M. Vesenjak [2] and Z. Ren [3]

Keywords: *cellular metamaterials, experimental testing, computational simulations, high strain rate*

Abstract

The engineered materials with designed and tuneable multifunctional properties are often called the "metamaterials" and in this lecture, we will address the materials with internal cellular structure - the "cellular metamaterial" [1]. The cellular metamaterials have been increasingly used in modern engineering applications over the past decade due to their attractive combination of improved mechanical and thermal properties relative to their weight. This work presents a detailed overview of the fabrication processes of cellular metamaterials, their exhibited properties, and potential applications. The advanced geometrical characterisation, experimental testing and computational modelling of various cellular metal structures (closed-cell foam, open-cell foam, auxetic cellular structure, UniPore structure, foam-filled tube and TPMS structure) will be described in detail. The mechanical behaviour of cellular structures under quasi-static and low- and high-rate dynamic loading conditions, which were thoroughly investigated both computationally and experimentally, will be presented [2]. The high strain rate loading of cellular metamaterials using the Split Hopkinson Pressure Bar (SHPB) and powder gun will also be discussed. Furthermore, the use of high speed cameras and Digital Image Correlation (DIC) to analyse the deformation behaviour will be presented on practical examples of modern metamaterials. The used methodology, main results and relevant conclusions will be discussed.

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FAST CONTINUOUS IN-SITU XCT OF ADDITIVELY MANUFACTURED CARBON FIBER REINFORCED TENSILE TEST SPECIMENS

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Keywords: *Additive Manufacturing, Composites, X-ray Computed Tomography, In-Situ Tensile Testing*

Abstract

The reinforcement of fused filament fabricated (FFF) components with continuous fibers allows for high versatility in the design of mechanical properties for a specific application's needs. However, the bonding quality between continuous fibers and the FFF matrix material has high impact on the overall performance of the composite. In a recent study [1], additively manufactured (AM) continuous fiber reinforced tensile test specimens have been investigated regarding the effect of amount and material of the embedded continuous fibers on tensile strength and AM build quality. During these tensile tests, a sudden reduction in tensile stress, which most likely was not related to actual rupture of continuous fibers, was noticeable. Since X-ray computed tomography (XCT) scans were performed only prior to and after the tensile testing, a detailed investigation on the origin of these drops in tensile stress was not possible. Within this work, we will expand upon these findings and present results of fast on-the-fly in-situ investigations performed on continuous carbon fiber reinforced specimens of the same AM build. During these investigations, specimens are loaded under the same conditions while fast XCT scans, with a total scan time of 12 seconds each, were performed consecutively. The resulting three-dimensional image data reveals internal meso- and macro-structural changes over time/strain to find the cause of the aforementioned reduction in tensile stress.

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INVESTIGATION OF LOCAL DEFECT FORMATION IN SHORT GLASS FIBRE REINFORCED POLYMERS BY MICRO-MECHANICAL SIMULATIONS AND INTERRUPTED IN-SITU EXPERIMENTS

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Keywords: *Short Fibre Reinforced Polymer, X-ray Computed Tomography, Digital Volume Correlation, Micro-mechanical Simulation*

Abstract

Discontinuous fibre reinforced polymers and especially, short glass fibre reinforced polymers (SFRPs,) are widely used in various industry sectors and often replace conventional materials, due to lower production costs and their lightweight structure. A lot of research on the mechanical behaviour of such composites have been conducted in recent years. However, for further improvement of the component design detailed knowledge of the failure mechanisms are necessary.

To better understand the defect formation and thus the micro-mechanical behaviour inside such composites, the strain behaviour in single fibres was analysed by micro-mechanical simulations of Representative Volume Elements (RVE). Therefore, selected fibres - similar orientated as in the real structure - were chosen for detailed analysis. Additionally, the defect formation next to such individual fibres was investigated by X-ray computed tomography (CT). For this purpose, interrupted in-situ scans were performed and the areas around selected fibres were examined.

It was revealed that the overall stress-strain behaviour of simulation and experiment fitted quite well. Further the simulation results correspond to theory, especially the strain distributions along the fibres depending on the fibre orientation to the load direction. However, the detailed local inspection of the experimental volume data showed a rather strong influence of neighbouring fibres. Exemplary fibres were selected from the CT data and examined for possible emerging defects such as fibre fracture, fibre pull-out and fibre-matrix debonding.

