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Book of Abstracts

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Welcome Address

The abstracts collected in this book represent the proceedings of the conference MECHCOMP7 (7th International Conference on Mechanics of Composites) , 1-3 September 2021. This book aims to help you to follow this Event in a timely and organized manner. Papers are selected by the organizing committee to be presented in virtual/phisical format. Such arrangement is due to the effects of the coronavirus COVID-19 pandemic. The event, held at FEUP-Faculty of Engineering, University of Porto (Portugal), follows the success of the first six editions of MECHCOMP. As the previous ones, this event represents an opportunity for the composites community to discuss the latest advances in the various topics in composite materials and structures.

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Contents

Welcome Address iii

Abstracts 1

Advanced Numerical Techniques 1

Functionally graded oxygen-rich metal films and their production on metal and ceramic bases using induction PVD technique (*Fomin, Aleksandr; Fomina, Marina; Koshuro, Vladimir*) 1

HOHWM for free vibration analysis of FGM nanobeams (*Majak, Jüri; Karjust, Kristo; Pohlak, Meelis; Eerme, Martin; Ratas, Mart*) 1

Molecular investigation on carbon fiber-epoxy matrix interface under sustained load conditions (*Tam, Lik-ho; Jiang, Jingqiao; Zhou, Ao; Hao, Huali; Wu, Chao; Yu, Zechuan*) 2

Numerical investigation on microscopic mechanisms of mode I fracture of composite laminate using different modelling techniques (*Song, Peihao; Hu, Haixiao; Cao, Dongfeng; Li, Shuxin*) 2

Anchor bolts for load introduction into cross-sectional faces of thick fiber-polymer composites: Investigation of the laminate layup (*Klein, Jens; Lessing, Vincent; Schürmann, Helmut; Mittelstedt, Christian*) 3

Static analysis of isotropic and orthotropic composite triangular plates by geometric transformation method (*Civalek Ömer; Ersoy Hakan; Mercan Kadir*) 4

Microstructure-Free Finite Element Modeling of Representative Volume Element for Elasticity Design of Random Particulate Composites (*Luo, Yunhua*) 4

Use of Artificial Neural Networks to Optimize Stacking Sequence in UHMWPE Protections (*Peinado, Jairo; Jiao-Wang, Liu; Olmedo, Álvaro*) 5

Chemo-Thermomechanical Simulation of an Epoxy Resin System in Composites using Time-Adaptive Finite Element Simulations (*Leistner, Chris; Hartmann, Stefan*) 5

Experimental tests and correlation of constitutive model with optimization procedure for reliable numerical modeling of failure in 3D printed composites (*Kucewicz, Michal; Mazurkiewicz, Lukasz; Tomaszewski, Michal; Baranowski, Pawel; Malachowski, Jerzy; Platek, Pawel*) 5

INVERSE DIFFERENTIAL QUADRATURE METHOD FOR BUCKLING ANALYSIS OF COMPOSITE PLATES (*Khalid, Hasan M.; Ojo, Saheed O.; Weaver, Paul M.*) 6

Research on impact performance of vehicle impact buffer device based on honeycomb composite function gradient (*Shuangyan Ju; Dian Wang; Yunfei Qu*) 6

DEVELOPMENT OF A NUMERICAL METHODOLOGY FOR THE SIMULATION OF THE FATIGUE INDUCED DELAMINATION IN COMPOSITE STRUCTURES (*Russo, Angela; Sellitto, Andrea; Saputo, Salvatore; Acanfora, Valerio; Riccio, Aniello*) 7

Axisymmetric response of FG-CNTRC circular plates subjected to step thermal shocks (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 7

Two-dimensional thermally induced vibration of cylindrical panels reinforced with functionally graded CNTs (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 8

Thermal buckling and post-buckling analyses of rotating Timoshenko beams reinforced with graphene platelet (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 8

Vibration characteristics of the embedded multi-scale GO/CF hybrid nanocomposite shell containing a viscous fluid flow (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 9

Moving load analysis on cross/angle-ply laminated composite nanoplates resting on viscoelastic foundation (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 10

Forced resonance analysis in advanced polymeric nanocomposite plate surrounded by an elastic medium (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 10

Size-Dependent Free Vibration Analysis of Honeycomb Sandwich Microplates Integrated with Piezoelectric Actuators Based on the Modified Strain Gradient Theory (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 11

Modified Couple Stress Theory Application to Analyze Mechanical Buckling Behavior of Three-layer Rectangular Microplates with Honeycomb Core and Piezoelectric Face Sheets (*Arameh Eyvazian; Chunwei Zhang; Afrasyab Khan; Tamer A. Sebaey*) 11

Linear piezoelectric material modelling with Peridynamics (*Vieira, Francisco S.; Araújo, Aurélio L.*) 12

A novel data-driven computing algorithm for strong nonlinear response simulation of thin-walled composite structures (*Bai, Xiaowei; Yang, Jie; Hu, Heng*) 12

Applications of Composites 14

A Formalized Selection of Composite Materials for Application on Large Power Transformer Tank (*Williams, Babajide; Hoffman, Joe; Predecki, Paul; Kumosa, Maciej*) 14

A design procedure of a structural device for vibroacoustic measurements in a wind tunnel facility (*Mazzeo, Giulia; Ichchou, Mohamed; Petrone, Giuseppe; Bareille, Olivier; De Rosa, Sergio; Franco, Francesco*) 14

Improving electrical, mechanical, adhesion properties of composite materials by surface modification (*Choe, Jaeheon; Lim, Jun Woo*) 14

Hydrothermal treatment based on the sulfonic species for improved efficiency of the carbon felt electrodes for the vanadium redox flow battery (*Kaur, Amanpreet; Lim, Jun Woo*) 15

Development of carbon felt electrode integrated composite bipolar plate (*Kaur, Amanpreet; Lim, Jun Woo*) 15

Effect of extrusion on microstructures and mechanical properties of in situ Al2O3/Al-Si composites fabricated by reactive sintering. (*El Oualid MOKHNACHE; Geng Ling; Guisong Wang*) . . . 16

Auxetic materials and structures . . . 17

Auxetic structure with tri-directional symmetry (*Logakannan, Krishna Prasath; Ruan, Dong; R, Velmurugan; R, Jayaganthan*) . . . 17

Multifunctional heating film of thermoplastic composite joints and its induction welding performance (*Lee, Daesung; Jung, Jaehyung; Choe, Hyeonseok; Kweon, Jinhwe; Nam, youngwoo*) . . . 17

PERFORMANCE OF AUXETIC CORE 3D PRINTED SANDWICH STRUCTURES UNDER ACOUSTIC AND SHOCK WAVES (*TURKOGLU, İBRAHİM KÜRŞAD; GÜÇLÜ, HARUN; YAZICI, MURAT*) . . . 18

Honeycomb sandwich structures made with cork (*Esteves, Mafalda; Rede, Francisco; Nóvoa, Paulo; Marques, António*) . . . 18

Beam, Plate and Shell Theories and Computational Models for Laminated Structures 20

Influence of the excitation direction on the dynamics of the laminated beam with symmetrical or anti-symmetrical layers arrangement (*Bochenski, Marcin; Borowiec, Marek; Gawryluk, Jaroslaw; Teter, Andrzej*) . . . 20

Influence of Composite Ply Sequence on Nonlinear Dynamics of a Hinged Beam Structure: numeric vs experimental investigation (*Borowiec, Marek; Kloda, Lukasz; Bochenski, Marcin*) . . . 20

Semi-analytical assessment of free-edge stress fields in circular cylindrical cross-ply laminated shells subjected to hygrothermomechanical loads (*Kappel, Andreas; Mittelstedt, Christian*) . . . 21

Free vibration analysis of tow-steered composite laminates by novel quasi-3D hierarchical models (*Yan Yang; Liu Bo*) . . . 21

Non-conventional 1D and 2D curvilinear finite elements based on CUF for the analysis of very complex geometries (*Cinefra, Maria*) . . . 22

Flexural analysis of laminated beams using zigzag theory and a mixed inverse differential quadrature method (*Trinh, Luan C.; Ojo, Saheed O.; Groh, Rainer M.J.; Weaver, Paul M.*) . . . 22

Propagation of guided waves in two dimensional quasicrystal multilayered plates with imperfect interfaces (*Feng, Xin; Zhang,Liangliang*) 23

A mathematical model for the specific gas sensor based on the oscillations of functionalized carbon nanotubes (*Nicolescu, Adrian Eracle*) 24

Accurate stress fields evaluation of post-buckled laminated composite plate structures with various geometrical and mechanical boundary conditions (*Daneshkhah, Ehsan; Augello, Riccardo; Carrera, Erasmo*) 24

VIBRATIONS AND BUCKLING OF COMPOSITE PLATES BASED ON STRAIN GRADIENT THEORY AND MESHLESS METHODS (*Saitta, Serena; Fabbrocino, Francesco; Vescovini, Riccardo; Fantuzzi, Nicholas*) 25

Numerical Model for Global/Local Buckling Analysis of I-Beam via Hierarchical One-Dimensional Finite Elements (*Yang, Yichen; Hui, Yanchuan; Yang, Jie; Hu, Heng*) 25

Natural Element Hierarchic Models for Laminated Composite Plates (*Cho, Jin-Rae*) 26

Large-deflection analysis of composite and FGM thin-walled beams under thermal pre-stresses. (*Carrera, Erasmo; Filippi, Matteo; Augello, Riccardo; Demirbas, Munise Didem*) 26

Composite Structures 28

Novel method for interlaminar reinforcement with no reduction of in-plane properties (*Moses, William; Dooher, Thomas; McIlhagger, Alistair; Archer, Edward*) 28

Effect of Eccentric Loading on the Stability and Load-Carrying Capacity of Thin-Walled Composite Profiles with Top-Hat Section (*Rozylo, Patryk; Debski, Hubert*) 28

Stability and Limit States of Thin-Walled Composite Profiles Subjected to Eccentric Load (*Debski, Hubert; Jonak, Jozef*) 29

Evaluation of stress distributions in the geometrical nonlinear regime of composite and FG structures by means of CUF (*Demirbas, Munise Didem; Augello, Riccardo; Xian Yang, Xu; Carrera, Erasmo*) 29

Time dependent spring-in of pultruded L-shaped profile (*Safonov, Alexander; Vedernikov, Alexander; Carlone, Pierpaolo; Tucci, Fausto; Akhatov, Iskander*) 29

On the axial and oblique impact response of an origami composite crash box: an approach to design crashworthiness (*Ciampaglia Alberto; Fiumarella Dario; Boursier Niutta Carlo; Ciardiello Raffaele; Belingardi Giovanni*) 30
Experimental and Numerical Analysis of Stability and Failure of Compressed Composite Plates (*Falkowicz Katarzyna; Rozylo Patryk; Ferdynus Miroslaw*) 31
Buckling state analysis of compressed composite plates with cut-out (*Wysmulski Pawel; Falkowicz Katarzyna*) 31
Effect of Fabric Parameters on Process-Induced Residual Deformation of Plain Woven Composite Structures (*Kim, Dong-Hyeop; Kim, Sang-Woo*) 31
STF-impregnated Fabric Composite Structures for Enhanced Damping Characteristics (*Lim, Jaehyeong; Kim, Sang-Woo*) 32
Behavior of FRP-confined FRP Reinforced Concrete Square Columns (FCFRCs) under Axial Compression (*Jun-Jie Zeng; Wen-Kai Lin; Jie-Kai Zhou*) 32
DESIGN GUIDELINES FOR COMPRESSION BUCKLING OF COMPOSITE CYLINDRICAL SHELLS ON ELASTIC FOUNDATIONS (*Ansari, Mohammad; Zucco, Giovanni; Trinh, Luan; Weaver, Paul*) 33
Study of the tensile fatigue behaviour of hybrid flax/glass fibre-reinforced epoxy composites (*Amirouche Goumghar; Mustapha Assarar; Wajdi Zouari; Krimo Azouaoui; Abderrahim El-Mahi; Rezak Ayad*) 33
Initial Approach to Development of New Composite Made Fully of Recycled Material (*Miedzinska, Danuta; Poplawski Arkadiusz; Zasada, Dariusz; Latko-Duralek, Paulina; Spychala, Maciej*) 34
Time-domain asymptotic homogenization for linear-viscoelastic composites: mathematical formulation and finite element implementation (*Zhai, Hongzhou; Wu, Qi; Yoshikawa, Nobuhiro; Xiong, Ke; Chen, Changhao*) 35
Tribological behavior of functionally graded unidirectional glass fiber reinforced epoxy composite: Effect of fiber orientation (*Alhazmi, Waleed; Jazaa, Yosef; Althahban, Sultan; Mousa, saeed; Sallam, Hossam Al-Din; Abd-Elhady, Amr*) 35
Manufacturing Hybrid Lightweight Structures in Fiber Metal Laminates (*Sapli, Hüseyin; Homberg, Werner; Heggemann, Thomas*) 35

Study of thermally insulated pair of collinear interfacial cracks parallel to a third interfacial crack situated in a composite medium (*Das, Subir; Tanwar, Anshika; Singh, Ritika; Craciun, E-M; Altenbach, Holm*) 36

Shape Distortions in Hybrid Composite Laminates (*Makinde, Olumide Mayowa; Alfredo Rocha de Faria; Maurício Vicente Donadon; Paul Olugbeji Jemitola*) 36

Structural shape and 3D printing design for continuous carbon fibre reinforced composite parts (*Chen Yuan; Ye Lin*) 36

Multi-level Optimization of Variable-Stiffness Shells with Cutouts based on Isogeometric Analysis (*Wang Yu; Hao Peng*) 37

THE EFFECTS OF DILATANCY IN COMPOSITE ASSEMBLIES AS MICROPOLAR CONTINUA (*Shi, Farui; Fantuzzi, Nicholas; Li, Yong; Trovalusci, Patrizia*) 37

Effect of hydrothermal environment on single-lap shear strength of induction welded CF/PEKK thermoplastic composites (*Jae-hyeong Jeong; Dae-sung Lee; Jin-hwe Kweon; Young-woo Nam*) 38

UHF microwave absorbing hybrid folded core sandwich composite structure (*Kim, Min-Jun; Choi, Won-Woo; Hong, So-Mang; Lee, Keung-In; Choi, Won-Ho; Kweon, Jin-Hwe; Nam, Young-Woo*) 39

Impact behavior of radar absorbing quartz/PEEK folded core sandwich composite structure dispersed with MWNTs (*Lee, Keung-In; Kim, Min-Jun; Choi, Won-Ho; Kweon, Jin-Hwe; Nam, Young-Woo*) 39

Design of radar absorbing structure with cobalt coated quartz fiber/aluminosilicate composite for ultra-high temperature microwave absorption (*Won-Woo Choi; Hyun-Seok Ko; Min-Jun Kim; So-Mang Hong; Joon-Hyung Shin; Jin-Hwe Kweon; Young-Woo Nam*) 40

Prediction of fatigue life in composite wind turbine blade using Miner and Strength-based model (*Kazemi Vanhari, Afrooz; Fagan, Edward; Goggins, Jamie*) 41

Topology Optimization strategies for continuous fiber-reinforced and functionally graded anisotropic composite structures: A brief review (*Gandhi, Yogesh; Minak, Giangiacomo*) 41

Self-Reinforced Polyethylene Composites with Gamma-Irradiated Dyneema Fibers (*Molnár, Kolos; Kara, Yahya; Somoskői, Balázs; Tatár, Balázs; Mészáros, László*) . . . 42

Dynamic behavior of three dimensionally printed functionally graded foams (*Bonthu, Dileep; Doddamani, Mrityunjay*) 42

A novel concept for realizing multi-stable periodic FRP structures (*Risso, Giada; Sakovsky, Maria; Ermanni, Paolo*) 43

Design of a Type III Pressure Vessel Considering Through Thickness Stress Gradient and Experimental Validation (*Talebi Cihan; Özaslan Emre; Ali Yetgin; Bülent Acar*) 43

Homogenization of shape memory polymer composite based nonperiodic corrugated structure (*Saurav, AK; Mujumdar, PM; Guruprasad, PJ*) 44

Dynamic stability of thin-walled FML profiles with implemented delamination (*Zaczynska, Monika; Mania, Radoslaw*) 44

Design and Testing of a CFRP Frame for an Innovative Railway Running Gear (*Anton Shipsha; Rocco Libero Giossi; Rickard Persson; Per Wennhage; Sebastian Stichel*) 45

Composite structures in civil engineering 46

Strength, toughness and microstructure of high performance concrete reinforced with steel-polypropylene hybrid fibers (*Smarzewski, Piotr*) 46

Ultimate Strength of Web-Flange Junction in Pultruded Composites: A Random Lattice Modeling Investigation (*FEO, Luciano; PENNA, Rosa; FASCETTI, Alessandro; ZHU, Yingbo*) 46

Compressive behavior of FRCM strengthened pre-damaged columns (*Abed, Farid; Alhoubi, Yazan; Abed, Farid; ElRefai, Ahmed; Maaddawy@uaeu.ac.ae*) 46

Shear Center Identification for Composite Structures via the Finite Volume Method (*Chen, Heze; Gomez, Jose; Pindera, Marek-Jerzy*) 47

Three-dimensional stress and free vibration analysis of steel-concrete composite beams using high order theories and closed-form solutions (*Shen, Jiahui; Pagani, Alfonso; Arruda, Mario Rui*) 48

Numerical modelling of recycled glass particle–polymer resin structural composites (*McCann, Finian*) 48

3D Textile Reinforced Cementitious Composites for Permanent Formwork to Achieve Fast Construction without Environmental Waste in Concrete Construction (*Lee, Jeongun; Park, Ji Woon; Kang, Jung Min; Lim, Yun Mook*) 48

