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S03 Experimental mechanics

List of abstracts

EXPERIMENTAL FIRE-EXPOSURE STUDY ON GLUE LAMINATED TIMBER AND WOOD-CFRP COMPOSITE BEAMS

Bartosz Kawecki[1], **Michał Pieńko**[1], **Tomasz Lipecki**[1], **Andrzej Stachowicz**[2]

[1] Wydział Budownictwa i Architektury, Politechnika Lubelska, Poland
[2] ABIES Polska sp. z o. o., Poland

b.kawecki@pollub.pl

The paper presents a complex solution for testing loaded structural-sized glue laminated timber and innovative wooden-composite beams exposed to local fire. It shows the entire procedure from predicting a static behaviour and a combustion time of the tested elements, designing and building an experimental stand, through conducting preliminary tests and discussing the results. The research included combustion of three glue laminated timber (BSH) and three wood-CFRP composite (BSH-CFRP) structural-sized beams in the most loaded section under three-point bending. A furnace was set under the centre of the beam on one-third of its span. The dimensions of the basket based on physical properties of firewood providing proper burning conditions of the elements. The self-designed and self-constructed experimental stand enabled applying high load and provided a stable loading during local fire exposure. The preliminary tests shows that using CFRP tapes inside the section may both increase or decrease a fire resistance of wooden members depending on the width of wood material covering CFRP tape. CFRP tapes provide a different nature of a beam failure, which is changing from sudden fracture (BSH) to plastic flow of the material (BSH-CFRP).

STUDYING DYNAMIC FRAGMENTATION OF METALLIC MATERIALS VIA AXIAL PENETRATION OF THIN-WALLED CYLINDERS

Juan Carlos Nieto-Fuentes[1], **Jose Antonio Rodriguez Martinez**[1]

[1] Continuum Mechanics and Structural Analysis, Universidad Carlos III de Madrid, Spain

junietof@ing.uc3m.es

Under extreme impact scenarios (e.g., sudden accidents in the aerospace, civilian-security, or automotive sectors), materials and structures are exposed to destructive conditions leading to a fatal failure. If one could control these catastrophic events, solid structures could be designed to delay/accelerate (i.e., control) failure, thus creating safer structures. Moreover, the necessity of minimizing the weight, improving the ductility and energy-absorbing capacity of structures, requires nowadays the use of advanced metallic materials, which could be efficiently created by additive manufacturing (AM) technologies. However, since previous studies have promoted the idea that defects control material failure in dynamic conditions, the inherent porosity of AM materials has questioned their applicability in structures subjected to extreme loads.

We have developed and demonstrated a novel high-velocity impact experiment to study dynamic fragmentation of AM metals. The experiment consists of a light-gas gun that fires a conical nosed cylindrical projectile that impacts axially on a thin-walled cylindrical tube fabricated by 3D printing. The diameter of the cylindrical part of the projectile is approximately two times greater than the inner diameter of the cylindrical target, which is expanded radially as the projectile moves in, leading to the formation of multiple necks that eventually develop into fractures. The experiments have been performed for impact velocities ranging from 150 to 400 m/s leading to strain rates in the cylindrical target that vary between 10000 to 25000 s-1. The cylindrical samples tested are printed by Selective Laser Melting out of aluminum alloy AlSi10Mg, with two different outer diameters, 12 and 14 mm, and two different wall thicknesses, 1 and 2 mm. A salient feature of this work is that we have characterized by X-ray tomography the porous microstructure of selected specimens before testing. Two high-speed cameras have been used to film the experiments and obtain time-resolved information on the nucleation of necks and on the formation and speed of propagation of fractures. Moreover, fragments ejected from the samples have been recovered, measured, weighted, and analyzed using X-ray tomography, so that we have obtained indications for the three materials tested of the effect of porous microstructure, specimen dimensions and loading velocity on the number of necks and on the distribution of fragment sizes.