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EFFECT OF THE LONG-TERM STORAGE METHODS ON THE STABILITY OF CARTILAGE BIOMECHANICAL PARAMETERS

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Keywords: *stability study, cartilage, biomechanical characterisation, compression loading, XCT imaging*

Abstract

Long-term stability of the tissue product in term of mechanical parameters is a key factor for it's expiration date [1]. For the investigation of storage effects on the cartilage tissues the experimental mechanical loading campaign combined with XCT scanning for the irregular shape inspection was performed [2, 3]. The samples preserved according to three different procedures for human tissue processing accomplish by NATIC based on i) dry freezing and storage in ambient temperature $-80\,^{\circ}\mathrm{C}$ ii) preserved by $3.0\,\%$ NaCl solution, and iii) preserved by $0.9\,\%$ avoiding the needs for radiation sterilization. The stability of the biomechanical parameters were tested within annual interval. All samples with height $5-7\,\mathrm{mm}$ were subjected to uni-axial compression loading using the in-house developed compact table top loading device in displace-driven mode with loading rate set to $10\,\mu\mathrm{m}\cdot\mathrm{s}^{-1}$ and displacement $3500\,\mu\mathrm{m}$. Based on the measurements, the results are represented in the form of stress-strain curves and quantified as elastic modulus and ultimate stress. It could be concluded that no significant difference in mechanical properties was observed within one year measurement interval neither as and affect of preservation method. The same testing procedure will be applied on the cartilage samples in the next two years to complete the stability study.

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CONDUCTIVE OPEN-CELL SILICONE FOAM FOR MODULATABLE DAMPING AND IMPACT SENSING APPLICATIONS

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Keywords: *Polydimethylsiloxane, conductive properties, deformation behaviour*

Abstract

Nature has long served as a source of inspiration for the development of new materials, with foam-like structures in fruits such as oranges and pamelos serving as examples of efficient energy dissipation. In this study, we present the synthesis and characterization of a conductive silicone foam for potential impact sensing applications. By blending Sylgard 184 and Carbon Black, we create a highly porous structure capable of dissipating energy and modulating its resistance. To investigate the properties of the foam, we utilized both micro-computer tomography (μCT) and scanning electron microscopy (SEM) imaging techniques. The μCT imaging revealed the intricate pore network of the foam, reminiscent of the complex structure found in natural sponges. SEM imaging allowed for observation of the uniform distribution of Carbon Black particles within the foam, enabling the conductive properties of the foam.

The foam's mechanical behavior was characterized by a compression test under μCT imaging to measure the deformation behavior and changes in the foam's resistance. Additionally, a ball drop test was conducted to investigate the foam's damping behavior while simultaneously measuring the impact location by the local change in resistance. Remarkably, our results demonstrate the exceptional damping capabilities of the conductive silicone foam, with the damping ratio modulated by adjusting the degree of compression-induced deformation. This is attributed to the collapse of the foam's porous structure, resulting in a significant increase in the foam's contact area. Overall, our study provides valuable insights into the behavior of conductive silicone foams and their potential as an impact sensing material. The use of both μCT and SEM imaging techniques allows for a comprehensive understanding of the foam's properties, which can be optimized for a variety of applications. The foam's ability to modulate its damping properties by adjusting the degree of deformation provides a promising avenue for future research in the field of materials science and engineering.

Acknowledgement

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SEGMENTATION OF PORES IN CARBON FIBER REINFORCED POLYMERS USING THE U-NET CONVOLUTIONAL NEURAL NETWORK

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Keywords: *Deep learning, segmentation, U-Net, 3D U-Net, computed tomography, pores, composites, polymers.*

Abstract

This work illustrates the use of deep learning methods applied to X-ray computed tomography (XCT) datasets to segment pores in carbon fiber reinforced polymers (CFRP) by binary semantic segmentation. The proposed workflow is designed to generate efficient segmentation models with reasonable execution time, applicable even for users using consumer-grade GPU systems. First, U-Net [1], a convolutional neural network, is modified to handle the segmentation of XCT datasets. In the second step, suitable hyperparameters are determined through a parameter analysis (hyperparameter tuning), and the parameter set with the best result was used for the final training. In the final step, we report on our efforts of implementing the testing stage in open_iA [2], which allows users to segment datasets with the fully trained model within reasonable time. The model performs well on datasets with both high and low resolution, and even works reasonably for barely visible pores. It also offers an efficient segmentation of pores with different shapes and size. We demonstrate our findings on different real-world CT datasets of carbon fiber reinforced composites. In our experiments, we could show that U-Net is suitable for pore segmentation. Even when trained only with a low number of datasets, it returns a reasonable prediction accuracy.