Design and test verification of connections between FRP deck panels and conventional girders in road bridges (*Kulpa, Maciej; Piątek, Bartosz; Rajchel, Mateusz; Siwowski, Tomasz*) 49

Enhancement of the adhesion between epoxy resin coating and cement-based substrates by using limestone powder sourced from quarry wastes (*Chowaniec, Agnieszka; Czarnecki, Sławomir; Sadowski, Łukasz*) 50

Simulation of Concrete-filled Square Steel Tubular Columns Stiffened with Encased I-Shaped CFRP Profile under Lateral Impact with a Fixed-fixed End (*Li, Guochang; Liu, Runze; Yang, Zhijian; Qiu, Zengmei; Li, Xiao*) 50

Lateral impact behavior of concrete-filled square steel tubular beam stiffened with encased I-section CFRP profile (*Li, Guochang; Li, Xiao; Liu, Runze; Qiu, Zengmei*) 51

Moment-Rotation Based Model for the Coupled Buckling Analysis of pGFRP Members (*Cardoso, Daniel*) 52

Composites in Innovative Applications 53

FRP-confined desert sand column: concept and compressive behavior (*Zhao, Hongchao; Zeng, Junjie; Rong, Chong*) 53

Determination and enhancement of bonding properties of hybrid steel-GFRP composites (*Uyttersprot, Jordi; De Corte, Wouter; Van Paepegem, Wim*) 53

Optimization stage of a composite quadrupole mass at high-speed rotation using finite element modeling (*Coppede, Daniel; Souza, Marco Antonio; Frajuca, Carlos; Bortoli, Fabio da Silva; Souza, Renato Chaves; Duarte, Roberto Nunes*) 54

Developing Innovative Approaches For Joining Structural Composite Parts (*Esenoğlu, Gözde; Türkdoğan, Ceren; İplikçi, Hande; Martin, Seçkin; Tanoğlu, Metin; Barışık, Murat; Aktaş, Engin; Dehneliler, Serkan; İriş, Erdem Mehmet*) 54

Influence on the axial stresses values and critical buckling load in a tube made of composite material due to the variability of geometrical and materials properties (*Solazzi, Luigi*) 55

An Investigation on the Mechanical Properties of a 3D Printed TPU/PLA Programmable Filament (*Darnal, Aryabhat; Shahid, Zaryab; Deshpande, Himani; Kim, Jeeeun; Muliana, Anastasia*) 56

Delamination, damage and fracture 57

DAMAGE SIMULATION OF MECHANICAL PROPERTIES OF COMPOSITE MATERIALS IN GENERALIZED GRADIENT THEORY ELASTICITY (*Sergey Lurie; Petr Belov; Dmitrii Volkov- Bogorodskii*) 57

The impact of the kissing bonding defects on properties in Fibre Metal Laminates (*Drożdziel, Magda; Podolak, Piotr; Nardi, Davide; Jakubczak, Patryk*) 57

The mechanical properties and failure analysis of thinply-fibre metal laminates (*Bienias Jaroslaw; Jakubczak Patryk; Drozdziel Magda; Podolak Piotr*) 58

MODE III NUMERICAL ANALYSIS OF COMPOSITE LAMINATES WITH ELASTIC COUPLINGS IN SPLIT CANTILEVER BEAM CONFIGURATION (*Rzeczkowski, Jakub; Pasnik, Jakub; Samborski, Sylwester*) 59

The curing effect on fiber bridging phenomena in mode I fracture of laminated composites (*Ping Hu; Ran Tao; Gilles Lubineau*) 59

Computational modeling based on XFEM and cohesive interfaces of the 3D fracturing process in anisotropic layered geomaterials (*Rinaldi, Martina; Trullo, Marco; Tornabene, Francesco; Dimitri, Rossana*) 60

ANALYTICAL EVALUATION OF MODE I II FRACTURE TOUGHNESS OF CFRP CURVED BEAMS (*Ryota,Sako; Ryoma,Aoki; Ryo,Higuchi; Tomohiro,Yokozeki; Masahito, Ueda; Yuta, Urushiyama*) 61

Development and fabrication of two-matrix composites: materials characterization and fracture mechanics (*Rimašauskas Marius; Kuncius Tomas; Mirauskaitė Akvilė; Rimašauskienė Rūta*) 61

INTERLEAVING AS A PRACTICAL ROUTE TO MAKE PSEUDO-DUCTILE HYBRID COMPOSITES MORE SUITABLE FOR INDUSTRIAL APPLICATIONS (*Marino, Salvatore Giacomo; Kuželová Košťáková, Eva; Czél, Gergely*) . . . 62

The use of recycled carbon fibres for interlay toughening of composite laminates (*QUAN*) 63

Reinforced crack in a prestressed and prepolarized piezoelectric ceramic material (*CRACIUN Eduard-Marius; GHITA Marius Glibert Daniel*) 64

Crack propagation in Hyperelastic material using phase field method (*Prusty Aurojyoti; Rajagopal Amirtham*) 64

A Nonlocal Phase Field Model for Fracture (*Srenivasa, Karthik; Reddy, K Surya Shekar; Nasedkina, Anna; Nasedkin, Andrey; Amirtham, Rajagopal*) 64

Phase-field modeling of brittle fracture with inertia effects (*K, Surya Shekar Reddy; Srenivasa, Karthik; Nasedkina, Anna; Nasedkin, Andrey; Amirtham, Rajagopal*) 65

Development of pseudo-ductile and repairable high-performance hybrid composites (*Czél, Gergely; Marino, Salvatore Giacomo*) 65

3D stress state failure analysis of thin-walled GLARE column subjected to axial loading in postbuckling range (*Banat Dominik; Mania, Radosław*) 66

A meso-scale approach for delamination and transverse cracking in cross-ply curved carbon-reinforced laminates (*Ghiasvand, Sara; Airoldi, Alessandro; Jinaga, Ujwal Kishore*) 67

Hybrid Toughening in Carbon/Epoxy Composite Laminates to Enhance Interlaminar Fracture Response under Mode-I Loading (*Akbolat, Mehmet Çağatay; Katnam, Kali Babu; Potluri, Prasad*) 67

Design and application of composite structures 69

DOPED POLYANILINE FILM COATING FOR LIGHTNING STRIKE PROTECTION (*Das, Sukanta; Zhou, Yu; Kumar, Vipin; Yokozeki, Tomohiro; Okada, Takao*) 69

A study on mechanical behavior of Liquid Crystalline Polyester (LCP) under high temperature condition for designing electronic devices (*Young-Hoon Ko; Jia-le Che; Seung-Hwan Chang*) 70

Advanced modeling technique of a Type III pressure vessel with the consideration of composite layer configuration (*Jia-le Che; Seung-Hwan Chang*) 70

Ballistic Tests of Material Systems for Bullet Catcher (*Pacek, Dawid; Badurowicz, Przemyslaw*) 71

Evaluation of deflection in concrete structural elements prestressed with unbonded FRP bars. (*Campos, Claudia Maria de Oliveira Campos; Honório, Gabriel de Carvalho*) 71

Nickel coated radar absorbing structure with lightning strike protection using 3D printing reinforced method (*So-Mang Hong; Won-Ho,Choi; Jin-Hwe Kweon; Young-Woo Nam*) 72

Durability of composite materials 73

Experimental results and numerical simulations on the durability of HPFRC beams subjected to freeze-thaw cycles (*FEO, Luciano; MARTINELLI, Enzo; PENNA, Rosa; PEPE, Marco*) 73

Effect of pre-loads on the fatigue life of composites with open holes immersed in seawater (*Amaro, Ana Martins; Branco, Ricardo; Neto, Maria A.; Reis, Paulo N.B.*) . 73

The effect of vascular self-healing factor orientation on repair efficiency in epoxy-glass fiber composite (*eyvazian, Arameh; Ashkan Farazin; Alkhedher, Mohammad*) . 74

Improved hygrothermal durability of flax/polypropylene composites after chemical treatments through a hybrid approach (*Zhong, Yucheng*) 74

Bleeding of cement pastes and mortars modified with granite powders (*Adrian Chajec; Lukasz Sadowski*) 75

The effect of accelerated environmental ageing on the interphase of a glass fibre/vinyl ester composite (*Xypolias,Georgios; Thomason, James; Yang, Liu*) 75

Dynamics of Composite Materials 77

Elastic waves and electron-phonon heat flow in composite thin films (*Cojocaru Sergiu*) 77

Free Vibration of Composite Laminated Cylindrical Shell with Orthogonal Stiffeners (*Xue, Jianghong; Yao Sishi*) 77

Nonlinear dynamics of fluid-conveying nanotubes (*Qiduo Jin; Yiru Ren*) 78

Scattering of elastic waves by a sphere with cubic anisotropy (*Jafarzadeh, Ata; Folkow, Peter D.; Anders, Boström*) 78

Dynamic Analysis of Second Strain Gradient Elasticity through a Wave Finite Element Approach (*yang bo; Droz Christophe; Zine Abdelmalek; Ichchou Mohamed*) . 79

Wave Propagation Analysis in non-local Flexoelectric Composite Material (*Nagham Mawassy; Hilal Reda; Jean-Francois Ganghoffer; Hassan Lakiss*) 79

Vibration Analysis of Multilayer Double-Curved Structural Systems Containing CNT Patterned Layers in the Framework of Different Shell Theories (*Avey, Mahmure; Sofiyev, Abdullah; Fantuzzi, Nicholas; Kuruoglu, Nuri*) 80

The Experimental and Theoretical Study on the Vibration Characteristic of a Multi-Mode Piezoelectric Energy Harvester (*Yao, Minghui; Liu, Pengfei; Wu, Qiliang; Niu, Yan*) . . . 80

PRODUCTION OF HIGH-PERFORMANCE ULTRA LIGHT COMPOSITE MATERIALS AND INVESTIGATION OF THE MECHANICAL PROPERTIES AND BLAST MITIGATION EFFICIENCY (*BOZTOPRAK, YALÇIN; YAZICI, MURAT*) . . . 81

Dynamics for anisotropic homogenized materials (*Colatosti, Marco; Fantuzzi, Nicholas; Trovalusci, Patrizia*) . . . 81

MECHANICAL FORCED VIBRATION OF THE SYSTEM CONSISTING OF "ELASTIC + PZT" BI-LAYERED PLATE, COMPRESSIBLE VISCOUS FLUID AND RIGID WALL (*EKİCİOĞLU KÜZECİ, Zeynep; AKBAROV, Surkay*) 82

Design Optimization of Dynamic Scaled Wing Models using Multi-Material Topology Optimization (*Brogliato Alessandro; Sohouli Abdolrasoul; Suleman Afzal*) . . . 83

Mechanical response of 3D printed honeycomb based structures made from BASF Ultrafuse 316L filament under various loading conditions (*Platek Pawel; Cieplak Kamil; Sarzynski Marcin; Jacek Janiszewski; Paweł Baranowski; Kucewicz Michał; Małachowski Jerzy*) . . . 83

Experimental investigation of the dynamic characteristics of wrapped and wound fiber and fiber/metal reinforced composite pipes (*Gowid,Samer; Mahdi, Elsadig*) 84

Electro-thermal properties of composite materials . . . 85

Electrical conductivity of MAX phases-based composite coatings and bulk material (*Prikhna, T.A.; Ostash, O.P.; Kuprin, A.S.; Podhurska, V.Ya.; Serbenyuk, T.B.; Gevorkyan, E.S.; Rucki, M.; Zurowski, W.; Kucharczyk, W.*) . . . 85

Electro-thermal multi-function deicing airfoil composite with nickel-plated carbon fabric (*Jun sung Lee; Hyeon seung Jo; Hyeon seok Choe; Dae sung Lee; Ho jin Jeong; Sang min Lee; Hye ree Lee; Hak jin Lee; Rho Shin Myong*) . . . 86

Multifunctional behaviour of PLA conductive composites. Dependence on infill rate and printing orientation (*Crespo-Miguel, Javier; Mejias-Fernandez, Javier; Rusinek, Alexis; Robles, Guillermo; Martinez-Tarifa, Juan Manuel; García-González, Daniel; Arias, Angel*) . . . 86

Experimental Methods 88

Influence of geometrical imperfections on damage process of real L-shaped thin-walled columns under axial shortening (*Gawryluk, Jarosław; Teter, Andrzej*) . . . 88

Fatigue Behavior and Damage Evolution of Additively Manufactured Short Carbon Fiber Reinforced Thermoplastics in the VHCF Regime (*Striemann, Patrick; Huelsbusch, Daniel; Baak, Nikolas; Niedermeier, Michael; Walther, Frank*) 88

Reduce of the variability in the measured impact energy of epoxy unnotched specimens with carbon-nanofillers (*Serna Moreno, Maria del Carmen; Horta Muñoz, Sergio*) 89

Assessing the thermal degradation of PEEK after excessive heating and its impact on PEEK's interfacial adhesion with carbon fibre (*Gaitanelis, Dimitrios; Worrall, Chris; Kazilas, Mihalis*) 89

Influence of laser generated micro- and nano-structuration of surface of intrinsic bonded hybrid system CFR-EP-EN AW 6082-T6 on its corrosion properties (*Delp, Alexander; Walther, Frank*) 90

Computed tomography-based characterization of impact and fatigue after impact behavior of carbon fiber reinforced polyurethane (*Gerdes, Lars; Walther, Frank*) 91

Fast assessing out-of-plane shear stress-strain behaviour for thick-section composite materials using a combination of neural network based optimization and digital image correlation (*Wei, gaojian; Hao, Ziqing; Deng, Linlin; Liu, Liu*) . 92

Determination of CFRP Intralaminar Fracture Properties in the Calibration of a Non-Local Damage Model for Crash Application (*Rondina, Francesco; Falaschetti, Maria Pia; Donati, Lorenzo*) 92

Characterisation and analysis of intraply shear and interply friction for UD prepreg forming: A critical review and roadmap for future studies (*Khan, Muhammad; Yuan, Hao; Qian, Connie; Kendall, Ken*) 93

Experimental Study on fluid-structure interaction of dilatant fluid and circular cylindrical shell under harmonic axial load (*Zippo, Antonio; Pellicano, Francesco; Iarriccio, Giovanni*) 93

Failure of Composites 95

Failure analysis of thin-walled composite structures using independent advanced damage models (*Rozylo, Patryk*) 95

A Multilateral Study on the FRP Composite's Matrix Strength and Damage Growth Resistance (*Skoczylas, Jakub; Samborski, Sylwester; Kłonica, Mariusz*) . . . 95

Failure mechanism of 3D printed continuous carbon fibre reinforced polymer composites with optimised topology and fibre orientation under three-point bending (*Yang, Dongmin; Zhang, Haoqi; Wang, Shuai; Li, Aonan*) 95

Bending damage evolution from micro to macro level in thick CFRP laminates studied by high-frequency ultrasound microscopy and acoustic emission (*Morokov, Egor; Ryzhova, Tatyana; Dubovikov, Evgeny; Gulevsky, Igor; Petronyuk, Yulia; Levin, Vadim*) 96

Low-velocity impact and residual compression performance of carbon fiber reinforced composite stiffened plates (*Zhao, Yun; Li, Hanhua; Yan, Shi; Zhang, Qiuhua; Jia, Jiale*) 97

Experimental study on low-velocity impact and residual compressive properties of composite grating after damp-heat aging (*Du, Changmei; Li, Hanhua; Yan, Shi; Zhang, Qiuhua; Jia, Jiale*) 97

Assessment of Cuntze and Puck inter fibre failure criteria in simulation of CFRP plates subjected to low velocity impact (*Rezasefat, M.; Gonzalez-Jimenez, Alvaro; Giglio, M.; Manes, A.*) 98

Combined compression-torsion fatigue failure of unidirectional carbon fiber reinforced composites (*Vankar , Sachin Rajaram; Kaore , Ameya; Yerramalli , Chandra Sekher*) 99

Microstructure-based analysis of residual stress concentration and plastic strain localization followed by fracture in metal-matrix composites (*Balokhonov, Ruslan; Romanova, Varvara*) 99

Influence of Cracks and Voids on the Responses of Composites (*H. Sam Huang*) . . 100

Modeling the interaction of interface with the anisotropic crack using cohesive zone model in a composite system (*Dhaladhuli Pranavi; Amirtham Rajagopal*) . . 100

High-fidelity modelling of single-edge notched cross-ply tensile laminates (*Nguyen, Minh Hoang; Waas, Anthony M.*) 100