DAMAGE ACCUMULATION MODELING OF EN AW 2024 T3 ALUMINIUM ALLOY AT ELEVATED TEMPERATURE

Anna Falkowska[1], **Andrzej Seweryn**[2]

[1] Faculty of Mechanical Engineering, Bialystok University of Technology, Poland
[2] Faculty of Mechanical Engineering and Ship Technology, Gdansk University of Technology, Poland

a.falkowska@pb.edu.pl

The purpose of the paper was to conduct experimental tests and to develop a damage accumulation model for the aluminium alloy under uniaxial low cycle at elevated temperatures. For this purpose, the technical aluminium alloy EN AW2024T3, designed especially for application in the aerospace industry, was used. Before fatigue testing, monotonic tensile tests were carried out on the specimens at different temperatures: 25℃, 100℃, 200℃, 300℃. As a result of the tests, monotonic tensile curves were obtained and basic strength parameters were determined.

After analysing the strength properties of the aluminium alloy tested at different temperatures, fatigue life tests were carried out. The tests were carried out at the same temperatures. Different values of strain amplitude were used. The hysteresis loops obtained were analysed on the basis of the tests carried out. Fatigue life curves were also developed for EN AW2024 T3 aluminium alloy samples tested at elevated temperatures. The effect of applied temperature on the change of fatigue life of this material was determined. Additionally, based on the obtained results, a model of the fatigue accumulation of the aluminium alloy was developed. The fatigue breakthroughs of the test specimens were carefully verified on a scanning electron microscope. The change of the structure of the tested material depending on the applied temperature during low-cycle fatigue tests was analysed.

EXPERIMENTAL TESTS AND NUMERICAL ANALYSIS OF THE TRUSS WITH COMPRESSED BOTTOM CHORD

Marcin Krajewski[1]

[1] Department of Structural Mechanics, Gdansk university of technology, Poland

markraje@pg.edu.pl

In lightweight metal structures, the upward wind loading may cause compression in the bottom chords of trusses. In such cases the absence of braces required to provide lateral stability of a truss may be decisive for structural failure. The present design codes include no information on effective buckling length of a bottom truss chord or a required brace stiffness in order to ensure that out-of-plane buckling occurs between the braces. Proper selection of brace location and translational or rotational stiffness may substantially affect structural stability and load-bearing capacity.
The paper is focused on an experimental test of the steel model of the truss subjected to upward loading. The structure was braced and loaded at three top chord joints. Pinned or rigid connections between the truss and the bracing members were taken into consideration. In the research the bottom chord was stiffened by translational elastic braces. During the loading the in-plane and out of plane structural deformations were measured.
The experimental test results were compared to the results of numerical analysis performed assuming the beam and shell structural models. The buckling load resulting from linear buckling analysis or the limit load based on non-linear analytical results assuming an imperfect truss model were compared to the loading obtained in the experiment. The buckling load was also appointed for the compressed bottom chord supported by elastic foundation as a replacement for the spatial truss structure.
Based on the numerical analysis results one can conclude that there was the threshold minimum brace stiffness that ensures the maximum capacity of the truss.

EXPERIMENTAL INVESTIGATIONS OF ALUMINUM MOBILE SCAFFOLDING

Michał Pieńko[1], Ewa Błazik-Borowa[1], Artur Ciebień[2]

[1] Lublin University of Technology, Poland
[2] MPC METAL Spółka z o.o., Poland

m.pienko@pollub.pl

The purpose of this work was to verify the correctness of the adopted design solutions of the mobile scaffolding made of aluminum alloys. Laboratory tests included tests of the entire scaffolding structure as well as tests of individual components. The main test was the study of the stiffness of the structure carried out on a complete set with a height of 6 m. The scaffolding was horizontally loaded using a proprietary solution in the form of a block system and water tanks. The structure was loaded in the perpendicular, parallel direction. As the scaffoldings are temporary structures, the task of which is to ensure safety during the work, tests were also carried out on the side protections that protect workers against falling from a height. The guardrails were loaded both vertically and horizontally. The handrail system has asymmetrical joints, therefore the load was applied both downwards and upwards, and to the inside and outside of the working platform. The toe-boards, which are part of the side protection, were also tested. The working platform is the element directly loaded by users of the scaffolding, therefore, as part of the laboratory tests, the platforms were loaded with a uniformly distributed load and a concentrated load. The concentrated load was applied in 5 different locations of the deck on the area of 0.2m x 0.2m and 0.5m x 0.5m, respectively.