Acknowledgment

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ANALYSIS OF PEEL AND SHEAR STRAINS IN CRACKED LAP SHEAR SPECIMENS SUBJECTED TO FATIGUE LOADING USING DIGITAL IMAGE CORRELATION

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Keywords: *Adhesively Bonded Joints, Cracked Lap Shear Specimen, Fatigue Loading, Digital Image Correlation*

Abstract

The use of adhesive bonding for structural joints presents many advantages, such as efficient manufacturing and improved structural performance. However, in structures subjected to fatigue loading, cracks might initiate and propagate in bonded joints, leading to service failure. Most adhesively bonded joints are subjected to combination of peel and shear stresses, so mixed I + II mode loading conditions are present at the crack tip. In this work, Cracked Lap Shear specimens, which feature mixed I+II mode loading conditions, were tested under fatigue loading. During tests, crack growth was monitored using Visual Testing and Digital Image Correlation (DIC). With the use of DIC, peel and shear strain components in the bondline were extracted from the substrates' displacement fields, revealing the presence of a highly strained process zone ahead of the crack tip. Results highlight the usefulness of DIC in accurately capturing the deformation behaviour of adhesive joints under mixed mode loading conditions. As a further exploitation, two different adhesives were considered and studied in order to compare their performance.

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COMPUTED TOMOGRAPHY SYSTEM WITH STRICT REAL-TIME SYNCHRONIZATION FOR IN-SITU 3D ANALYSIS OF PERIODICALLY VIBRATING OBJECTS

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Keywords: *computed tomography, hardware trigger, harmonic motion, real-time synchronization*

Abstract

Computed tomography has become commonly used X-ray imaging method during the testing of materials in the field experimental mechanics. Especially heterogenous materials with complex shapes and inner structure, such as rocks, biomaterials, 3D-printed lattices, etc. subjected to quasi-static mechanical loading and in-situ computed tomography has been the topic of recent scientific interest [1]. Furthermore, X-ray imaging has been adopted to inspect non-stationary objects and material samples subjected to dynamic loading [2]. In the contribution, we present a tabletop laboratory system capable of acquiring X-ray computed tomography of an oscillating object. The system is an in-house developed X-ray computed tomography setup with electromagnetic voice coil actuator mounted on top of the rotary stage of the setup. The strict synchronization of the components, the rotary stage, the electromagnetic actuator movement and the detector readout is accomplished with use of the detector hardware trigger and hard real-time Linux system. Sample of epoxy resin with metal particles is scanned stationary and with the electromagnetic actuator periodically moving. The volumetric data of the scans is compared and the results of this contribution represent an important step towards identification of defects through modal analysis of in-situ harmonically vibrating object.

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IMPROVING STRAIN WAVE MEASUREMENT ACCURACY IN DIRECT IMPACT HOPKINSON BAR TESTS OF CELLULAR MATERIALS USING A 2 MEASURING POINTS WAVE SEPARATION TECHNIQUE

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Keywords: *Strain Wave Propagation, Wave Separation, Direct Impact Hopkinson Bar*

Abstract

Cellular structures are known for their superior shock absorption properties, making them a popular material for applications where protection from impact is necessary. In the Direct Impact Hopkinson Bar experimental setup, accurate determination of strain wave propagation is crucial for reliable results when characterizing the mechanical properties of cellular materials under high strain rate loading conditions. Typically, propagating strains are measured in the transmission bar with strain gauges to determine strain wave propagation. However, the actual strain wave in the sample can be obscured by reflected superimposed waves, which may lead to significant errors in strain measurement. To address this issue, a 2 Measuring Points Wave Separation Technique has been developed, which separates superimposed waves and allows for a more accurate determination of the strain wave in the Direct Impact Hopkinson Bar test. The effectiveness of this technique has been demonstrated through significant improvements in the accuracy of strain measurements in Hopkinson Bar tests of cellular materials under high strain rate loading conditions.