Linking tensile strength of carbon fibre composites to strength of single fibres: An experimental, probabilistic and micromechanical approach (*Kumar, Rajnish; Mikkelsen, Lars; Lilholt, Hans; Madsen, Bo*) 101
An approach to damage tolerance assessment for composite structures based on the Hashin criterion (*Sałaciński, Michał; Andrzej, Leski; Dragan, Krzysztof; Synaszko, Piotr*) 102
Influence of elastic pads on the post-buckling state of the thin-walled L-profile column (*Gawryluk, Jaroslaw; Teter, Andrzej*) 102
FRP in concrete, steel and composite steel/concrete structures 104
Technological Peculiarities of Strengthening RC Members with Prestressed FRP Laminates (*Slaitas Justas; Valivonis Juozas*) 104
Effects of seawater immersion on shear performance of BFRP and GFRP bars embedded in seawater sea-sand mortar (*Zhongyu Lu; Yongchao Li; Jianglin Li; Jianhe Xie*) 104
Behavior of concrete-filled FRP tube columns internally reinforced with FRP-steel composite bars under Axial compression (*Jun-Jie Zeng; Shu-Hua Xiao; Yong-Chang Guo*) 105
Compressive and Transverse Shear Behaviour of Novel FRP-UHPC Hybrid Bars (*Yu-Yi Ye; Jun-Jie Zeng*) 105
Effects of fire insulation scheme and anchorage system on fire performance of insulated CFRP-strengthened RC beams (*Dong, Kun; Gao, Wan-Yang; Hu, Ke-Xu; Yang, Jian*) 105
The influence of the recycled carbon fibres reinforcement on the load bearing capacity of eco-firendly, self-compacting, fibre reinforced concrete. (*Ostrowski, Krzysztof Adam*) 106
FRP reinforced concrete structures 107
Numerical behavior of externally CFRP prestressed beams with FRP/steel rebars (*Lou, Tiejiong; Li, Zhangxiang; Pang, Miao*) 107
Stress-strain behavior of thermally damaged concrete columns confined with FRP composites (*Song, Jiang; Liu, Wang-Wei; Gao, Wan-Yang; Ouyang, Li-Jun*) 107
Full-Range Axial Load-Strain Model for GFRP-RC Columns (*Yu-Yi Ye; Jun-Jie Zeng*) 108

Confinement of concrete columns with composite materials: FRP vs. TRM design and modelling (*Monaco, Alessia*) 108

Sustainable confinement of concrete columns using Natural-FRP composites: efficacy of current design provisions and analytical models (*Monaco, Alessia; Tondolo, Francesco; Marano, Giuseppe Carlo*) 109

Functionally graded materials and structures 111

Free Vibrations Analysis of Composite and Hybrid Axisymmetric Shells (*Moita, José S.; Araújo , Aurélio L.; Correia, Victor F.; Mota Soares, Cristóvão M.*) 111

On the structural bending response of P-FG nano-beams under hygro-thermo-mechanical loadings. (*PENNA, Rosa; FEO, Luciano; LOVISI, Giuseppe*) 111

THE STATIC RESPONSES AND STRESSES OF FUNCTIONALLY GRADED EXACT CURVED BEAMS (*Aribas, Umit Necmettin; Atalay, Mert; Omurtag, Mehmet Hakkı*) 112

Schmidt method to study a problem of heat conduction in a functionally graded layered structure with an arbitrary oriented crack (*Singh, Ritika; Das, Subir*) . 112

Investigation of the Structural and Acoustic Response of Functionally Graded Lightweight Panel (*Isaac, Chukwuemeke William; Wrona, Stanislaw; Pawelczyk Marek*) 113

Analysis of porosity effect on temporal response of functionally graded plate with simple and efficient finite element model (*Zghal Souhir; Trabelsi Sourour; Dammak Fakhreddine*) 113

Multi-scale topology optimisation design of porous femur implant with graded-density anisotropic microstructures using latent variable Gaussian process (*Zhao, Jiuzhou; Deng, Xiaowei*) 114

Theoretical tolerance modelling of axially functionally graded slender beams (*Jędrysiak, Jarosław*) 114

Topology Optimization of Gradient Lattice Structures Using Surrogate Models (*Costa,Mauro; Sohouli, Abdolrasoul; Suleman, Afzal*) 115

Health Monitoring Techniques in Composite Structures 117

Wave propagation in thin delaminated composite strips (*Punith, P; Mitra, Mira; Guruprasad, PJ*) 117

Two-directional strain measurement of a composite with a single FBG sensor inscribed in the microstructured highly birefringent side-hole fiber (*Wachtarczyk, Karol; Gąsior, Paweł; Kaleta, Jerzy; Anuszkiewicz, Alicja; Osuch, Tomasz; Bender, Marcel; Schledjewski, Ralf*) . . . 117

Impact Problems . . . 119

Low velocity impact (LVI) and compression after impact (CAI) of GFRP laminates (*Gliszczynski Adrian*) . . . 119

Numerical dynamic response of RC slabs subjected to combined blast and impact loading using plasticity based material model (*K, Akshaya Gomathi; Amirtham, Rajagopal*) . . . 119

Numerical investigation on the hybridization effect in glass and aramidic woven composites subjected to ballistic impacts (*Vescovini, Alessandro; Scazzosi, Riccardo; Amico, Sandro Campo; Giglio, Marco; Manes, Andrea*) . . . 120

Impact damage modelling in composite structures using strain rate dependent failure models (*Ivančević, Darko; Giannaros, Efthymios*) . . . 120

THE EFFECT OF LOW ENERGY IMPACT LOADS ON THE PROPERTIES OF A SANDWICH COMPOSITE WITH HEREX CORE (*Andrzej Komorek; Paweł Przybyłek; Robert Szczepaniak; Jan Godzimirski; Marek Rośkowicz*) . . . 121

A NUMERICAL-EXPERIMENTAL STUDY ON THE IMPCAT RESPONSE OF AN ADDITIVE MANUFACTED HYBRID METAL-COMPOSITE STRURCTURE. (*Acanfora, Valerio; Saputo, Salvatore; Russo, Angela; Sellitto, Andrea; Riccio, Aniello*) . 121

Numerical analysis of thin-walled aluminum profiles with hexagonal triggers using ANN (*Gajewski, Jakub; Rogala, Michał*) . . . 122

Crashworthiness analysis of thin-walled circular column filled with aluminum porous structure. (*Rogala, Michał; Gajewski, Jakub*) . . . 122

Joints . . . 123

The efficiency analysis of innovative anchorage spiral frictional system for flat CFRP strips (*Gribniak Viktor; Rimkus Arvydas; Arnautov Aleksandr K.*) . . . 123

The issue of use of mechanical fasteners in the assembly of CFRP composite elements (*Rośkowicz, Marek; Chalimoniuk, Marek; Jasztal, Michał; Wiśniewski, Adam*) 123

Enhanced structural integrity of CFRP T-joints by embedding sacrificial cracks throughout the bondline (*Wagih, Ahmed; Hashem, Mjed; Lubineau, Gilles*) 124

Keynote Lectures 127

Emerging numerical approaches for numerical design and optimization of composite structures (*Pinho, Silvestre*) 127

Layerwise mixed models for thermo-mechanical analysis and multiobjective design optimization of multilayered plates: composite laminates and functionally graded plates (*Moleiro, Filipa*) 128

A Semi-Discrete Model for Progressive Damage and Failure of Fiber Reinforced Laminates (*Waas, Antony*) 128

Variable stiffness composites by means of additive manufacturing technology: multi-scale analysis, design and manufacturing (*Montemurro, Marco*) 129

Nano-Scale Mechanical Systems: Recent Trends in Nano-Structural Mechanics (*Luciano, Raimondo*) 130

Mixed-mode buckling of shear-deformable composite laminated beams with arbitrary cross-sections and non-orthotropic layups (*Mittelstedt, Siham; Schneider, Jens; Mittelstedt, Christian*) 131

Micromechanics 132

Convergence of Homogenized Moduli of Random Fiber Composites Under Homogeneous Boundary Conditions and Local Stress Field Statistics (*Yin, Shizhen; Pindera, Marek-Jerzy*) 132

Modeling in Mechanics and Materials 133

Data-driven intelligent optimisation of aligned discontinuous composites (*Pimenta, Soraia; Finley, James; Shaffer, Milo S P*) 133

An improved mean-field homogenisation scheme based on CZMs to describe particles/fibres debonding (*Gentieu Timothée; Catapano Anita; Jumel Julien; Broughton James*) 133

Modeling, simulation and testing of sandwich and adaptive structures 135

DESIGN AND OPTIMIZATION OF 3D-PRINTED-HONEYCOMB SANDWICH COMPOSITE STRUCTURES FOR IMPACT ENERGY ABSORPTION APPLICATIONS (*ANDRES CECCHINI; MARCO MENEGOZZO; FREDERICK JUST AGOSTO; DAVID SERRANO*) 135

FE implementation of Sublaminate Generalised Unified Formulation models for sandwich plates (*Di Cara, Girolamo; D'Ottavio, Michele; LE, Thi H.C.; Polit, Olivier*) 135

Computer-aided Design for Fiber-Metal-Laminates (*Triebus, Marcel; Tröster, Thomas*) 136

Numerical modelling of damage effect in composite sandwich structures (*Ivañez, Ines; Paredes-Gordillo, Marco A.; Garcia-Castillo, Shirley K.; Rubio, Patricia*) 136

Modelling and simulation of shape memory polymer-based composite structures for morphing application (*Bhola, Lalit; Mujumdar, P.M.; Guruprasad, P.J.*) 137

Modelling and Characterization of CNT-Polymer Composites 138

Modulating the extension-bending-twisting coupling in composite laminate using carbon nanotube grafted laminas (*Bedi, Harpreet; Padhee, Srikant; Agnihotri, Prabhat*) 138

Morphing of composites 139

Flexible joints based on corrugated composite laminates: numerical development and manufacturing (*Riva, Marco; Turconi, Tommaso; Airoldi, Alessandro; Boiocchi, Matteo; Ballarin, Pietro; Bottasso, Luigi*) 139

Development of intrinsically heated, interleaved composites with controllable flexural stiffness and shape memory capability (*Murali, Gokul Ganesh; Robinson, Paul; Bismarck, Alexander; Burgstaller, Christoph*) 140

Experimental and numerical evaluation of a multi-degree of freedom biomimicking fish locomotion with micro fibre composite actuation for a flexible robot (*Weber, Christian-Toralf; Abbaszadeh, Shokoofeh; Hoerner, Stefan*) 140

Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites . . 142

Graphene Nanoplatelet (GNPL) Reinforced Cylindrical Shell (*Arefi, Mohammed; Mercan, Kadir; Civalek, Omer*) 142

Resonance in dangerous mode of a rotating pre-twisted graphene reinforced composite blade with variable thickness (*Niu, Yan; Yao, Minghui*) 143

REVIEWS ON EXPERIMENTAL AND THEORETICAL APPROACHES TO CHARACTERIZE THE ELASTIC BEHAVIOR OF CARBON NANOTUBE-REINFORCED POLYMERIC NANOCOMPOSITES (*Taegeon Kil; Jin-Ho Bae; Beomjoo Yang; H.K. Lee*) 143

Multiscale Analysis of Natural Fibre Composites 145

Efficient off-line database construction technology for data-driven computational mechanics (*Li Liang; Shao Qian; Yang Jie; Hu Heng*) 145

Multiscale and Multiphysics Modelling for Complex Materials 146

Application of fast statistical homogenization procedure for estimation of effective properties of ceramic matrix composites having random microstructure (*Pingaro Marco; De Bellis Laura Maria; Reccia Emanuele; Trovalusci Patrizia; Sadowski Tomasz*) 146

Nano-Composites 147

Nonplanar Vibrations of an Imperfect Composite Nanobeam Employing Nonlocal Strain Gradient Theory (*Wu, Qiliang; Yao, Minghui; Niu, Yan*) 147

Free Vibration of FGM Nanoscale Thick Beams (*Loja, M.A.R.; Barbosa, J.I.*) 147

Nano-Composites and Micro-mechanics 148

Infusing Energy Transferability into Coastal Bridge Infrastructures by elucidating a unique IEPM Chemical Bond Feature via IDA Surface Modification (*Attard, Thomas*) 148

Natural Fibre Composites 149

NUMERICAL MODELING OF DATE-PALM FIBRE-REINFORCED MORTAR (*Zanichelli, Andrea; Carpinteri, Andrea; Ronchei, Camilla; Scorza, Daniela; Vantadori, Sabrina*) 149

CHARACTERISTICS OF COIR AND FLEECE MICROFIBRIL REINFORCED POLY-LACTIC ACID (PLA) HYBRID GREEN COMPOSITES (*Sujito; Musyarofah, Lailatul; Sutisna, Sutisna; Asrofi, Mochamad; Salid, Mohd. Sapuan; Supriyanto, Edy; Rofi'i, Imam*) 150

Non-destructive Inspection Techniques for Composite Materials and Structures 151

Effect of carbon nanotubes on the environmental assisted degradation and damage sensing abilities of glass fiber/epoxy composites (*Chauhan, Ankit; Bedi, Harpreet Singh; Agnihotri, Prabhat K*) . . . 151

Optimization techniques and methods . . . 152

Multi-objective optimisation designs for thin-walled deployable composite hinges using surrogate models and Genetic Algorithms (*Liu Tianwei; Bai Jiangbo; Fantuzzi Nicholas; Bu Guangyu; ldyhhxxa@163.com*) . . . 152

Influence of electromagnetic field on the orientation of steel fibres in high-performance concrete (*Carrera Kristýna; Künzel Karel; Konrád Petr; Mára Michal; Kheml Přemysl; Fornůsek Jindřich; Papež Václav; Sovják Radoslav*) . . . 152

Topology and Fiber Path Optimization of Variable Stiffness Composite Structures with Eigenvectors Constraints (*Elvas, André; Sohouli, Abdolrasoul; Suleman, Afzal*) 153

The effect of magnetic field shape and strength on fiber orientation in fresh HPFRC mixture (*Carrera, Kristýna; Sovják, Radoslav; Künzel, Karel; Konrád, Petr; Mára, Michal; Papež, Václav; Kheml, Přemysl; Fornůsek, Jindřich*) . . . 154

Shunted damping configurations for noise reduction in laminated composite sandwich panels (*Araujo, Aurelio; Cotrim, Bruno; Tome, Marta; Madeira, Jose*) . . . 154

Porous and cellular materials . . . 155

Large deflection of composite beams by finite elements with node-dependent kinematics (*Pagani, Alfonso; Augello, Riccardo; Carrera, Erasmo*) . . . 155

Modelling of effective thermal conductivity of a packed bed of steel bars with the use of chosen literature models (*Bagdasaryan, Vazgen; Tomczyk, Barbara; Wyczółkowski, Rafał*) . . . 156

Probabilistic modeling and reliability of composites . . . 157

Finite element reliability analysis of edge delamination onset due to the interlaminar stresses in general composite laminates (*Delbariani-Nejad, Ali; Farrokhabadi, Amin; Haddad Khodaparast, Hamed; Fotouhi, Mohammad*) . . . 157

Adaptive dimensional reduction of probability spaces in the RBRDO of composite laminates structures (*das Neves Carneiro, Gonçalo; Conceição António, Carlos*) . . . 157

Smart Composites . . . 159

A spectral Tchebychev solution for electrostatic analysis of functionally graded composite plates with integrated piezo-patches (*lahe motlagh, Peyman; Rafiei Anamagh, Mir Meysam; bediz, bekir; basdogan, ipek*) 159

Microstrip Patch Antenna with Sandwich Type Radar Absorbing Structure (*Jang, Woo-Hyeok; Jang, Min-Soo; Kim, Sol; Kwon, Hyunseok; Jin, Do-Hyun; Kim, Chun-Gon*) 159

Finite Element Analysis of Intrinsically Self-healing UD Composite Material (*Smojver, Ivica; Ivančević, Darko; Brezetić, Dominik*) 160

Effect of Rain and Sea Water Immersion of Magnetorheological Elastomers (*U, Ubaidillah; Krismawati, Novita; Wibowo, w*) 160

Rate dependences in the magneto-mechanical response of magnetorheological elastomers: an experimental study (*Miguel Angel Moreno; Jorge Gonzalez-Rico; Maria Luisa Lopez-Donaire; Angel Arias; Daniel Garcia-Gonzalez*) 161

Stability of Nano, Micro and Macro Composite Structures 162

Approximate postbuckling analysis of omega-stringer-stiffened composite panels (*Schilling, Jakob C.; Mittelstedt, Christian*) 162

FG beam thermal buckling analysis (*Lanc, Domagoj; Turkalj, Goran; Kvaternik Simonetti, Sandra*) 162

A locking-free shear deformable beam model for stability analysis of beam-type structures with composite thin-walled cross-sections (*Turkalj, Goran; Banić, Damjan; Lanc, Domagoj*) 162

Structural Health Monitoring 164

Self-sensing of CFRP Impact Damage using Electrical Route Models (*Oh, So Young; Roh, Hyung Doh; Park, Young-Bin*) 164

Impact Self-sensing Algorithm Embedded Smart CFRP for Structural Health Monitoring and Non-destructive Evaluation using Artificial Neural Network (*Roh, Hyung Doh*) 164

Structural Health Monitoring of Various Carbon Fiber Reinforced Plastic Tubes using Electrical Resistance (based Self-sensing) (*Lee,Dahun; Roh, Hyung Doh*) . 164

Life-cycle structural health monitoring of composite laminate using encapsulated phase-shifted fiber Bragg grating with cantilever structure (*Zhang Hanqi; Wu Qi; Chen Changhao; Xiong Ke*) 165

Design, analysis and manufacturing of a smart composite skateboard with self-sensing capability (*Tabatabaeian, Ali; Fotouhi, Mohamad; Harrison, Philip*) 166
Application of Electrical Resistance Change Method for Impact Damage Monitoring in Quasi-isotropic Hybrid Composites (*Fotouhi, Sakineh; Tabatabaeian, Ali; Zuo, Siming; Liu, Sixin; Heidari, Hadi; Fotouhi, Mohammad*) 166
Thermal problems on Composite structures 167
New analytical thermal buckling solutions of orthotropic rectangular thin plates with two opposite edges free and the other rotationally restrained (*Jinghui Zhang; Salamat Ullah; Ömer Civalek; Zhao Qingxin*) 167
Determination of operating times and temperatures of carbon fibre-reinforced polymers at different heat fluxes (*Bibinger Johannes; Eibl Sebastian; Gudladt Hans-Joachim*) 167
Numerical modelling of composite panels with microvascular channels (*Upnere Sabine*) 168
Variable Stiffness Composite Laminates 169
Improving the buckling capacity of composite panels with cutouts using continuous curvilinear fibres and stiffeners based on streamlines (*Alhaj Ahmad, Ahmad; Mittelstedt, Christian*) 169
Experimental and numerical analysis of the effect of processing parameters on the deformation behaviour of continuous fiber reinforced plastics made by Tailored Fiber Placement under tensile loading (*Uhlig, Kai; Bittrich, Lars; Spickenheuer, Axel; Stommel, Markus*) 169
Dynamic Response Optimization of Variable-Angle Tow Laminates (*Carvalho, João; Sohouli, Abdolrasoul; Suleman, Afzal*) 170
Buckling Optimization of Grid-Stiffened Curvilinear Fiber Composite Panels (*Arranz, Sofia; Sohouli, Abdolrasoul; Suleman, Afzal*) 170