In order to create a numerical model representing the behavior of the structure, it is necessary to obtain information on the nature of the connections. In the considered mobile scaffolding system, there are both detachable joints and fixed (welded) joints. The joint tests included 4 types of connections: snap connections, screw connections (clamps), pin connections and welded connections. Each of the above-mentioned tests was carried out to full destruction, which made it possible to identify and indicate the sensitive areas in which the destruction occurred. Since the connection of the pipe and the coupler is obtained by crimping the pipe, the conducted tests allowed for the verification of such a solution.

Comprehensive laboratory tests included 15 different forms of load. Over 100 tests have confirmed the correctness of the adopted design solutions in the analyzed aluminum mobile scaffolding. The destruction of the welded joint took place in the heat affected zone, while in the case of detachable connections, the coupler cracked. The obtained results can be used to create a numerical model of the entire mobile scaffolding structure.

ANALYSIS OF MECHANICAL BEHAVIOR OF MICRO SPECIMEN USING MICRO DIC METHOD AND NUMERICAL SIMULATIONS

<u>Grzegorz Kokot</u>[1], Tomasz Rusin[2]

[1] Department of Computational Mechanics and Engineering, Silesian University of Technology, Poland
[2] Dantec Dynamics GmbH, Germany

grzegorz.kokot@polsl.pl

Studying the mechanical behaviour of microelements at the microscale is difficult mainly due to the small dimensions and the difficulty in measuring displacements and deformations. This article presents contemporary possibilities of micro-testing and simulation of structural elements used in micromechanisms. The study examined the image correlation technique, in particular its variant applied in the microscale range. The research problem will be presented with an example of micro-tests performed for a micromechanism element. Experimental tests are carried out in the form of micro-tensile and micro-bending testing combined with a high-resolution optical microscope and DIC. Specific methods of sample preparation for tests related to the non-contact optical measurement technique and tests preparation will be presented. The results obtained in the form of color maps of displacement and strain distribution in selected parts of the element were compared with the results of numerical simulations of experimental tests. The experimental results and numerical simulations confirm that the micro-testing system built with a testing machine and an optical microscope can be successfully applied to measure the full-filed strain and mechanical properties of small-scale specimens.

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INFLUENCE OF LOCAL CORE DEFORMATIONS ON THE LOAD-BEARING CAPACITY OF SANDWICH PANELS

Monika Chuda-Kowalska[1], **Michał Malendowski**[1], **Zbigniew Pozorski**[1]

[1] Institute of Structural Analysis, Poznan University of Technology, Poland

monika.chuda-kowalska@put.poznan.pl

Polymer foams are widely used in various areas of engineering. In this paper, sandwich panels composed of thin metal sheets and a thick foam core are considered. When analyzing this type of sandwich panels, despite the rather complex foam structure, it is usually assumed that the core material is homogeneous and isotropic or orthotropic. The conducted experimental studies show that the core is heterogeneous. It is possible to use averaged material parameters, which quite well reflect the global behavior of the panels. Difficulties arise when local effects play a significant role, such as in the case of wrinkling of metal facing, where the stiffness of the core directly adjacent to the facing is decisive.

This paper deals with the problem of the behavior of bent, multi-span sandwich panels. At the intermediate support core shear and compression of the core as a result of interaction with the support is observed. The mechanical state of the core is very complex, and the core deformation depends on the material parameters. Moreover, the deformation of the core causes local bending of the facing which ultimately damages the panel.

The aim of the paper is to determine the influence of core deformation on the load-bearing capacity of a sandwich panel. For this purpose, a 3-line bending test of the panel is performed, in which the load is transferred by a steel beam of different width. The action of this beam simulates the action of an intermediate support on a multi-span panel. Panels with a span of 5 m and 3 m are analyzed. The panels are 100 mm thick and came from the same production batch. The obtained results clearly show that the higher stresses under the loading beam lead to faster failure of the panel.

Another goal of the work is to develop an advanced numerical model reflecting the observed phenomena. This model should include, inter alia, the experimentally measured variability of Young's modulus over the core thickness. Due to the porous structure of the foam, the use of classic strain gauges in experiments is impossible. Therefore, contactless, Digital Image Correlation (DIC) technique is applied. Basic material parameters are determined by means of compression, tensile and shear tests. Next, numerical analysis of full-scale panels in bending are carried out to determine the behavior of sandwich panel under the load. The geometric imperfections and imperfections related to the applied load are taken into account in the model. The numerical simulations are compared to the experimental results and the relevant conclusions are presented.