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SCALABLE ACTIVATION FUNCTION EMPLOYMENT IN HIGHER ORDER NEURAL NETWORKS IN TASKS OF SUPERVISED LEARNING

P. Kovář [1] , J. Fürst [2]

Keywords: *machine learning, higher order neural networks, scalable activation function*

Abstract

Present contribution deals with methods of supervised learning. A novel approach - scalable activation function [1] and its influence to speed of convergence is studied. Furthermore, unlike classical deep learning approaches, presented neural networks architectures are built with higher order neural units [2] that enable to capture higher levels of non-linearity in tasks. Basics of higher order neural networks and learnable activation function are introduced. The applicability of aforementioned approach is tested and proved on various well-known task of supervised learning, e.g., unknown non-linear functions introduced by Klassen [3], Gupta et al. [4] and well-known logic function - XOR problem. It turned out that presented method outperformed standard deep learning methods in terms of convergence speed.

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THE POSSIBILITIES OF UTILISING THE SKIDOMETER T2GO FOR FORENSIC ENGINEERING

T. Kohout [1] , P. Vrtal [2] , M. Frydrýn [3] , A. Hoffmann [4] , T. Blodek [5]

Keywords: *Forensic Engineering, Friction, Walking Speed Measuring Device*

Abstract

The aim of the article is to verify the applicability of the T2GO skidometer measuring device, which measures by the walking speed, for measuring the coefficient of friction for forensic practice in accordance with the legislative framework of the Czech Republic. In the introduction, the article discusses the problem of friction coefficient measurement in a broader context. Firstly, the parameters affecting the value of the friction coefficient are analysed (the basic physical context of friction or adhesion forces and the factors influencing the characteristics of friction coefficients and their measurement are mentioned) and at the same time the article discusses the legislative regulation of measuring devices not only for walking speed in the international context. The results of the comparison with dynamic measuring devices standardly used in the Czech Republic and at the same time the determination of the correlation rate with these devices, based on data obtained within the National Comparative Measurement Action, are presented. The measurements were performed on several specific surfaces that represented the most common surfaces found on roads in the Czech Republic. These measurements were also made to verify the accuracy and repeatability of the measurements with the device in question. The article concludes with an interpretation and discussion of the results of the comparative measurements. In cases where no correlation was found, an analysis and reasoning of these results is provided. Last but not least, based on the synthesis of the results, a procedure is proposed for future use of the T2GO skidometer in practice within the legislative conditions of the Czech Republic.

Acknowledgment

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DESIGN OF THE ALGORITHM, PRINT AND ANALYSIS OF POROUS STRUCURES WITH MODIFIABLE PARAMETERS

R. Grabiec [1] , J. Tarasiuk [2] , S. Wroński [3]

Keywords: *Porous structure, Rhinoceross, Grasshooper, microtomography, porosity*

Abstract

The purpose of this project was to create an algorithm capable of creating a porous structure with variable properties. The structure, made by this method, was then printed using a 3D printer, and cross-sections obtained by microtomography were analyzed. At the beginning of the paper, the basic concepts related to it were introduced, such as bone structure, mathematical basis of Voronoi diagrams, and types of 3D printing. The tools and software used were also mentioned. Then step by step, the process of creating an algorithm in *Rhinoceros* software, using the graphical development environment *Grasshooper* was described. Having a suitable test group of porous structures (30 and 80% porosity), it was shown that it is possible to modify their porosity by changing only the parameter of the thickness of the beads and the number of centers of the Voronoi diagram on which the structure is based. In the next step, the structures were presented for printing and its effect. Once the finished physical models were obtained, they were examined by microtomography, giving an image resolution of 15um in the results. The resulting cross-sections were graphically processed in ImageJ Fiji software, and then an additional BoneJ plugin was used to analyze them. Having cross-sections of the original bone and printed structures, it was possible to compare their porosity and the average diameter of the trabeculae in the structure. With this procedure, it is possible to deduce whether it is possible to print accurate structures that will serve as porous bone implants in the future using the algorithm created in this work. The resulting differential porosity comparison was 2 - 7.5 %, while the thickness was about 18- 34%.

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GEOMETRY PROJECTION METHOD FOR DESIGNING AND MANUFACTURING VARIABLE-STIFFNESS COMPOSITE LAMINATE.