Author Index **173**

Abstracts

Advanced Numerical Techniques

Functionally graded oxygen-rich metal films and their production on metal and ceramic bases using induction PVD technique

abst. 2009
Repository

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To increase the mechanical properties (hardness) and functional characteristics (wear resistance, corrosion resistance, biocompatibility), the surface of metal products, in particular dental and orthopedic implants, metalworking steel tools (cutting plates, drills, etc.), is subjected to strengthening treatment and coating deposition. Usually, as a result of thermal or chemical-thermal modification, the elemental composition and surface structure change, which leads to the formation of a layered or gradient structure of the diffusion type. Induction heat treatment (IHT) is a fairly effective method for increasing strength, hardness and elastic modulus, which has been repeatedly shown for steels, and more recently for titanium. However, the IHT also allows controlled sputtering of metallic materials, e.g. titanium and titanium alloys, at a lower pressure. Thus, in this study, a fundamental possibility was established for the implementation of the induction sputtering of metals (titanium, zirconium, tantalum) and subsequent deposition (IPVD) of oxygen-rich metal films at low vacuum on the surface of other metals, in particular X12Cr18Ni10Ti stainless steel (analogue of AISI 316) and high-speed HSS 6-5-3 tool steel (analogue of DIN 1.3343), as well as ceramic materials (amorphous quartz SiO2, polycrystalline aluminum oxide Al2O3). Preliminary results of IPVD of metals, in particular titanium, and the formation of functionally graded oxygen-rich films on the surface of HSS 6-5-3 steel confirmed the possibility of obtaining an adhesive strong and hard Ti[O] layer with a hardness over 98 HRN15 (over 2500 HV). The temperature for efficient (high-velocity) sputtering of titanium in low vacuum must exceed 1300–1400 °C. At a lower temperature about 1200–1250 °C, the process was characterized by a lower rate – about 70–80 nm/min. It was found that the cooling rate and the composition of the atmosphere affect the saturation of the metal film with oxygen, i.e. the oxygen content increased from 16–19 wt.% to 59–61 wt.% upon accelerated cooling in air. In this case, the resulting coatings had a large thickness (over 2000 nm) and were destroyed (partially chipped off) when the hardness was measured. This treatment also made it possible to retain the high hardness of the underlying base of the product, in particular the hardness of the HSS 6-5-3 steel remained at about 66–66.5 HRC, and for ceramics, aluminum oxide Al2O3, no cracking was observed after the metal layer was formed. It was also noted that the titanium-containing layers had high electrical conductivity, which indicated the possibility of obtaining conductive layers on dielectric materials. The research was supported by the Russian Science Foundation (project No. 18-79-10040).G32

HOHWM for free vibration analysis of FGM nanobeams

abst. 2010
Room 3
Wednesday
September 1
16h10

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The wavelet methods provide new, interesting approach for solving differential, integro-differential and integral equations in comparison with traditional/classical methods. In the current study the higher order Haar wavelet method, introduced recently by workgroup, is adapted for the free vibration analysis of the functionally graded nanobeams. The main focus is on two important factors: the accuracy and complexity of the proposed approach. The results are compared with widely used Haar wavelet method.

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abst. 2023
Room 3
Thursday
September 2
11h50

Molecular investigation on carbon fiber-epoxy matrix interface under sustained load conditions

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The strong integrity between carbon fiber and epoxy matrix plays a key role in ensuring the durability of carbon fiber-reinforced polymer (CFRP). During the service-life, CFRP composite is exposed to the sustained load conditions, which significantly affects the integrity of fiber/matrix interface. So far, it is unclear about the change of the interfacial microstructure and contact under the sustained load conditions. Here we use the molecular simulation to investigate the interfacial degradation under sustained load. The molecular interface model consists of the epoxy molecule bonded at the top of graphite sheets representing the fiber outer-layer. The graphite sheets are subject to the shear and peel simulations at different load levels. During the simulation, the interfacial structure and interaction, strain and stress evolution are examined, which are used to explore the effect of load conditions on the molecular structure of fiber/matrix interface. Meanwhile, the threshold stress and energy barrier for the onset of the interfacial failure are compared to quantify the effect on the interfacial adhesion. The research findings contribute to the nanoscale insight into interfacial degradation mechanism of CFRP composites under sustained load, which form basis for predicting performance and interfacial degradation of CFRP composites in consideration of sustained load. Keywords: Carbon fiber/epoxy matrix, Sustained load, Molecular dynamics simulations

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abst. 2046
Repository

Numerical investigation on microscopic mechanisms of mode I fracture of composite laminate using different modelling techniques

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Cohesive zone model (CZM), extended finite element method (XFEM) and virtual crack closure technique (VCCT) are three widely used simulation methods for modelling delamination initiation and its propagation of composite laminates. In CZM and XFEM approaches, both stress- and/or strain-based criteria are employed to determine crack initiation, and energy-based criteria to define the following crack propagation. On the other hand, the linear elastic fracture mechanics (LFEM) based VCCT method governs the fracture behaviour by total energy released rate at crack tip against the critical

fracture toughness. The full validation of the suitability of each technique should include the agreements of the numerical results and the experimental results at both global (macro-) and local (micro-) levels since both are important and unique for a given test. Most studies so far have mainly focused on the macroscopic phenomena such as the global load-displacement and delamination growth rate from the experiments. The parameters used in the various modelling techniques are correlated or even adjusted to enable a good match with the global experimental results. However, there is a lack of investigation on microscopic mechanisms such as the damage process zone, stress distribution near the crack tip and within the process zone. This resulted in that the macroscopic results from a given experiment with unique physical mechanisms could be well correlated by various modelling techniques even the microscopic mechanisms or local responses predicted by each technique are significantly different. Consequently, it is doubtful about the fitness of the modelling technique. In this study, the Mode I delamination of carbon fibre reinforced plastic (CFRP) composite laminate is numerically simulated using CZM, XFEM and VCCT associated with a double cantilever beam (DCB) test result. The simulation results obtained from the models mentioned above are compared in both the global (macro-) and local (micro-) levels to explore the fundamental characteristics of the different modelling techniques. It is demonstrated that validation with the macroscopic phenomena at the global level only is not sufficient to justify the suitability of the modelling techniques. The microscopic mechanisms or local responses predicted by the modelling technique should be supported by the unique physical mechanisms form the experiments.

Anchor bolts for load introduction into cross-sectional faces of thick fiber-polymer composites: Investigation of the laminate layup

abst. 2049
Room 3
Wednesday
September 1
16h30

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Load introductions are a key challenge designing fiber-reinforced polymer composite (FRPC) structures. This is mainly caused by the anisotropic material properties. Without adequate technological concepts for load introductions, the potential lightweight advantage of the material cannot be exploited to its full extent. Therefore, basic research - i.e. the detailed analysis combined with experimental validation of new concepts - is essential and needs to be provided to design engineers. Industries yet untypical to the use of FRPC structures, e.g. machine tool manufacturing, show an increasing interest in fiber-reinforced polymer composites. In these industries structures generally exhibit greater wall thicknesses and therefore demand the development of new load introduction concepts exactly suited to the material properties and the present boundary settings. In addition to mechanical demands, concepts need to be economically viable. Concerning these economic requirements, for many cases screw joints are desirable for easy mounting and demounting of structural components. Subsequently bonded, threaded bolts are a favorable and thus commonly used concept to implement local loads into concrete or timber structures. Tests demonstrate that an adaption of this concept into cross-sectional faces of thick FRPC results in high maximum loads for the joint due to the strength of the substrate. Beside this primary advantage the concept offers a standard screw joint between the FRPC and the surrounding structures. A subsequent integration can be easily performed by drilled or milled bores and adhesive bonding of the anchor bolt. It can therefore facilitate and standardize load introductions into FRPC structures and enable their economic use. The presented work focuses on the examination of the laminate layup's influence on the load bearing capacity of anchor bolts. The objective is the numerical analysis and discussion of different laminate layup configurations and dominating geometry parameters as well as their interaction with regard to the stress distribution within the laminate. The numerical results will be complemented by an experimental study determining the influence of the laminate layup on the load-bearing capacity and on the failure characteristic. Further a comparison will be made to cross-bolts as a reference load introduction.

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abst. 2089
Repository

Static analysis of isotropic and orthotropic composite triangular plates by geometric transformation method

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Triangular plates with isotropic or composite material are commonly used as structural component with a wide application in automobile, aerospace, civil, mechanical, railroad bridge, and aeronautical engineering. It is important to understand its stability, dynamic, modal and bending behavior for acceptable, safely and accurate design of triangular plates in different engineering system. Thus, the accurate numerical or analytical analysis of mechanical behaviors such as static or modal responses are currently of particular interest and studied extensively in this area in many years. In this investigation, modeling and numerical solution of bending problem of triangular (Fig.1) plates with isotropic or composite material have been investigated in detail. First-order shear deformation theory, and Kirchhoff thin plate theories have been used for kinematic modeling of triangular plates with isotropic or orthotropic composite cases. The method of discrete singular convolution (DSC) and harmonic differential quadrature (HDQ) methods were used for solution of equations of bending via discretization [1-5]. For achieve this, the triangular domain is mapped into a square domain in the computational space using a four-node element. By using the geometric transformation, the governing equations and boundary conditions of the triangular plate are transformed from the physical domain into a square computational domain[6-8]. Verification of the accuracy of the present DSC and HDQ results is verified by appropriate convergence study and checked with the results available in the open literature for isotropic, and orthotropic composite cases. The influence of loads, orthotropic materials, boundary conditions, loads and geometrical parameters on bending moments and deflection have been investigated in details.

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abst. 2091
Repository

Microstructure-Free Finite Element Modeling of Representative Volume Element for Elasticity Design of Random Particulate Composites

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Microstructure-based finite element modeling of material representative volume element (RVE) is a powerful tool in characterization and design of various composites. However, microstructure-based finite element modeling has a number of limitations, e.g. time-consuming in generation of geometric model, challenge in achieving high volume fraction of inclusions and poor quality of finite element mesh. In this paper, we demonstrate that, for particulate composites that have statistically uniform distribution and orientation of inclusions, if the ratio of inclusion characteristic length to RVE size is adequately small, elastic properties characterized from the RVE are independent of inclusion shape and size. Based on this fact, we propose a microstructure-free finite element modeling (MF-FEM) approach for elasticity characterization and design of particulate composites. MF-FEM first generates a uniform finite element mesh of the RVE, then a number of elements, determined by the given volume fraction of inclusions, are randomly selected and assigned with material properties of inclusion, the rest elements have the material properties of matrix. MF-FEM is validated against experimental data reported in the literature and compared with widely used micromechanical models. The results show that for a composite with small contrast of phase properties, MF-FEM has excellent agreement with both experimental data and micromechanical models. However, for a composite that has large contrast of phase properties and large volume fraction of inclusion, there exist significant difference between MF-FEM and micromechanical models, which may be caused by the special assumptions adopted in micromechanical models. MF-FEM has a number of advantages over microstructure-based finite element modeling in the design of particulate composites.

Use of Artificial Neural Networks to Optimize Stacking Sequence in UHMWPE Protections

abst. 2110
Room 3
Wednesday
September 1
16h50

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A methodology to evaluate the influence of stacking sequences on the ballistic performance of ultra-high molecular weight polyethylene is proposed based on the combination of experimental tests, numerical modelling, and Artificial Neural Networks (ANN). A Finite Element Method (FEM) model validated by means of high-velocity impact tests was used to provide a dataset to train and to validate an ANN which was utilized to find the best stacking sequence by combining three different qualities of UHMWPE. Results showed that the three UHMWPE materials can be properly combined to provide a solution with a better ballistic performance than using only the material with highest quality.

Chemo-Thermomechanical Simulation of an Epoxy Resin System in Composites using Time-Adaptive Finite Element Simulations

abst. 2144
Repository

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In order to model this behavior, elaborate experiments are required on curing, the volume changes that occur and the thermo-mechanical material properties. Based on these experiments, a thermo-mechanically consistent material model is developed which satisfies the Clausius-Duhem inequality. It is shown that curing models represent inherently unstable differential equations, which have to be solved by suitable time integration methods. When curing processes are considered, they always exhibit inhomogeneous thermal and mechanical distributions of temperatures and deformations. In addition, they exhibit different time scales, since curing takes place over several hours. The developed constitutive model is implemented in a stepsize-controlled (time-adaptivity) finite element program, which solves the resulting system of differential-algebraic equations (DAE-system) consisting of the discretized principle of virtual displacements (quasi-static equilibrium conditions), the transient heat equation, and the ordinary differential equations (evolution equations) describing the chemo-thermomechanical material properties. Stiffly accurate diagonal-implicit Runge-Kutta methods are drawn on to solve the DAE-system used for this purpose. Numerical simulations of curing processes with their experimental uncertainties are presented (validations examples), and calculations in fiber composites are reproduced.

Experimental tests and correlation of constitutive model with optimization procedure for reliable numerical modeling of failure in 3D printed composites

abst. 2184
Room 1
Friday
September 3
11h30

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Thanks to the 3D printing technology design and manufacturing process gave new opportunities. The strength of simple 3D printed components is relatively low. However, it can be considerably increased by the addition of reinforcements and this way develop a new composite characterized with better parameters compared to the original component. Over the last few years a technology allowed to mix a continuous fiber (made of glass, carbon, basalt, etc.) with a thermoplastic material. Eventually,

the mechanical properties as elastic modulus and maximum strength increase up to the values close to composites made in a traditional way. However, the main disadvantage of this technology is related to the relatively high costs and time-consuming issues. In this paper a wide range of experiments were considered. Quasi-static tension, compression, bending and shear test were performed for selected printing orientation in all three printing directions (XY, XZ and YZ). A fracture of fibres was noticed for tension along fibre axis, while decohesion was observed in other directions. Microscopic observations of printing defects and analysis of fracture sections were performed to evaluate the interfaces between matrix and fibre. For further studies, numerical simulations were utilized and the tested composite structures were modelled with two methods. In the first one solid elements connected with cohesive interface described by bilinear traction-separation law were implemented taking into account mixed mode delamination criterion and a damage formulation. When the maximum separation is reached the cohesive connection fails which leads to separation of the composite elements. The interaction between layers after cracking development is defined using penalty contact algorithm with friction process. The prepared numerical models considered several types of composite material failure modes such as fibre breakage, intra and interlaminar cracks propagation parallel to the plane of layering, the propagation of longitudinal cracks in plane, bending and fragmentation of layers and transverse shear of layers. In the second proposed method the beam elements representing fibres were constrained in Lagrange solid elements with failure criteria. Finally, the correlation of the constitutive model was performed based on experimental tests based on an optimization procedure adopted to iteratively minimize the error for several load cases A good correlation between experimental and numerical results was achieved.

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abst. 2191
Repository

INVERSE DIFFERENTIAL QUADRATURE METHOD FOR BUCKLING ANALYSIS OF COMPOSITE PLATES

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Buckling analysis often plays a major role in driving the design procedure of lightweight structures. To comprehensively characterise the buckling deformation of these structures requires efficient computational tools that guarantee accurate solution of systems of high-order partial differential equations, since closed form or exact solutions of such system of equations for buckling analysis are only feasible for limited cases of geometries and boundary conditions. In this work, a novel inverse differential quadrature method (iDQM) is proposed for performing buckling analysis of laminated composite plates kinematically described by Classical Laminated Plate Theory (CLPT). The iDQM method is based on the approximation of high-order derivatives of a function in the governing equations as a linear weighted sum of the function derivatives over the discretised domain. The ensuing iDQM-based generalised eigenvalue problem is solved using a preconditioning strategy, since iDQM discretisation leads to a non-square system of equations. The results obtained for specially orthotropic laminates show good agreement with Navier- and Levy-type solutions for different sets of boundary conditions. In addition, improved accuracy and convergence are recorded for iDQM solutions over estimates obtained by differential quadrature method (DQM).

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abst. 2221
Room 3
Thursday
September 2
12h10

Research on impact performance of vehicle impact buffer device based on honeycomb composite function gradient

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Aiming at the equivalent energy-absorption characteristics of the double-arrow honeycomb structure and the actual working conditions of the front bumper crash box, a negative Poisson's ratio crash box based on the functional gradient was proposed. Under the conditions of a given impact speed of 30 km/h and an impact time of 80 ms, the mechanical properties, impact response and energy absorption characteristics of three uniform negative Poisson's ratio structures and five functionally graded structures were compared. The study found that: (1) The two-dimensional functionally graded structure had a specific energy absorption (SEA) of 5350 J/kg, which was 4.6 times that of the uniform negative Poisson's ratio structure and had a smoother stress response during the entire impact process. (2) The proposed three-dimensional functionally graded structure had a total absorbed energy of 182000 J, which was 2.6 times that of the uniform negative Poisson's ratio structure, and the maximum collision force was 78.6 KN, which was reduced by 86%, which can significantly improve the durability of the car. (3) The proposed three-dimensional functionally graded structure was applied to the crash box of the bumper system, and the standard crash test was carried out. The results showd that the functionally graded negative Poisson's ratio structure can significantly improve the safety in collision compared to the traditional crash box structure. The above research can meet the performance of the structure through the reasonable selection of density and size parameters according to different design requirements, and provide a basis for the large-scale application of negative Poisson's ratio structure crash box in automobile design. Key words: Double arrowhead honeycombs; Negative Poisson's ratio; Functionally graded; Energy absorption.