EXPERIMENTAL STUDY OF STRUCTURAL ACOUSTIC FLOWS IN OPEN-ENDED CIRCULAR AND SQUARE WAVEGUIDES

Stefan Weyna[1]

[1] West Pomeranian University of Technology in Szczecin, Poland

weyna@zut.edu.pl

It is of particular importance for supplementing acoustic knowledge with new, so far unknown from experimental studies, descriptions of acoustic energy transport in a real medium. The new knowledge arising from the study of vector characteristics of acoustic waves suggests that the paradigm of classical acoustics should be changed, because it is not from the analysis of sound pressure that one should start the description of the origin of sound, but from the analysis of "mechanical vibrations of an elastic medium"- exact definition of sound. The role of oscillatory motion of particles in solids, liquids and gases is the overriding physical phenomenon causing the sound effect.
Investigations of the acoustic wave vector parameter, i.e. sound intensity, make it possible to record images of reflection, refraction of wave scattering on obstacles, generation of sound inside waveguides, description of the mechanism of sound and noise radiation through vibrating surfaces, evaluation of structural forms of acoustic field, effectiveness of acoustic barriers and screens, etc. We can now see the invisible acoustic effects of wave reactions. The metrological validity check of the innovative SI-AOD analytical techniques (oun-developed methods) will be documented in the paper.
Such a direct study of the energetic effects of an acoustic wave could not be carried out using the classical method of measuring sound pressure, a scalar acoustic wave parameter. An additional advantage of acoustic vector investigations are possibility to SI-AOD validation of numerical modelling results in fluid mechanics (in CFD, FSI, CAA platforms), where reliable results of vector acoustic wave parameters measurements, obtained from tests conducted on real models, are the reference point.
The paper will present results of orthogonal decomposition of SI flux in circular and square channels. The problem is reduced to 2D and 3D graphical visualisation of acoustic vector fields and distinction of coherent and modal structures occurring in the audible frequency ranges as well as demonstration of the wave motion in the whole waveguide cross-section (3D animations). The results of the research introduce new knowledge into classical acoustics, not yet known from research using traditional methods. The innovative SI-AOD research allows to better understand the complexity of turbulent perturbed flows and, in the validation process, to relate the theoretical assumptions of acoustic aeroacoustic flows (VST) to experimental results.

ELASTIC WAVE APPLICATION FOR DAMAGE DETECTION IN CONCRETE SLAB WITH GFRP REINFORCEMENT

Dominika Ziaja[1], Michał Jurek[1], Agnieszka Wiater[2]

[1] Department of Structural Mechanics, Rzeszow University of Technology, Poland
[2] Department of Roads and Bridges, Rzeszow University of Technology, Poland

dziaja@prz.edu.pl

Concrete is a very popular construction material, applied in many structural members. Due to its properties, in many cases, the application of reinforcement is necessary. Despite the use of reinforcement in concrete structures, cracks appear, but the exact prediction of crack appearance and its further propagation path is impossible, because of the inhomogeneous structure of this material.

Control of cracking in reinforced concrete is important for many reasons, e.g. aesthetic, or to prevent water leaking. The load-bearing elements, in which cracks have appeared should be regularly examined in detail, because cracks of large width and height may be a signal of deterioration of the structure's condition.

Crack opening measurements are performed manually during periodic or ad hoc inspections. Typical tools used for this purpose are feelers or fracture width measuring instruments. Application of these tools requires manual control made by the appropriate person. An alternative to traditional methods is using non-destructive testing (NDT). One of them is the elastic wave propagation measurement, which was applied in a presented task, in connection with artificial intelligence for the determination of alarm level of crack opening in concrete slab with GFRP (Glass Fibre Reinforced Polymer) reinforcement.

As a specimen, a deck plate made of concrete with the target C30/37 class under three-point bending was selected. The slab specimen was 3 m long, 1 m wide, and 180 mm thick, which corresponds to the typical dimensions of a road bridge deck slab supported on prestressed concrete or steel beams. The concrete slab was reinforced with 10mm diameter solid GFRP bars with spiral ribbing. The average values of the tensile strength (1000 MPa) and modulus of elasticity (55 GPa) for the bars were determined experimentally using the ISO 10406-1 standard.