Y. Gandhi [1] , G. Minak [2]

Keywords: *geometry projection, manufacturing constraints,fiber-reinforced plastic, composite laminates*

Abstract

We present geometry projection [1] for laminate (*gP-lAM*)—design for a manufacturability framework for variable-stiffness composite laminate comprising material distribution, fiber orientation, and stacking sequence optimization strategies, including generalized manufacturing constraints well-suitable for conventional or additive manufacturing technology for continuous carbon fiber-reinforced plastic material.

Much literature is available on optimization strategies for both constant and variable stiffness composite laminate, especially when optimizing for material distribution of CFRP material, i.e., topology optimization such as density-based methods, which are majorly adopted because of their simplicity and ease of implementation [2]. However, these methods severely affect the optimization design space for anisotropic material as design variables dramatically increase with the number of design points in the discretized model, i.e., finite element mesh. Furthermore, it optimizes each design point so the optimized design can be organic and thus unrealizable. Therefore, we adopt the geometry projection method to circumvent these drawbacks yet retain the density-based method's simplicity. In this method, design variables are not the design points but the high-level parameterized geometric features such as bars or plates. Wherein the *gP-lAM* approach, we use fiber-reinforced bars (FRBs) [3] as the design variables, which automatically provide a manufacturable solution as an optimized design is an arrangement and merging of the bars in the given discretized space.

Finally, various examples of topology optimization of VSCL under different loading conditions are carried out to demonstrate the effectiveness of attaining manufacturable design.

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DYNAMIC TESTS OF THE PROTECTIVE AND SECURITY BARRIER SYSTEM PROBAR

P. Vrtal [1] , T. Kohout [2]

Keywords: *Ressistant Systems, Accident Reconstruction, Road Safety, Crash Tests, Security Barrier*

Abstract

The purpose of this paper is to present a series of dynamic tests for testing the protective and security barrier of the PROBAR system, developed by STRIX Chomutov, a.s., according to the PAS 68:2013 standard. The structure resembles cable guardrails but is designed to prevent unwanted or intentional penetration of vehicles into defined areas. Its application is primarily to ensure pedestrian protection in pedestrian zones, buildings, or other significant security targets. The goal of the tests was to assess how the obstacle resist impacts and whether it can absorb the energy exerted on it. Verification of the mechanical properties of the device was performed in two types of impact configurations. In the first case, a vehicle weighing $3.5\,\mathrm{tons}$ collided with a steel column, and in the second case, a vehicle of the same weight collided with steel cables connecting individual columns. Testing was carried out using the DEWESoft Krypton measurement system and additional sensors in the form of 3-axis accelerometers. In terms of monitoring the effects on the vehicle occupants, a Hybrid III crash test dummy was placed inside the vehicle. Emphasis was placed on the behavior of both the obstacle and the vehicle during the impact and in the short time interval after the collision. In terms of auxiliary criteria for evaluating the main purpose of impact tests, it can be stated that Test 2 exceeded the Theoretical Head Impact Velocity criterion by $20\,\mathrm{km}\cdot\mathrm{h}^{-1}$, while Test 1 did not exceed the limit value. However, all values for other criteria (ASI, PHD, HIC, 3ms) were within the specified limits, and the safety barrier met the required criteria.

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ASYNCHRONOUS TIME INTEGRATION WHILE ACHIEVING ZERO INTERFACE ENERGY

R. Dvořák [1] [2] , R. Kolman [3] , J. Falta [4] , M. Neühauserová [5]

Keywords: *Finite element method, Direct time integration, Asynchronous integration, Domain decomposition, Localized Lagrange multipliers*

Abstract

The paper deals with an asynchronous [1] direct time integration of the finite-element model. The proposed method is applied to the phenomenon of wave propagation through an elastic linear continuum. The numerical model is partitioned into individual subdomains using the domain decomposition method by means of localized Lagrange multipliers [2]. For each subdomain, different time discretizations are used. No restrictions for relation between subdomain's time steps are imposed. The coupling of the subdomains is forced by an acceleration continuity condition. Additionally, we use the a posteriori technique to also provide the displacement and velocity continuity at the interfaces, and hence we obtain exact continuity of all three kinematic fields. The proposed method is experimentally validated using the modified SHPB setup.

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