DEVELOPMENT OF A NUMERICAL METHODOLOGY FOR THE SIMULATION OF THE FATIGUE INDUCED DELAMINATION IN COMPOSITE STRUCTURES

abst. 2236
Repository

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Composite materials are characterized by extraordinary strength and stiffness properties which can be strongly affected by intralaminar and interlaminar failure modes. Among the different damages, delaminations can be considerably influenced by the fatigue induced material properties degradation. Indeed, delamination propagation phenomena could begin at a fairly low number of cycles, progressively leading to the growth of the delaminated area and to the decrease of the global structural stiffness until the structural catastrophic failure. In this paper, a numerical procedure for fatigue induced delamination simulation has been developed. The mechanical behaviour of composite panels under cyclic loading conditions have been numerically investigated. The proposed approach, implemented in ANSYS® FEM software by using the Ansys Parametric Design Language (APDL) adopts a mesh and time step independent procedure based on the Virtual Crack Closure Technique (VCCT), combined with the Paris-Law formulation, which permits to take into account the local damage accumulation along the delamination front.

Axisymmetric response of FG-CNTRC circular plates subjected to step thermal shocks

abst. 2246
Repository

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Axisymmetric thermally induced vibration of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) circular plates is analyzed in the present research. The effective material properties are obtained utilizing homogenization techniques. First, the energy equation along the structure thickness is derived and solved by means of finite difference and Crank-Nicolson approaches. After extracting the temperature profile in the structure and also obtaining the thermal forces and moments over time, the equations of motion are extracted. The time-position-dependent partial differential equations are solved utilizing a combination of the generalized differential quadrature method and the Newmark time marching technique. The effects of various material and geometrical parameters and also boundary conditions on the FG-CNTRC circular plate are investigated.

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abst. 2247
Repository

Two-dimensional thermally induced vibration of cylindrical panels reinforced with functionally graded CNTs

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Rapid heating of functionally graded carbon nanotube-reinforced composite (FG-CNTRC) cylindrical panels is examined in the current study. The equivalent material properties are achieved using homogenization techniques. First, the heat conduction equation along the thin shell thickness is extracted and solved employing finite difference and Crank-Nicolson methods. After obtaining the temporal evolution of the temperature profile in the shallow panel and also attaining the thermal forces and moments over time, the two-dimensional motion equations are derived. These equations are derived based on the Donnell strain-displacement assumption. The in-plane and out-of-plane displacements are calculated by implementing the generalized differential quadrature method accompanied by the Newmark time-stepping procedure. After successful validating, the influences of CNT volume fraction, the geometry of the cylindrical panel, and boundary conditions are investigated on the shell response.

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abst. 2248
Repository

Thermal buckling and post-buckling analyses of rotating Timoshenko beams reinforced with graphene platelet

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A comprehensive study is established to investigate on the thermal buckling treatment and post-buckling response of rotating nanocomposite beams reinforced with graphene platelet (GPL). The nanocomposite beam is a multi-layered beam where the GPL weight fraction may differ in each layer. However, in order to have a functionally graded (FG) nanocomposite beam where its elastic stiffnesses are continuously and gradually varying along the beam height, a convergence study is accomplished. The rotating GPL nanocomposite beam is subjected to a constant temperature change along its thickness while it is rotating at constant speed. The Timoshenko beam theory comes along the von-Karman strain displacement relations to extract the governing equations of motion. The modified Halpin-Tsai micromechanical model is employed to determine the effective thermo-elastic constants of the GPL nanocomposite beam. Three different GPL dispersion patterns including X-, O-, and U-GPL patterns are considered for the analysis. The Ritz technique is accompanied by the Chebyshev orthonormal polynomial set to discretize the weak form of the nonlinear equations of motion. The Newton-Raphson technique is applied to the discretized static nonlinear equations of motion to compute the static deformation due to the centrifugal force. On the basis of two effective algorithms the nonlinear equations of motion are attacked to find out the critical buckling temperature change as well as the post-buckling response. The results reveal the influences of the boundary condition types, the GPL distribution pattern, the GPL weight fraction, the GPL geometry, the beam rotation speed, the slenderness ratio, and the rotor radius to the beam length ratio on the buckling results as well as the post-bulking response. It is inferred that among the GPL attributes, the GPL weight fraction beside the GPL distribution pattern are the most impressive parameters in the determination of the buckling behavior and the corresponding outcomes. Moreover, the boundary condition type is also a very important parameter which can change qualitatively the buckling response. Keywords: Rotating nanocomposite beams; Graphene platelet reinforcement; Thermal buckling; Post-buckling response.

Vibration characteristics of the embedded multi-scale GO/CF hybrid nanocomposite shell containing a viscous fluid flow

abst. 2254
Repository

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Abstract In current paper, an investigation has been carried out on free vibrational behavior of the fluid conveying multi-scale hybrid nanocomposite shell once the structure is embedded on two-variant elastic foundation. The structure is composed of Graphene Oxide (GO) nanofillers and macro Carbon Fibers (CFs) utilized as reinforcements of the polymeric matrix. The effective material properties of the structure are obtained via the Halpin-Tsai micromechanical scheme for GO nanofillers and the rule of mixture method for CFs. The differential governing equations are derived by Hamilton's principle on the basis of the first order shear deformation theory and then by applying Galerkin's method, the natural frequencies of the hybrid nanocomposite shell are achieved for the different boundary conditions. Furthermore, the accuracy of the present model is verified with previous works via different methods. Finally, the influences of the various parameters such as fluid flow velocity, radius and length to thickness ratio, weight fraction of the GO nanofillers, CF's volume fraction, elastic foundation coefficients and various boundary conditions are illustrated in the framework of graphical results and then discussed thoroughly in the manuscript. Finally, it is indicated that the fluid flow velocity plays a damping role in dimensionless natural frequencies and this decreasing effect got intensified at the higher fluid flow velocities and radius to thickness ratios.

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abst. 2255
Repository

Moving load analysis on cross/angle-ply laminated composite nanoplates resting on viscoelastic foundation

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ABSTRACT. In this research contribution, size-dependent forced vibration analysis of embedded cross/angle-plies laminated composite nanoplate in a viscoelastic foundation while subjected to a moving load is investigated. Through Hamiltonian principle, the governing motion equations are derived based on a four-variable refined higher-order shear deformation theory in Cartesian coordinate and Eringen nonlocal differential model (ENDM) is used in order to predict the size-dependent effects. Afterwards, in order to solve the equations, a time-dependent system of state-space in conjunction with an analytical solution method is implemented over the structures. For the first time, the effect of [U+FB01] ber orientations of involved layers, lay-up sequences and numbers, elastic/viscoelastic foundation coefficients, and nanoplate geometries on the size-dependent dynamic behavior of laminated composite nanoplate under moving concentrated load with different values of velocity and time span is examined. Keywords: Laminated composite materials; Viscoelastic foundation; Moving load; State-space method.

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abst. 2256
Repository

Forced resonance analysis in advanced polymeric nanocomposite plate surrounded by an elastic medium

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ABSTRACT. The resonance phenomenon is a key factor in studying different structures. This research work aim is at reporting a size-dependent model to analyze the forced resonance phenomenon in advanced polymeric composites that are reinforced with single-walled carbon nanotubes (SWCNTs). To reach this aim, third-order shear deformation theory in cartesian coordinate combined with a strain gradient elasticity model is adopted. A virtual work of Hamilton statement is implemented over the aforementioned theories to obtain governing motion equations as well as boundary conditions. Then, an analytical Navier based technique is applied to solve the problem of getting the resonance position. The numerical examples are devoted to reporting a variety of active parameters such as geometrical conditions, small scale and elastic medium coefficients, as well as CNTs weight fraction and its distribution patterns. Keywords: Forced vibration; Advanced composite materials; Carbon-based reinforcements; Elastic medium.

Size-Dependent Free Vibration Analysis of Honeycomb Sandwich Microplates Integrated with Piezoelectric Actuators Based on the Modified Strain Gradient Theory

abst. 2257
Repository

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ABSTRACT Applications of the honeycomb structures due to their lightweight and high stiffness together are developed rapidly in different areas of sciences and technologies. Therefore, in the current study, the vibrational behavior of a sandwich honeycomb rectangular microplate, which is integrated with piezoelectric actuators and is rested on the Pasternak elastic foundation is investigated. Based on von Karman's assumptions, the strains are related to the displacements, which are defined via the sinusoidal shear deformation theory. The modified strain gradient theory, which suggests three length-scale parameters, is used to predict the results in the micro-scale. Hamilton's principle and variational approach are employed to derive the governing motion equations. A closed-form solution based on the Navier's method for a simply supported edges microplate is chosen to obtain the natural frequencies. After ensuring the reliability of the results by comparing them in the simpler state with the previously published one, the effect of different parameters on the natural frequencies is considered and discussed. It is seen that the geometrical parameters of the honeycomb cells have a significant effect on the results. Since it is the first analysis of honeycomb structures in small dimensions, so the result can be used as benchmarks for further analyses. Keywords: Sandwich microplate; Honeycomb structures; Piezoelectric materials; Modified strain gradient theory; Sinusoidal shear deformation theory.

Modified Couple Stress Theory Application to Analyze Mechanical Buckling Behavior of Three-layer Rectangular Microplates with Honeycomb Core and Piezoelectric Face Sheets

abst. 2258
Repository

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ABSTRACT The current study is aimed to analyze the mechanical buckling of a three-layered microplate made from honeycomb structures sandwiched between two piezoelectric face sheets. The microplate is located on an elastic foundation that stands both normal and shearing loads. Minghui and Jiuren relations were employed to determine the effective mechanical properties of the honeycomb core. The sinusoidal shear deformation theory (SSDT) was also employed as a higher-order theory with trigonometric shear deformation function to describe the displacement components. The governing equations were derived using the virtual displacement principle and modified couple stress theory

(MCST) was employed to predict the results in micro dimension. Navier's solution method was chosen to analytically extract the critical buckling loads for a simply supported edges microplate. The effect of the most important parameters such as geometrical specifications of the honeycomb core on the results was also considered and discussed. Nowadays the honeycomb structures are widely used in different areas of sciences and technologies due to their lightweight and high stiffness. Also, the piezoelectric materials are applied as sensors and actuators in smart engineering structures. Therefore, the outcomes of this study may help in designing and manufacturing more applicable structures and smart devices capable of tolerating loading conditions, especially in small dimensions. Keywords: Mechanical Buckling; Honeycomb structures; Piezoelectric materials; Sandwich microplate; Modified couple stress theory; Sinusoidal shear deformation theory.

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abst. 2261
Room 3
Wednesday
September 1
17h10

Linear piezoelectric material modelling with Peridynamics

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Peridynamics [1,2] is a recent theoretical and numerical method that allows the natural appearance and propagation of cracks without an additional special treatment and due to its formulation, the theory is nonlocal, which allows the simulation of materials at multi scale due. Numerically, its implementation is also straightforward, since no local derivatives are present in the equation of motion. Its numerical implementation can be done as a typical meshless point collocation scheme. Peridynamics has been used to model complex constitutive material behaviors like viscoelasticity, plasticity and viscoplasticity. Besides the classical solid/structural mechanics problems, peridynamics can also be used to describe coupled-field phenomena such as thermomechanics and electromechanical coupling. For instance, recently Roy et al. [3] proposed a flexoelectric PD model for centrosymmetric dielectrics. The current work concerns the expansion of electromechanical peridynamic models to piezoelectricity. More specifically, an implicit non-ordinary state-based peridynamic model of piezoelectricity is developed. Due to the implicit implementation, the model is resolved more expediently. This allows the analysis of the static, quasi-static, dynamic behaviour of the proposed model with discontinuities/cracks in a straightforward manner. Results are presented to illustrate the performance of the present model. REFERENCES [1] S.A. Silling, Reformulation of elasticity theory for discontinuities and long-range forces, J. Mech. Phys. Solids. 48 (1) (2000) 175–209 [2] S.A. Silling, M. Epton, O. Weckner, J. Xu, E. Askari, Peridynamic states and constitutive modeling, J. Elast. 88 (2) (2007) 151–184 [3] Roy, P.; Roy, D. Peridynamics model for flexoelectricity and damage. Appl. Math. Model. 2019, 68, 82–112. [4] H. Chen, Bond-associated deformation gradients for peridynamic correspondence model, Mech. Res. Commun. 90 (2018) 34–41

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abst. 2275
Room 3
Thursday
September 2
11h30

A novel data-driven computing algorithm for strong nonlinear response simulation of thin-walled composite structures

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This work aims to propose a novel data-driven computing algorithm for strong nonlinear response simulation of thin-walled composite structures. The specificity of the present work lies in the using of model reduction and directly embedding the generalized stress and strain data (normal strain, curvature, normal force, bending moment, etc.) into mechanical simulations. Towards this end, the tensile-bending and buckling analyses of composite beam, whose property is described by non-linear material and geometrical behavior, are carried out to demonstrate the efficiency and accuracy of the proposed scheme. It consists of three main aspects: (1) hybrid database construction, (2) tensile-bending and buckling analyses and (3) mesoscopic instability phenomena. Firstly, by using the combination of uniaxial tension/compression and bending numerical experiments, the generalized stress and strain data can be collected so as to construct the structural genome database. Secondly, the tensile-bending and buckling analyses of the elastoplastic beam are conducted by using the proposed data-driven approach, in which Newton-Raphson method is utilized for the nonlinear iterative process. Ultimately, a composite beam with complex mesoscopic geometry and material properties is investigated to validate the proposed method. It is found that the proposed algorithm permits to efficiently trace the strong nonlinear equilibrium path and is able to perform numerical simulation for composite structures with complex mesoscopic mechanisms.

Applications of Composites

abst. 2094
Repository

A Formalized Selection of Composite Materials for Application on Large Power Transformer Tank

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Large Power Transformers (LPT) are a major element of the modern transmission grid. They consist of several components including steel oil tanks, bushings, radiators, cores, and other elements. The tanks of the traditional LPTs are made of low carbon steel which could contribute to their overall weight. This study provides a preliminary evaluation and selection process to modernize LPT tank material following well established principles of advanced materials engineering. One of the primary objectives of this study was to select an advanced material for an LPT tank to make it more resilient to potential in-service structural damage, and weight reduction. In the selection process, CES EDU PACK software was first used to identify potential candidates for new tank materials. This resulted in the selection of five advanced composite materials based on glass and carbon fibers with epoxy and phenolic resins employing two different fiber architectures. These composites were further screened to identify the most suitable materials considering several environmental conditions that the tank could be exposed to in service. Conditions such as extreme heat and cold, seismic vibrations, impact resistance, and acid rain were considered. As part of the final materials selection analysis, the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) method was employed for the final ranking of the LPT tank replacement materials which are GFRP and CFRP of unidirectional and woven architectures. These composites were arranged in a sandwich structure with a novel core made of woven glass fiber to improve the impact resistance of the tank.

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abst. 2199
Room 2
Thursday
September 2
09h40

A design procedure of a structural device for vibroacoustic measurements in a wind tunnel facility

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In order to measure the vibrational response of a test model subjected to an aerodynamic load inside a wind tunnel facility, a support system needs to be designed. The design process should ensure an energy transmission decoupling between the support and the test model under experiment, so that structural vibrations would not be transmitted to the test model, and consequently the measurement purity is guaranteed. The present work focuses on the development of a quick design method, based on Statistical Energy Analysis, which will guarantee an energy transmission decoupling between generic support systems and test model, expressed as difference of vibrational velocity levels between the two structural systems. An application of the design procedure is shown, together with the main effect that different design parameters – as area, thickness, material stiffness, damping – might present. A validation method is presented too, in order to test the designed structure before using it directly in a wind tunnel facility.

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abst. 2281
Room 2
Thursday
September 2
10h00

Improving electrical, mechanical, adhesion properties of composite materials by surface modification

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In this study, a soft layer method is applied to overcome the low electrical contact resistance of CFRP. In addition, the electrical, mechanical and adhesive properties of various CFRP bipolar plates manufactured through this study are investigated. Polymer release films (PTFE or FEP) are inserted on both sides of the composite laminate and compression molded. The excess resin on the surface is compressed and removed by compression deformation of the release film. The experimental comparison of the electrical, mechanical, and adhesive properties of CFRP is conducted. The contact resistance is lowered by direct contact of the carbon fiber exposed to the surface, and the tensile strength is increased by the soft layer uniformly distributing the compressive load during curing. Finally, the carbon fibers exposed on the surface form surface roughness and shows the effect of increasing the adhesive properties without additional surface treatment.