During the examination, the specimen was loaded in eight cycles with bigger and bigger force and observed with a digital image correlation (DIC) system (strain field observation), a set for elastic wave measurements based on signals recorded with PZT (lead zirconate titanate) sensors, as well as typical crack opening measurements. The changes in the shape and the amplitude of the registered signals caused by the appearance of the crack and its growth were observed. For damage detection, artificial neural networks (ANN) were applied. The reason for using ANN was the fact that the changes were not obvious and depended on the location of the sensors and the strain/stress state.

ANALYSIS OF CRACKING EVOLUTION AND FRACTURE ENERGY CHANGE OF STEEL FIBER-REINFORCED CONCRETE

Iwona Pokorska[1], Mariusz Poński[2], Wojciech Kubissa[3], Tomasz Libura[1], Adam Borecki[1], Zbigniew Kowalewski[1]

[1] Institute of Fundamental Technological Research Polish Academy of Sciences, Poland
[2] Desigma Engineering (civil engineering company), Poland
[3] Civil Engineering, Warsaw University of Technology, Faculty of Civil Engineering, Mechanics and Petrochemistry, Poland

ipokorsk@ippt.pan.pl

The fracture mechanics defines concrete as a quasi-brittle material. Concrete cracking process is a common problem, because a period to the first micro-cracks may occur even before it is loaded. This is due to the loss of moisture from the concrete. The production method, admixtures, porosity, hardening conditions, maximum aggregate size, etc., as well as its inherent disadvantages are the main reasons that the process of cracks formation in concrete and their subsequent growth up to failure is complex. The usage of fracture mechanics helps to better understand this process.
Probabilistic fracture mechanics (PFM) is becoming more and more popular for realistic assessment of the fracture response and reliability of structures. However, the application of stochastic nonlinear computational mechanics to real world applications faces a major impediment as detailed information is lacking on the stochastic properties of the material parameters related to the problem.
The paper presents the results of analysis concerning an evolution of the fracture process developing in the fibro-concrete specimens subjected to several types of mechanical tests. The results elaborated in the form of probability distributions and force - CMOD curves enabled to check suitability of the stochastic constitutive models with special emphasis of taking into account the random nature of the parameters describing the material tested and the analysis of cross-correlation of these parameters.
For experimental research mixture of 380 kg/m3 cement by 0.44 w/c ratio was prepared. Fraction of river sand of 0-2 mm and natural gravel fraction of 2-8 mm were used. The sand point was established to be SP=37% that allowed the aggregate grading curves to fit between the boundary curves. Superplasticizer Atlas Duruflow PE-220 and VMA admixture Atlas Duruflow VM-500 were used according to PN-EN 934-2. Steel fibers of 0.8 mm diameter and 40 mm length were used. The compressive strength tests were conducted on 100 mm cubic specimens after either 28 or 134 days of hardening. The tests were carried out in accordance with PN-EN 12390-3 by using a ToniTechnik instrument of 3000 kN compression force capacity. The flexural strength tests were conducted on the beams with dimensions of 500x100x100 mm after 134 days of hardening. The tests were carried out in accordance with PN-EN 12390-5 by using a Matest instrument of 300 kN compression force capacity. The rate of loading was maintained at 0.5 MPa/s for compressive strength tests and at 0.05 MPa/s for tensile splitting strength tests.

YIELD SURFACE IDENTIFICATION OF TITANIUM ALLOY AND ITS EVOLUTION REFLECTING COMPLEX PRE-DEFORMATION

Ved Prakash Dubey[1], Mateusz Kopec[1], Zbigniew Kowalewski[1]

[1] Department of Experimental Mechanics, Institute of Fundamental Technological Research, Polish Academy of Sciences, Poland

vdubey@ippt.pan.pl

Mechanical tests of materials generally performed under simple stress conditions do not simulate real-world stress conditions that can occur in most engineering applications. The characterization of materials using only uniaxial testing methods provides only limited data, that are not sufficient to identify all aspects of their behaviour like a texture or anisotropy coming from the manufacturing processes used to produce them [1]. Titanium and its alloys have been widely used in significant engineering disciplines such as medical devices, aerospace, and marine engineering, due to their high specific strength, corrosion resistance, high impact resistance, and other properties [2]. Therefore, this article presents an experimental investigations identifying the physical mechanisms responsible for the plastic deformation resulting from the complex mechanical loading and initiation and subsequent propagation of micro-cracks from inherent defects in the titanium metal.