Hydrothermal treatment based on the sulfonic species for improved efficiency of the carbon felt electrodes for the vanadium redox flow battery

abst. 2282
Room 2
Thursday
September 2
10h20

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Electrochemical behavior of the carbon felt electrode for vanadium redox flow battery (VRFB) has been improved by means of successful introduction of the sulfonic species at the surface of the carbon felt electrode. Influence of the temperature have been studied towards the reaction of the VRFB. The structure, composition and electrochemical properties of the treated specimens have been characterized by the X-ray photoelectron spectroscopy, X-ray diffraction analysis and battery test. The improvement in the wettability has also been evaluated. The treatment of the carbon felt electrode leads to the electrode for better electrochemical activity towards the VO2+/VO2+ and V3+/V2+ redox couple. This method introduces the sulfonic species which, enhance the active sites for the vanadium redox couples and reduce electrochemical polarization. Moreover, the sulfonic species enhances the wettability of the carbon felt electrode which leads to the enhance in mass transfer of the active species. The reduction in electrochemical polarization and increase in mass transfer of the active species results in the improvement of the battery cell performance with treated carbon felt composite electrode.

Development of carbon felt electrode integrated composite bipolar plate

abst. 2283
Room 2
Thursday
September 2
10h40

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Vanadium Redox Flow Battery (VRFB) is Energy Storage System (ESS) that converts chemical energy into electrical energy and stores it within the cell, Renewable energy has recently attracted attention. At the same time, VRFB, which can store renewable energy, has no risk of fire, has easy capacity expansion, and has an operating life of more than twice that of lithium-ion batteries, is attracting attention. However, VRFB has a problem in that it has a lower energy density than lithium-ion batteries. In this study, it was conducted to increase the efficiency of the VRFB stack. Since the pressure inside the stack of VRFB is relatively low, high contact resistance occurs between the carbon felt electrode and the bipolar plate. This becomes a factor that reduces the stack energy efficiency. To solve this problem, the central part of a single carbon felt is made of a carbon felt/epoxy bipolar plate. Since the electrode and the bipolar plate are made of a single felt, the contact resistance doesn't exist. To verify the performance of the carbon felt electrode integrated composite bipolar plate, area specific resistance (ASR) and gas permeability were measured. In addition, a single cell test was conducted to confirm the improvement of stack efficiency.

Effect of extrusion on microstructures and mechanical properties of in situ Al2O3/Al-Si composites fabricated by reactive sintering.

abst. 2314
Repository

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The effect of extrusion on the microstructure and tensile properties of in situ Al2O3/Al-Si composites was studied. The microstructures results showed micro-cracks and cleavage of Al2O3 and Si particles owed to the applied compressive forces during extrusion process. In addition, these particles were distributed homogeneously along the extrusion direction. In case of 30vol.%, the massive silicon blocks ([U+FF5E]130μm) were refined to (5[U+FF5E]10μm) and dispersed into an alignment distrubution, However, the hot extrusion deformation didn't affect much the size of the massive Si blocks at the side of the billet, thereby, a luck of homogeneous distribution was observed.. Mechanical properties including brinell hardness and room tensile strength of the as extruded composites were tested, analyzed and compared with that of the as sintered composites. The as extruded composites with volume fraction of 10 and 20.vol% showed significant improvements in Ys and UTS of (125%, 66%), (84%, 50.8%) and (94.9%, 99%), respectively. This was also accompanied with further improvement in ductility of 47.5% and 120.5%, respectively. Whereas, the as extruded composite with 30vol.% depicted a similar elongation with that obtained in case of the as sintered state. Increments in hardness of 20, 19.3 and 11.11% were obtained.

Auxetic materials and structures

Auxetic structure with tri-directional symmetry

abst. 2181
Repository

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A new auxetic structure with tri-directional symmetry was designed in this paper. Experimental samples were fabricated through Multi-jet Fusion process and experimentally compressed quasi-statically. Finite element model was developed using ABAQUS and validated by experimental results in terms of deformation mode, stress-strain curve, and Poisson's ratio. Size effect analysis revealed that a minimum of 5×5×5 cells are required to eliminate boundary effect. Theoretical model was also developed to predict the Poisson's ratio of a unit cell of the new auxetic structure. The theoretically predicted Poisson's ratio matched well with that obtained from a finite element model which utilized periodic boundary conditions. Parametric study using the theoretical model revealed that angle of the inclined members had a significant impact on the Poisson's ratio.

Multifunctional heating film of thermoplastic composite joints and its induction welding performance

abst. 2228
Room 1
Friday
September 3
13h10

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This paper presents the use of sendust/poly-ether-ketone-ketone (sendust/PEKK) films to improve the induction welding performance of carbon fiber/poly-ether-ketone-ketone (CF/PEKK) composite joints. A flake-shaped sendust was selected as a heating element due to the remarkable intrinsic characteristics such as high magnetic permeability, high electrical resistivity, and low magnetostriction. The types of the sendust (10, 20, 30, 40, and 50 wt.%) were employed to weld CF/PEKK adherents, and they were fabricated by solution mixing PEKK and magnetic particles. The microstructure characterization and magnetic properties of sendust/PEKK were investigated by scanning electron microscope (SEM) and vibrating sample magnetometer (VSM). A quality of the films with different sendust contents was evaluated by comparing the heating rate. Also, the welding performance of CF/PEKK composite joints was assessed through single-lap shear strength (SLSS) and interlaminar shear strength (ILSS) tests. The test results can be seen that as sendust contents increased, the mechanical property improved due to their highly magnetic flux. Based on these results, the multifunctional heating film was proved as a promising candidate for thermoplastic composite joint. Acknowledgement This study was supported by the " Development of Composites Repair Process for Aircraft Winglet" through the Ministry of Land, Infrastructure and Transport (19ACTP-B147766-02). Keywords: Multifunctional heating film, Thermoplastic composites, Induction welding, Mechanical properties, Energy efficiency, Edge effect.

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abst. 2249
Repository

PERFORMANCE OF AUXETIC CORE 3D PRINTED SANDWICH STRUCTURES UNDER ACOUSTIC AND SHOCK WAVES

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Composite sandwich structures have become more attractive materials, thanks to their high strength, rigidity, and lightweight. In addition to being designable for the desired working conditions and many advantages (easy to install and assembly, being easily reparable etc.); due to the porous and hollow structure of the core geometries forming the structure, they are also ideal materials for sound and heat insulation, especially in structural applications. By the production technologies developed in recent years, it has become possible to produce structures with Negative Poisson's Ratio (NPR), known as "metamaterials." These structures, also known as auxetic metamaterials, can exhibit unique mechanical properties thanks to their NPR feature. Compared to conventional materials, auxetic structures exhibit superior strength, better energy absorption capability, higher impact resistance, and shear modulus. In this study, two different sandwich structures (traditional hexagonal honeycomb and re-entrant auxetic) were produced by 3D printers. One of the structures is configured with a traditional feature and the other with NPR feature core geometry. Acoustic performances were measured with Acoustic Impedance Tube. Furthermore, the Shock Loading behavior of the sandwiches was carried out by using a shock tube test set up. Thus, both the acoustic performances and the mechanical behavior of the structures under shock load have been studied experimentally. For both loading cases, the effect of auxetic core was studied and compared. Moreover, the results were discussed according to the wave speed.

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abst. 2250
Room 1
Friday
September 3
12h50

Honeycomb sandwich structures made with cork

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Honeycomb sandwich structures made with cork Mafalda Esteves, Francisco Rede, Paulo Nóvoa, António Torres Marques* *marques@fe.up.pt The increasing enviromental concern and the systematic search for new and sustainable solutions, allowed the application of cork in fields and areas where once seemed impossible for it to fit. Cork is a natural resource used by Humanity for over 5000 years and it has, currently, a well-noted importance and the most diverse applications from bottling to aeronautical industry. As Portugal is the world's leading exporter of cork, its investment brings direct economic benefits, as well as the creation of new factories, thus generating higher employment. The majority of the cork is used under the form of composites that added to other materials can become parts and pieces of great mechanical endurance and durability. Cork is also well known for its thermal, acoustic and vibration isolation properties. From the structural point of view, its integration as a core of composite sandwiches has also shown very interesting results. Mainly, due to the combination of the low density of cork, along with the properties of the face-sheets - usually composed by fibers - which confer mechanical characteristics similar to those of structures with polymeric cores. This paper aims to present the advantages that can arise from changes in the core structure of a sandwich construction with fiberglass composite face-sheets. In this study, a low-density cork board (150 kg/m3) was used to produce both a cylinder honeycomb, a hexagonal honeycomb and na auxetic cork core. The mechanical properties of the obtained composites were compared with other well-known materials and composites. To find the optimized structure, a few simulations were carried out using the software ABAQUS CAE. The simulations were based on four different mechanical tests, according to the standards, namely: ASTM C393/393M-11 for the bending test; ASTM C365/C365M-11a for the compression test; ASTM

D7136/D7136M-0.5 for the low-velocity impact and finally, ASTM C 273 – 00 for the shear core test. To choose the dimensions of the honeycomb cell size, the three tests simulated were a three-point bending test, a compression test, and a low velocity impact test, using cork NL10. Since the comparison is between cell sizes, the elastic properties (modulus and Poisson ratio) were taken from a database, CES Edupack. A comparison of sandwich core will be made mainly evaluating the possible advanteges of an auxetic core.

Beam, Plate and Shell Theories and Computational Models for Laminated Structures

abst. 2017
Room 3
Wednesday
September 1
14h50

Influence of the excitation direction on the dynamics of the laminated beam with symmetrical or anti-symmetrical layers arrangement

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Influence of the excitation direction on the dynamics of the laminated beam with symmetrical or anti-symmetrical layers arrangement Marcin Bochenski, Marek Borowiec, Jaroslaw Gawryluk, Andrzej Teter, Lublin University of Technology, Faculty of Mechanical Engineering, Department of Applied Mechanics, Nadbystrzycka 36, PL-20-618 Lublin, Poland; e-mails: m.bochenski@pollub.pl, m.borowiec@pollub.pl, j.gawryluk@pollub.pl, a.teter@pollub.pl; The research was financed within the framework of the Lublin University of Technology - Regional Excellence Initiative project, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19). The cantilever beam made of laminate with symmetrical or anti-symmetrical layers arrangement was excited in different directions and with various amplitudes. The couplings of vibration modes in flexible, stiff and torsional directions are taken place. In this case, it is difficult to predict the dynamic response of the system, especially if the kinematic excitation can assume any direction and amplitude. Numerical simulations using the finite element method were performed. The beam was made of unidirectional pre-impregnate with a matrix of thermosetting epoxy resin reinforced with high-strength R-type glass fibers. The following layers arrangement was considered: alpha(5)/0/alpha(5) and alpha(5)/0/-alpha(5) called symmetrical and anti-symmetrical, respectively. A substantially rectangular cross-section of the structure leads to significant differences in bending stiffness in two perpendicular directions. The continuum shell finite elements SC8R was used to prepare a numerical model of the beam. The implicit dynamic analysis using direct integration was used. Experimental verification of the selected numerical results for various angles (denoted as alpha) of layers arrangement was carried out. The structure was mounted on the specialized grip on the electromagnetic shaker, which was a source of kinematic excitation. The response of the system was measured using piezoelectric patches, strain gauges, and contactless laser sensors. The piezoelectric element type Macro Fiber Composite was included in the numerical model of the structure. The non-linear characteristics, both types progressive and regressive, for the system response versus amplitude of excitation were found. The strong influence of layers arrangement on the system behavior was confirmed. Configurations characterized by low and high values of coupling coefficients were determined.

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abst. 2018
Room 3
Wednesday
September 1
15h10

Influence of Composite Ply Sequence on Nonlinear Dynamics of a Hinged Beam Structure: numeric vs experimental investigation

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The hinged – hinged beam with additional moments of inertia at the ends was modelled by finite element method. In the analysis, distribution of hinge's mases were taken into account. The beam was made of unidirectional pre-impregnate with a matrix of thermosetting epoxy resin reinforced with high-strength R-type glass fibers. For manufacturing the composite structures of selected layers arrangement, the autoclave technique was applied. The symmetrical as well as anti-symmetrical fiber configurations were analyzed in layers configuration alpha(5)/0/alpha(5) and alpha(5)/0/-alpha(5), where alpha is the

angle of fibers orientation related to the axis of the beam. The considered boundary conditions lead to the nonlinear dynamic response in the vicinity of the primary resonance zones under harmonic kinematic excitation generated in the beam's plane of lower flexural stiffness. For selected fibers configurations, interactions in two orthogonal flexural (flexible and stiff) and longitudinal directions and also torsion due to beam's span responses were analyzed. The numerical results were verified in the experimental investigation. The dedicated setup of the beam, which allows changing the boundary conditions (masses values and their inertia) was manufactured and then mounted on to the electromagnetic slip table. Good agreement in the numerical and experimental results was achieved. The influence of the fibers configuration on nonlinear behavior of the structures was observed. The research was financed within the framework of the Lublin University of Technology - Regional Excellence Initiative project, funded by the Polish Ministry of Science and Higher Education (contract no. 030/RID/2018/19).

Semi-analytical assessment of free-edge stress fields in circular cylindrical cross-ply laminated shells subjected to hygrothermomechanical loads

abst. 2042
Repository

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This paper contributes to the topic of efficient computational methods by introducing a semi-analytical approach which enables the three-dimensional stress assessment in circular cylindrical symmetrically and unsymmetrically cross-ply laminated shells undergoing combined mechanical and hygrothermomechanical loads. The presented analysis method incorporates a closed-from plane-strain analysis in the innermost regions of the laminated shell, which is upgraded by a higher-order displacement-based approach resulting from a discretization of the shell panel with respect to the thickness direction and introducing a priori unknown displacement functions for each of the numerical plies. By employing the principle of minimum elastic potential, the governing equations are obtained which, further on, are solved by means of the state-space approach. Enforcing traction-free boundary conditions finally leads to a formulation which enables the full-scale interlaminar stress assessment in thick composite laminated shells. A comparison of the presented semi-analytical approach with existing analysis methods in the literature as well as finite element simulations shows that the developed computational method works with comparable accuracy, however, only at a fraction of the effort that is required for highly detailed three-dimensional finite element computations.

Free vibration analysis of tow-steered composite laminates by novel quasi-3D hierarchical models

abst. 2045
Room 3
Thursday
September 2
13h10

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Liu Bo (liubo68@buaa.edu.cn), School of Aeronautic Science and Engineering, Beihang University, Xueyuan Road 37, 100191 Beijing, China, China

The present work analyses the free vibration behavior of variable stiffness composite laminates (VSCL) featured by spatially varying fibres orientations via novel quasi-three-dimensional solutions. The Carrera Unified Formulation (CUF) is employed to construct such novel models, where the cross-section kinematics are described with improved hierarchical Legendre expansions (IHLE) of the primary mechanical variables. Such novel expansions maintain the hierarchical properties of HLE but also become less sensitive to the numbering of expansion terms. Accordingly, the Equivalent Single Layer (ESL) and Layer-Wise (LW) models can be formulated more robustly via this enhanced kinematics. The weak form differential quadrature finite element method (DQFEM) is employed to solve the governing equations derived by the principle of virtual displacements. Based on CUF-based DQFEM, even a single beam element is sufficient enough to tackle many complex issues with high accuracy. Compact VSCL

beams and plates with various fibre paths, boundary conditions, lamination schemes, and thickness-to-width ratios have been studied in numerical examples. The accuracy and effectiveness of the proposed method are verified by comparing the results with the data in the published literature.

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abst. 2092
Room 1
Wednesday
September 1
13h10

Non-conventional 1D and 2D curvilinear finite elements based on CUF for the analysis of very complex geometries

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The Finite Element Method (FEM) is a well-established method and yields accurate results for the structural analysis of any geometrical shape. However, when dealing with innovative materials - such as metamaterials or biomaterials with complex architected microstructure - or structural components with non-conventional beam/shell geometry, this method can become very costly in calculations and time. Moreover, classical 1D and 2D models cannot be employed for the analysis of beam-like and plate-like structures that don't present conventional geometrical features, such as uniform cross-section for beams or constant thickness for shells. In these cases, the researchers have to resort to very fine 3D meshes encountering the following main drawback: the high computational cost associated with the classical 3D elements that sometimes make the analyses infeasible. In this framework, the Carrera Unified Formulation (CUF) allows the formulation of a series of 1D and 2D finite elements with 3D capabilities that strongly reduce the number of degrees of freedom of the analysis with respect to classical 3D elements, being equal the accuracy of the results [1]. Moreover, a novel approach, called Node-Dependent Kinematics (NDK), has been proposed to further increase the numerical efficiency of the models and it implements local kinematic refinements on the selected FE nodes within the domain of interest [2]. Since the structures mentioned above usually present curved geometry, it is convinient to formulate such finite elements using local curvilinear coordinates. Shell finite elements have been commonly used for the analysis of general shell structures and these discretizations can be used generally for both thick and thin shells. However, the use of these elements is limited to the analysis of shells with constant thickness. The study of general curved structures (with curvature also in the third direction) requires a deeper mathematical as well as physical understanding [3]. This research aims to formulate the non-conventional CUF finite elements already presented in work [4] in general curviliear coordinates for the analysis of beam-like and shell-like components having curved geometry. These new elements are formulated on the basis of a simple idea: the computation of the Jacobian matrix inside the element in '3D form', by still employing one-dimensional or two-dimensional kinematics of the CUF. In this work, only Lagrange expansions are considered but the approach can be straightforwardly applied also to other kind of expansions. The main advantage of these non-conventional 1D and 2D elements is represented by the possibility to adopt local refinements of the mesh where the geometrical features of the component, in addition to the kinematic behavior, require that. A free-vibration analysis of beam-like and shell-like curved components is performed and the results, in terms of natural frequencies, are compared with the convergence solutions computed with commercial softwares. [1] Carrera E., Cinefra M., Petrolo M., Zappino E., 'Finite Element Analysis of Structures through the Carrera Unified Formulation', John Wiley Sons, UK, 2014. [2] G. Li, E. Carrera, M. Cinefra, A.G. De Miguel, A. Pagani and E. Zappino, An adaptable refinement approach for shell finite element models based on Node-Dependent Kinematics, Composite Structures, 2019, vol. 210, pp. 1–19. [3] M. Cinefra, Formulation of 3D finite elements using curvilinear coordinates, Mechanics of Advanced Materials and Structures, 2020, pp. 1-10, doi:10.1080/15376494.2020.1799122. [4] M. Cinefra, Non-conventional 1D and 2D finite elements based on CUF for the analysis of non-orthogonal geometries, European Journal of Mechanics/A Solids, 2021, vol. 88, 104273.

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abst. 2128
Room 3
Wednesday
September 1
15h50

Flexural analysis of laminated beams using zigzag theory and a mixed inverse differential quadrature method

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Zigzag theories are robust equivalent single layer models for stress analysis of laminated structures. They provide highly accurate stress predictions, especially in combination with through-thickness higher-order shear deformation theories, with significant reduction of computational time in comparison with finite element modelling or layer-wise theories [1]. However, the interlaminar continuity of transverse stresses is usually not guaranteed via the constitutive relations. Indefinite integration from Cauchy's equilibrium equations can address this issue but the inconsistency between transverse stresses from this equilibrium integration and those from constitutive relations remain. By employing a compact form of the Hellinger-Reissner mixed variational principle, the Cauchy's equilibrium conditions can be included in the variational statement to provide a variationally consistent solution. This approach was implemented successfully for analysing stresses in highly heterogeneous laminated beams [1]. It is worth mentioning that the governing equations resulting from this variational statement include fourth-order derivatives of the functional unknowns, which necessitate multiple successive differentiations in numerical methods. This current study presents an inverse DQM (iDQM) recently proposed by the authors [2,3] to investigate the flexural behaviour of constant and variable angle tow (VAT) laminated beams. In the iDQM approach, derivatives of primary quantities are approximated, thereby reducing the order of differentiation that needs to be performed. Moreover, the necessity of using higher-order axial displacements for better predictions of stresses near the boundaries is examined. Together with refined zigzag theory (RZT) and Murakami zigzag theory (MZZF), third- and fifth-order global displacement fields are employed in this example for stress prediction of moderately thick sandwich and VAT beams. Numerical results from the first-order mixed iDQM, i.e. first derivatives of functional unknowns are approximated using Lagrange polynomials, are verified with those obtained from conventional DQM and a high-fidelity 3D finite element solution (Abaqus commercial software). With the same third-order zigzag displacement fields (HR3-RZT/HR3-MZZF), improvement is observed in using iDQM for solving the governing equations. Moreover, the results also show that a fifth-order zigzag model (HR5-MZZF) is needed for predicting stresses in the vicinity of boundaries in VAT beams. References [1] R.M.J. Groh and P.M. Weaver (2015). On displacement-based and mixed-variational equivalent single layer theories for modelling highly heterogeneous laminated beams. International Journal of Solids and Structures, 59, 147-170. [2] L.C. Trinh, S.O. Ojo, R.M.J. Groh and P.M. Weaver (2021). A mixed inverse differential quadrature method for static analysis of constant- and variable-stiffness laminated beams based on Hellinger-Reissner mixed variational formulation. International Journal of Solids and Structures, 210-211, 66-87. [3] S.O. Ojo, L.C. Trinh, H.M. Khalid and P.M. Weaver. Inverse differential quadrature method: mathematical formulation and error analysis, Accepted in Proceedings of the Royal Society A.

Propagation of guided waves in two dimensional quasicrystal multilayered plates with imperfect interfaces

abst. 2151
Room 3
Thursday
September 2
12h30

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Composite materials are proposed to meet the needs of the rapid development of the industry. Quasicrystals (QCs) are a new type of composite material, and the ordered and quasi-periodic atomic arrangement in QCs enable them to exhibit some complex structures and special properties in theoretical analysis and experiments, such as high hardness, high toughness, high abrasion resistance, high resistivity, low friction coefficient, and low thermal conductivity and so on. Due to these unusual properties, QCs possess many potential applications in engineering, including solar thin film, thermoelectric converter, thermal barrier coating for the engine, and structural reinforcement phase in composites. With the in-depth development of the research studies on the promising composites of QCs, the multilayered structure models provide significant instructions to understand the characteristics of QC coatings or thin films. The two-dimensional (2D) QC belongs to a three-dimensional (3D) structure with quasi-periodic in two directions and periodic in another. To predict the mechanical properties of the 2D QC multilayer structure, various analytical/numerical studies and mechanical models have been carried out on these multiphase and multifunctional materials, which include research on the static response, free vibration, and the effective bulk material properties. However, the delamination and cracking problems may appear in multilayered composites with homogeneous/ non-homogeneous layers, which can limit the application of 2D QC laminates. Therefore, nondestructive inspection based on the propagation of elastic waves plays an important role in damage identification in multilayered structures. In this paper, an analytical solution for the propagation of the guided wave in an orthotropic, multilayered, two-dimensional decagonal quasicrystal plate with imperfect interfaces is derived. According to the elasto-dynamics basic equations of quasicrystals, the time-harmonic wave propagating problem in the plates is converted into a linear control system by employing the state vector approach, from which the general solutions of the extended displacements and stresses can be obtained. These solutions along the thickness direction are utilized to derive the propagator matrix which connects the physical variables on the lower and upper interfaces of each layer. Making use of the discontinuity conditions of the field quantities at the interface of two adjacent layers, the total propagator relation is constructed to propagate the solutions in each interface and each layer. Furthermore, if we assume that the upper and bottom surface traction of the laminate is free, the dispersion equation can be obtained. Finally, typical numerical examples are presented to illustrate the marked influences of stacking sequence, the orientation angle of the wave, and interface coefficients on the dispersion curve and displacement mode shapes of the QC laminates.

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abst. 2190
Room 3
Wednesday
September 1
15h30

A mathematical model for the specific gas sensor based on the oscillations of functionalized carbon nanotubes

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This present paper is proposing a carbon nanotubes based sensor to determine concentration of one specific gas component in the atmosphere. The operation of the sensor is based on the change in the frequency of the transverse oscillations of the carbon nanotubes following their attachment to a specific gas molecule. The problem of nanotube selectivity for a certain gaseous component in the atmosphere is solved by functionalizing the nanotube. Through functionalization, the mechanical properties of carbon nanotubes will be modified. After activating the oscillations of the nanotubes, the initial spectrum of frequencies is recorded, then the sensor is exposed in the atmosphere to be evaluated, and the gas molecules attached to the nanotubes change the frequency of the oscillations. The initial frequencies spectra of the parallel carbon nanotube matrix with the same geometry is compared with the oscillation frequency spectra collected after the sensor is exposed to the atmosphere. The mathematical model presented in this paper shows the dependence between the concentration and the variation of the oscillation frequencies of the carbon nanotubes. Keywords: functionalized carbon nanotube; sensor; gas concentration; oscillation frequency of the nanobeam.

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abst. 2200
Room 1
Wednesday
September 1
12h50

Accurate stress fields evaluation of post-buckled laminated composite plate structures with various geometrical and mechanical boundary conditions

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The accurate nonlinear analysis of highly flexible plate structures is of primary importance because of their broad range of applications in different engineering fields such as aerospace and construction. In this research, the Carrera Unified Formulation (CUF) is used in order to investigate the large-deflection and post-buckling behavior of rectangular laminated composite plates. According to the intrinsic scalable nature of the CUF, the structural theory approximation order and the strain-displacement assumptions are tuned opportunely, and different nonlinear strain assumptions are considered in 2-D CUF with the total Lagrangian framework. In this regard, the Newton- Raphson linearization scheme is employed with the path-following method based on the arc-length constraint. Therefore, several numerical assessments of large-deflection and post-buckling of symmetric and antisymmetric composite plates are conducted. The well-known von Kármán theory and some modified strain displacement relationships with various nonlinear terms are compared with the full Green-Lagrange nonlinear model based on the 2-D CUF model. Furthermore, a comprehensive investigation of the effect of geometrical and mechanical

boundary conditions on the nonlinear response of laminated composite plate structures is presented. A number of interesting conclusions regarding the efficiency of the presented model are highlighted. The post-buckling equilibrium curves and the stress distributions of laminated composite plates obtained accurately by the proposed efficient method are compared by many strain displacement assumptions made in the literature on the kinematics of highly flexible plates. The findings of this research demonstrate that the full Green-Lagrange nonlinear model based on the 2-D CUF model can predict the nonlinear behavior of laminated composite plates efficiently and accurately that can be a basis to evaluate the effectiveness of different structural theory approximation orders and nonlinear strain assumptions.

VIBRATIONS AND BUCKLING OF COMPOSITE PLATES BASED ON STRAIN GRADIENT THEORY AND MESHLESS METHODS

abst. 2263
Repository

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In the current literature MEMS (Micro-Electro-Mechanical- System) and NEMS (Nano-Electro-Mechanical-System) are topics of relevant interest because of their various uses. Indeed, these types of materials can be employed in many areas of application, i.e. engineering, medicine and electronics, in the form of generators, transistors, sensors, actuators, resonators, detectors etc. Vibrations and buckling of nano plates are investigated using second-order strain gradient theory. The differential problem has been solved by means of weak forms meshless methods for different boundary condition configurations for the plates as well as stacking sequencies. Different geometries and material properties for isotropic and laminated materials are considered, and numerical simulations are discussed in terms of plate aspect ratio and non local ratio. A comparison with the classical analytical solution is provided whenever possible for buckling loads and fundamental frequencies.

Numerical Model for Global/Local Buckling Analysis of I-Beam via Hierarchical One-Dimensional Finite Elements

abst. 2278
Room 3
Thursday
September 2
12h50

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Thin-walled structures, including I-beam, have wide application in engineering. However, these structures tend to have severe instability phenomena such as buckling, wrinkling and global-local coupling buckling before reaching the ultimate strength state of the material because of the large slenderness ratio and the narrow cross-section features. This paper proposes a numerical model based on a hierarchical one-dimensional unified formulation for the analysis of buckling and wrinkling phenomena in the I-beam. The model is constructed within the framework of Carrera's Unified Formulation (CUF), which uses Lagrange polynomials to express the three-dimensional displacement field as an arbitrary order approximation by displacement variables on each layer. Due to its high efficiency and step size adaptability by expanding nonlinear equilibrium path with power series, Asymptotic Numerical Method (ANM) is adopted to solve the nonlinear governing equations. Numerical investigations show that the proposed model are able to capture the instability phenomena in thin-walled I-beam. In order to validate the reliability and efficiency, the critical buckling point and wrinkling displacement field can be precisely obtained by the proposed model, and a very good agreement is found in the comparison with those obtained via three-dimensional finite element solution.

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abst. 2295
Repository

Natural Element Hierarchic Models for Laminated Composite Plates

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This paper presents the hierarchic models for laminated composite plates in the framework of 2-D natural element method (NEM). The current study was inspired by the fact that the classical composite plate theories are restricted to thin structures and most of hierarchic models have been implemented by FEM. The NEM was introduced to overcome the disadvantages of conventional mesh-free methods, and currently it becomes a most widely-used mesh-free method. In the hierarchic models, the displacement field is expressed in the product of the 2-D in-plane unknown functions and the 1-D out-of-plane assumed polynomials. The model level of hierarchic model is controlled by the maximum orders of 1-D polynomials in three displacement components, and the in-plane unknown functions, which are supported on the mid-surface of composite plate, are approximated by the 2-D locking-free NEM. The approximated strains and stresses are smoothened by the global recovery technique, and furthermore the transverse shear stresses are improved by the equilibrated post-processing technique. The proposed hierarchic models are applied to four-layered inhomogeneous orthotropic composite plates. Through the numerical experiments, the fundamental features of hierarchic models are investigated in terms of the model level, the structure thickness and the grid density. And, from the numerical results, it is found that the proposed hierarchic models effectively and accurately analyze the laminated composite plates. ACKNOWLEDGEMENT This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (2020R1A2C1100924).

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abst. 2313
Repository

Large-deflection analysis of composite and FGM thin-walled beams under thermal pre-stresses.

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In some applications, working structures, such as rotor shafts, can be simultaneously exposed to mechanical and thermal loads. Moreover, due to extreme service conditions, me- chanical loads may induce large deflections and rotations within the structure, so an accurate evaluation of the geometrical nonlinear behavior of the structure is mandatory for an ac- curate design of such components. Finally, the thermal condition causes pre-stresses which afflict the static nonlinear equilibrium path, so they need to be included within the analysis. The moderns techniques rely on three-dimensional (3D) Finite Element (FE) models for the numerical simulation of such structures (see [1]). Despite significant advances in computing power, complex three-dimensional (3D) Finite Element (FE) models still impose large com- putational costs, especially during the iterative design stage. For this reason, reduced refined models may be used to obtain solutions with lower computational efforts The proposed methodology for the structural analysis of components subjected to thermal pre-stresses and large-deflections was built in the framework of the Carrera Unified Formu- lation (CUF) ([2]). This methodology, according to which the 3D displacement field can be evaluated as an arbitrary expansion of the unknowns evaluated through FE method, is extremely suitable for this analysis. In fact, every component or layer within the structure can have its own kinematic described independently from the others, without the need of any ad-hoc theory implementation. As a matter of fact, one can evaluate the influence of pre-stress, material properties and geometric characteristics in a unified manner. Arch-type structures are analyzed, comparing obtained results with those provided from lit- erature and experimental tests. The results establish and reports graphs showing the effects of the reinforcements on the overall behavior of the components, with the aim of providing a reliable starting point for future design of structure in the civil engineering field. References: [1] M. Zhuo, L.H. Yang, and L. Yu. The steady-state thermal effect on rotordynamics of a rod- fastened rotor-bearing system. In ASME International Mechanical Engineering Congress and Exposition, volume 46483, page V04BT04A014. American Society of Mechanical Engineers, 2014. [2] E. Carrera, M. Cinefra, M. Petrolo, and E. Zappino. Finite element analysis of structures through unified formulation. John Wiley Sons, 2014.

Composite Structures

abst. 1005
Room 1
Friday
September 3
09h40

Novel method for interlaminar reinforcement with no reduction of in-plane properties

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Carbon fibre composites are known for their impressive mechanical properties, but delamination is an issue due to poor reinforcement between layers. A low energy impact (such as a dropped tool) can be enough to initiate delamination. This is termed "barely visible impact damage" (BVID) as such damage may be difficult to notice in a visual inspection. Once a part has started to delaminate, it has essentially failed. A great deal of research has been carried out to address this (such as z-pinning, sewing and tufting) but, as a general rule, these also tend to reduce the in-plane properties of the composite due to effects such as; crimp, waviness, in-plane fibre fracture or simply by reducing the volume of fibre dedicated to in-plane re-enforcement. In this work, a new method of through-thickness reinforcing a composite has been developed which appears not to impact the in-plane properties. A blunted hypodermic needle was inserted through the dry fabric preform allowing a polymer coated carbon filament to be inserted through the needle. The needle was then withdrawn leaving the filament in place and the filament was then cut with approximately 5mm of the filament protruding from each side of the part. This process was repeated for the remainder of the composite plaque to give the required pin density. The dry pinned fibre was then pressed in a heated tool to bend the filaments over and press them into the fibres. Thermoset epoxy resin was infused through the tool using the RTM method and cured to form the composite. Several plaques were produced for tensile, bearing and mode 1 tests. These were at a nominal volume fraction of 47%. No statistically significant reduction in the in-plane tensile properties was observed between the pinned and unpinned laminate. Mode I delamination testing is ongoing, but preliminary testing has been positive, and it is expected that this method will significantly improve the interlaminar properties. Further work will investigate optimising the procedure, with potential to look at other filaments, pin densities and providing additional benefits such as through-thickness conductivity. Given the repetitive nature of the pinning, the potential for automation may also be investigated.

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abst. 1007
Poster

Effect of Eccentric Loading on the Stability and Load-Carrying Capacity of Thin-Walled Composite Profiles with Top-Hat Section

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The objective of this study was to investigate the influence of eccentric compressive load on the buckling, post-buckling and load-carrying capacity of thin-walled top-hat cross-section composite columns. The CFRP columns were manufactured by the autoclave technique. The scope of the study involved performing experimental tests on real structures as well as numerical calculations by the finite element method. The experimental tests were conducted in the full range of loading, until the structure's failure. Post-buckling equilibrium paths and acoustic emission signals were measured in order to determine actual condition of the composite material. Nonlinear FEM calculations were made by the progressive damage criterion, in which the damage initiation of the composite material was estimated based on Hashin's theory, whereas damage evolution was described by the energy criterion. The numerical simulations were performed using the commercial software ABAQUS®. The numerical results were in good agreement with the experimental results obtained for real structures. The results demonstrated a significant influence of eccentric compressive load and configuration of composite layers on the buckling and post-buckling characteristics of the tested structures.

Stability and Limit States of Thin-Walled Composite Profiles Subjected to Eccentric Load

abst. 1008
Poster

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The objective of this study was to investigate the influence of eccentric compressive load on the buckling, post-buckling and load-carrying capacity of thin-walled CFRP composite columns. The scope of research included numerical calculations using the finite element method and experimental tests carried out in the full load range - for collapse of the structure. Post-buckling equilibrium paths and acoustic emission signals were measured in order to determine actual condition of the composite material. Non-linear numerical calculations were carried out using the Newton-Raphson incremental iterative method. Hashin's criterion was used to assess the initiation of damage to the composite material. The evolution of damage to the composite has been described using the progressive failure criterion. The tests carried out made it possible to determine the failure load values and to assess the failure of a thin-walled structure. High compatibility of numerical calculations with the results of experimental studies has been obtained, which confirms the adequacy of the developed numerical models.