Complex loading tests were performed on tubular specimens under simultaneous application of axial force and torque to produce axial and shear stresses. Material characteristics of pure titanium in the form of stress-strain show decrease in yield limit or increased inelastic response under simultaneous loading executed by the axial tension and proportional cyclic torsion. Subsequently, the effect of prior plastic deformation induced by cyclic torsion and monotonic tension on the shape and size of yield surface has been studied. Yield surfaces were determined by the technique of sequential probes of the single specimen along 17 different strain-controlled paths in the plane stress state. It was found, that material in its as-received state exhibits anisotropic behaviour for the defined plastic offset strain. Such an effect could have come from either the bimetal production, or specimen manufacturing process applied. Furthermore, the yield surface sizes of the material in the pre-deformed state are reduced in all directions, except of that representing axial tension.

References:
[1] Socha, G. (2004). Prediction of the fatigue life on the basis of damage progress rate curves. International Journal of Fatigue, 26(4), 339-347.
[2] Alipal, J., Pu'Ad, N. M., Nayan, N. H. M., Sahari, N., Abdullah, H. Z., Idris, M. I. and Lee, T. C. (2021). An updated review on surface functionalisation of titanium and its alloys for implants applications. Materials Today: Proceedings, 42, 270-282.

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EXPERIMENTAL INVESTIGATION OF AN INDIRECT FREE COOLING SYSTEM INCLUDING A DRY COOLER EQUIPPED WITH EVAPORATIVE COOLING PADS FOR DATA CENTER

Mohamad Hnayno[1], **Ali Chehade**[2], **Chadi Maalouf**[1], **Guillaume Polidori**[1]

[1] MATIM, Universite de Reims Champagne-Ardenne, France
[2] Company, OVHcloud, France

mohamad.a_hnaino@hotmail.com

Cooling systems in data centers (DCs) represent the largest portion of total electrical consumption after Information Technology equipment. Workload of heat rejection systems used to evacuate the heat of DC to the exterior ambience can be significantly reduced by appropriate utilization of on-site available free cooling. The dry coolers play an important role in DC cooling systems. External air is used to cool the liquid being pumped from DC without resorting to a refrigeration process. In ambiences where dry coolers ambient temperatures are higher than liquid cooling supplied temperature, evaporative cooling (EC) can be used as pre-coolers. This paper presents an experimental investigation conducted on a dry cooler equipped with evaporative cooling pads for high outdoor conditions, variable fan speed, reduction in cooling pad’s surface and increasing in water supply temperature.
The dry cooler is successfully operated under 20 K data center temperature difference for air intake temperature range from 38 °C to 42 °C at relative humidity ratios less than 20%. Besides, cooling pad shows a stable thermal efficiency between 88 and 90%. Fan speed variation from 50% to 100% RPM show that pads' outlet temperature increases with the increase of fans rotation speed. The total growth is of 0.6 K whereas the relative humidity tends to decrease about 9%. Moreover, the efficiency is higher at low speeds due to the better contact of air with pads' water. A test simulating the suction of 20 leaves is conducted. Cooling pad's outlet relative humidity decreases about 5%, while dry cooler's water return temperature increases about 1 °C and cooling pad's thermal efficiency decreases 6% with respect to without any clogging of pad's surface case. Some modifications conducted on the test apparatus to highlight the impact of EC supplied water temperature on the cooling performance. A plate heat exchanger connected to the boiler is placed on the pads' water supply circuit to variate EC water pumped temperature. Water temperature supplied to the pads is varied from 23 °C to 44 °C. A slight rise of 1.24 K in air outlet temperature and a decrease of about 3.3% and 2.5% in relative humidity and cooling pad thermal efficiency respectively were observed as the water temperature increased up to 44 °C. Consequently, an optimized system with precooling data center supply water is proposed to reduce its cooling demand by at least 31%.