Evaluation of stress distributions in the geometrical nonlinear regime of composite and FG structures by means of CUF

abst. 1018
Repository

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In many engineering applications, due to overload conditions, large deformations and rotations can appear within working structures. In such cases, residual stresses may occur in the system. Then, for an accurate design process, a rigorous determination of the stress distribution in the nonlinear regime plays a crucial role. To consider these conditions, a geometric nonlinear analysis should be performed. The nonlinear analysis proposed in this study is based on the Carrera Unified Formulation (CUF). CUF offers a hierarchical formulation that considers the order of the structural model as an input of the analysis. Thus, no specific formulation is required to obtain any model. The possibility of producing high-grade structural elements makes it possible to analyze any loading condition, including the post-buckling situation. In addition, CUF can automatically calculate the hardness matrix, making it possible to evaluate laminated structures without any simplification of the three-dimensional (3D) stress tensor. In this study, stress distributions in the geometric nonlinear regime of composite and functionally graded structures are evaluated with CUF. The results are compared with the literature and the success of this approach in evaluating the 3D stress conditions is demonstrated.

Time dependent spring-in of pultruded L-shaped profile

abst. 1021
Room 1
Friday
September 3
10h00

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Currently pultruded profiles are widely applied as structural elements in different areas due to their high strength, low weight, improved corrosion and fatigue resistance properties. Nevertheless, production of pultruded elements presents challenging aspects related to the peculiarities of pultrusion manufacturing process. For example, produced profiles exhibit shape deformations immediately after curing such as spring-in and warpage. These manufacturing induced shape distortions evidence time evolution behavior. The present paper presents an experimental/numerical investigation of the shape distortions of L-shaped profiles 75x75x6 [mm] made of an ethylene-vinyl acetate resin system reinforced with E-glass rovings and fabrics. The samples were pultruded at three different pulling speeds, namely 200, 400 and 600 [mm/min]. For each of them, the spring-in angle was regularly measured for the 100 days successive to the production. The results evidence the dependence of the shape distortions on pulling speed and on time. A numerical finite element model of the performed process was implemented in Abaqus to simulate the shape distortions. A multiple criteria optimization of process parameters based on the model developed is also discussed.

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abst. 1031
Room 1
Friday
September 3
10h20

On the axial and oblique impact response of an origami composite crash box: an approach to design crashworthiness

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Crash boxes in automotive applications are thin-walled structures designed to absorb energy in frontal crashes. These components are designed to protect the occupants from injuries and preserve the frontal elements of the vehicle from severe damages. Thin-walled structures made of steel or aluminum are often preferred because of progressive and predictable collapse modes and low manufacturing cost. However, in recent years, European emission directives led car manufacturers to investigate alternative engineering solutions to reduce the vehicle's mass and achieve lower fuel consumption. Accordingly, carbon fibre-reinforced polymer (CFRP) for vehicle applications became an alternative to the common metal structures. Different geometries and forms of CFRP crash absorbers have been widely investigated in literature. The energy absorption mechanism of CFRP crash boxes is a combination of several failure modes such as interlaminar failure, fibre-matrix debonding, matrix cracking, fibre breakage and delamination. The interaction between these concurring failure mechanism yields to a complex global crush response, whose prediction was proved to be challenging. Different origami geometries have been the object of research in recent years to obtain controllable mechanical behavior and programmable response. This study proposes a methodology to design a crash box with 1) reduced weight and 2) superior and predictable mechanical performance compared to common metal crash boxes. The first target is achieved by using CFRP as material for the crash box, while the second is accomplished by implementing an origami geometry that collapses and absorbs energy in a predictable and controllable manner. The origami structure here considered is composed by multiple basic modules made of two layers of pre-preg woven fabric, and stacked along the axial direction. The crush response of the full crash box depends on the structure of each basic module. The crush response is extensively investigated at module level on a large set of geometries. A numerical study is here presented in order to define the best sequence of the basic modules that allow to optimize the axial crushing behavior of the full crash box, while reducing its weight. The basic modules are simulated by varying the characteristics of the geometry. In particular, the thickness, the face inclination and the height of the module are handled as design variables. Results of the sensitivity analysis are used as baseline to define a methodology indicating the full crash box structure that exhibits a pre-defined global crush behavior. From the crush response of the basic modules, the crash tube can be particularly assembled. An axial and oblique crash simulation of the assembled crash box is finally performed to validate the proposed approach. The results show that the proposed methodology with assembled single modules allows to design crash boxes with programmable crush responses according to the loading conditions. Specifically, in the event of an oblique impact, the metal crash box evidenced low performances: it deformed in bending and collapsed, considerably reducing the absorbed energy. In contrast, due to the possibility of optimizing

the shape and the geometry, the CFRP origami crash box has globally shown a high bending resistance when subjected to an oblique impact and a greater energy absorption capability.

Experimental and Numerical Analysis of Stability and Failure of Compressed Composite Plates

abst. 2013
Room 2
Wednesday
September 1
12h10

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This paper investigates the stability, load-carrying capacity and failure analysis of thin-walled plate elements weakened by cut-out and subjected to axial compression. Tested plates were made in asymmetric configuration from CFRP composite material with used autoclave technique. The scope of the research included experimental tests on real samples and numerical calculations with using the finite element method in the ABAQUS® program. The influence of the compressive load on the buckling and postbuckling behavior and loss of load capacity of thin-walled composite plates was investigated. Both, the experimental tests and the numerical analysis were carried out in the full load range, up to the structure failure. In the experimental tests, acoustic emissions were used to analyze the damage state of the composite material. Numerical calculations were carried out with the use of progressive failure analysis, based on the initiation of the failure from the Hashin's theory and the further evolution of the failure based on the energy criterion. Numerical results of critical and post-critical state were compare with experimental research showing areas prone to failure of the material. A measurable effect of the conducted research was obtaining a high compatibility of the results of numerical and experimental calculations. Funding: 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 number 030/RID/2018/19).

Buckling state analysis of compressed composite plates with cut-out

abst. 2016
Poster

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The subject of the research was a thin-walled plate weakened by a cut-out, made of carbon-epoxy laminate, subjected to compression. The study included analysis of the critical and weakly post-critical behaviour using experimental and numerical methods. As the result of the research conducted on physical plates, a post-critical equilibrium paths, which were then used to determine the critical loads by approximation methods, were determined. Simultaneously, numerical calculations with finite element method were performed, using linear analysis of eigenvalue problems, which the results led to determination of the critical loads for the developed numerical model. The second step of the calculations included the performing of nonlinear analysis of the structure with initiated geometrically imperfection corresponding to the flexural-torsional buckling mode of the plate. The numerical results were compared with the experimental funding, revealing that the developed numerical model of the structure was correct. The numerical simulations were performed using the ABAQUS® software.

Effect of Fabric Parameters on Process-Induced Residual Deformation of Plain Woven Composite Structures

abst. 2055
Room 2
Thursday
September 2
12h50

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Process-induced residual deformation of plain woven composites is affected by their fabric parameters such as the yarn thickness and gap between adjacent yarns. In this study, the effects of the fabric parameters of the plain woven composite were evaluated on the curing process-induced residual deformation of composite structures. The mechanical properties of composite yarns were calculated by direction-selective micromechanical models, and they were used to estimate the effective mechanical properties of plain woven composites together with the geometric and elastic models. The viscoelastic constitutive model was adopted to consider stress relaxation behavior of composite materials during curing. The process-induced residual deformation of plain woven composite laminates with several fabric parameters was examined by curing simulation based on the finite element method. The results revealed that the deformation of the fully cured plain woven composite laminates usually increased with an increase in the composite yarn thickness and the gap between adjacent yarns. Therefore, the residual deformation owing to the curing process considering various fabric parameters examined in this study will be used to build the basic data for improvement of the quality of composite structures in the design phase.

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abst. 2057
Room 2
Thursday
September 2
13h10

STF-impregnated Fabric Composite Structures for Enhanced Damping Characteristics

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In the operating environment of carbon fiber reinforced polymer (CFRP) composite structures with high specific stiffness, they are susceptible to resonance vibration, and their damping characteristics are considered as one of the critical parameters characterizing the structural behavior. In this study, the STF-impregnated fabric composite (STFFC) was proposed to reduce the risk of resonance vibration. The STF composed with nano-silica particles and polyethylene glycol (PEG), has a unique rheological behavior of shear thickening effect (STE); that is, the sudden rise of viscosity with an increase in the applied shear rate or shear stress. The rheological behavior of STF was investigated using a rheometer, and the STFFC beams were fabricated by inserting the STF-integrated woven carbon fabric into CFRP laminate using a hot-compression molding method. The modal tests were performed for the STFFC and pristine beams, and their responses were examined. The results revealed that the damping ratios for the initial six vibration modes were enhanced 17.71– 417.86%. Therefore, it was believed that the proposed STFFC will contribute to reducing the risk of resonance vibration of CFRP composite structures.

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abst. 2079
Repository

Behavior of FRP-confined FRP Reinforced Concrete Square Columns (FCFRCs) under Axial Compression

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Polyethylene terephthalate (PET) fiber-reinforced polymer (FRP) composites have gained more and more attention in recent years on account of their environmentally friendly origin and large tensile strain capacity. However, PET FRP-confined concrete easily exhibits a strain-softening stress-strain behavior, especially that in square columns. In this study, novel FRP-confined FRP reinforced concrete square columns (FCFRCs) are proposed. Capitalizing the benefits of internal FRP reinforcement, the strain-softening behavior of PET FRP-confined concrete is expected to be alleviated, leading to excellent mechanical performance of the proposed square columns. The axial compressive behavior of FCFRCs, as well as square concrete-filled PET FRP tube columns (CFFTs) and FRP reinforced concrete columns (FRCs) as reference columns, were investigated via experimentation. It is found that the stress-strain behavior of the confined concrete in FCFRCs has been substantially enhanced with the internal FRP

reinforcement, confirming the viability of the system. The parameters investigated in this study included the FRP tube thickness, the pitch of the internal reinforcing spiral. A design-oriented stress-strain model is then proposed for confined concrete in FCFRCs. Comparisons between experimental results and predictions show that the proposed model provides satisfactory predictions.

DESIGN GUIDELINES FOR COMPRESSION BUCKLING OF COMPOSITE CYLINDRICAL SHELLS ON ELASTIC FOUNDATIONS

abst. 2099
Room 2
Wednesday
September 1
12h30

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Thin-walled cylindrical shells are commonly used in space, marine and civil structural applications. Their buckling behaviour is not only sensitive to geometrical imperfections but also highly sensitive to boundary, material, and loading imperfections. These imperfections can reduce the critical buckling load significantly. To consider this reduction, the knockdown factor (KDF) was proposed for isotropic and orthotropic cylindrical shells in NASA SP-8007, 1965 (revised 1968) [1] and are widely used in practice. However, different boundary conditions are not well considered. Thus, there is a necessity for up-to-date knockdown or design factors [2] that can consider the effect of elastic boundaries for preliminary designs. These new KDF relations can help designers predict the margin of safety and critical buckling load more accurately to design robust and lightweight cylindrical shell structures. In most cases, shell structures in practice are components connected to structures with finite values of stiffness. Considering boundary conditions with infinite stiffnesses in the preliminary design phase could change the buckling load by 50-60% [3]. Therefore, to find appropriate design factors, which reflect more accurate boundary stiffness by representing them by elastic foundations is important. To model effects of elastic foundations on buckling behaviours of cylindrical shells, Python scripting in Abaqus has been developed to model spring elements at one end of the cylinder together with a compressive load being applied at its opposite end using multi-point constraints. Thereby, empirical design factors for critical buckling loads of axially compressed composite cylindrical shells due to axial, radial, and tangential elastic foundations are determined based on stiffness ratios between cylindrical shells and elastic foundations in pertinent directions.

Study of the tensile fatigue behaviour of hybrid flax/glass fibre-reinforced epoxy composites

abst. 2121
Room 2
Wednesday
September 1
13h10

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In the last decades, composites reinforced with natural fibres have been extensively studied by many researchers in order to answer current ecological challenges. In fact, bio-based composites are ecological, biodegradable and they have unlimited availability [1]. To this end, the quasi-static mechanical

properties of natural fibre-reinforced composites have been widely studied in the literature, in particular those reinforced by flax fibres [2]. In addition to the static mechanical behaviour, the cyclic fatigue behaviour of natural fibre-reinforced composites is of great importance since they are subjected to cyclic loading in various applications. This work investigates the static and fatigue behaviours of non-hybrid and hybrid flax/glass fibre-reinforced epoxy composites. The studied laminates were manufactured using the vacuum infusion technique. The composite specimens were then cut and subjected to tensile static and fatigue tests. For the fatigue tests, two levels of displacement were chosen: 50% and 75% of the displacement at failure with an amplitude of 15% and 10%, respectively. The fatigue tests were conducted using sinusoidal type of waveform at two frequencies 5 and 10 Hz based on the literature results. The obtained results show that the non-hybrid and hybrid flax/glass composite materials consistently lose stiffness at low number of cycles and tend to stabilise at high number of cycles until break. Even for the composite specimens subjected to low load level, they are found to significantly lose stiffness. From the hysteresis curves, the loss of dissipated energy for different cycles is evaluated and an important loss of the energy is observed in the earlier cycles. The stress-logN curves allow concluding that the glass-based laminates are more sensitive to fatigue then flax-based laminates. Besides, the hybridization improves the behaviour of the non-hybrid flax laminates. [1] M. Ben Ameur, A. El-Mahi, J-L. Rebiere, M. Beyaoui, M. Abdennadher, M. Haddar, Experimental fatigue behaviour of carbon/flax hybrid composites under tensile loading, Journal of Composite Materials, 2021, Vol. 55(5)581-596. [2] K. Cheour, M. Assarar, D. Scida, R. Ayad, X-L. Gong, Identification of damping properties of flax fibre reinforced composites, Revue des composites et des matériaux avancés, n°3-4 /2016, 367-382. [3] S. Manteghi, A. Sarwar, Z. Fawaz, R. Zderoz, H. Bougherara, mechanical characterization of the static and fatigue compressive properties of a new glass/flax/epoxy composite material using digital image correlation, thermographic stress analysis, and conventional mechanical testing, Materials Science Engineering C, 2019, 940-950. [4] F.C. Campbell, Elements of metallurgy and engineering alloys, ASM international, 2008.

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abst. 2123
Room 2
Wednesday
September 1
12h50

Initial Approach to Development of New Composite Made Fully of Recycled Material

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The presented work deals with the initial approach to the development of a composite material which is fully made of the recycled components. The matrix of the composite is a recycled HDPE granulate. The matrix is reinforced with the glass fibres mixed with polyester resin and acryl. The reinforcing material comes from the recycled canoe construction, which was mechanically milled. The bone-shaped samples of the composite with the wg.25% of reinforcement were prepared on the HAAKE MiniJet Pro Piston Injection Molding. The structural study (FTIR and SEM) was carried out. To assess the strength parameters of the composite the static compression test was carried out. The achieved results are characterized with the wide scatter for compression characteristics. Also the material has a lower strength parameters in comparison to the pure recycled HDPI.

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abst. 2129
Repository

Time-domain asymptotic homogenization for linear-viscoelastic composites: mathematical formulation and finite element implementation

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Asymptotic homogenization (AH) is a rigorous method to model the multiscale mechanical behavior of periodic composites. However, the complexity of the mathematical formulation and the difficulty in finite element implementation are the two main issues that restrict the use of the AH method to viscoelastic materials. Unlike conventional AH methods that express time-domain-based heterogeneity with multiple characteristic displacement tensors, the mathematical formulation proposed in this study solves the problem using one unified characteristic displacement tensor. Based on the newly proposed formulation, an implementation method was developed by establishing location- and time-related stress loads. A user-designed Python subroutine was also developed to compute the effective viscoelastic properties from the results of finite element implementation. The homogenization results of the unidirectional composite and woven fabric composite were compared to those from the conventional representative volume element method, indicating high effectiveness and accuracy. The proposed AH method is a powerful tool for modeling the two-scale mechanical behavior of a viscoelastic composite and compatible with the existing commercial software.

Tribological behavior of functionally graded unidirectional glass fiber reinforced epoxy composite: Effect of fiber orientation

abst. 2138
Repository

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In this research, the wear resistance of functionally graded polymeric composite material (FGM) is investigated experimentally. Fabricated by a hand lay-up manufacturing technique, the unidirectional glass fiber reinforced epoxy composite (GFRE) composed of ten layers is used in the present investigation. To produce ten layers of FGM beams with different patterns, the fiber volume fraction (Vf%) ranges from 10% to 50%. A comparison between FGM beams and conventional GFRE having the same average Vf% is made. The experimental results show that the friction and wear properties of conventional GFRE depend on the sliding speed, fiber orientation, and fiber volume fraction. The coefficient of friction increases with increasing the sliding velocity at low pressure but at high pressure, it is independent of the sliding velocity. The highest value of the coefficient of friction is obtained when the fibers are oriented normal to the sliding surface and the sliding direction. On the other hand, the highest value of the wear rate is obtained when the fibers are oriented longitudinally to the sliding surface and the sliding direction. Furthermore, increasing the fiber volume fraction resulted in an augmentation of both the coefficient of friction and the wear resistance.

Manufacturing Hybrid Lightweight Structures in Fiber Metal Laminates

abst. 2140
Repository

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Reducing the fuel consumption and pollutant emissions of future car generations are now very important issues in the automotive industry. These aims can be achieved by reducing the weight of the car, for example, thus boosting the driving dynamics. In most currently mass-produced cars, the body in white (BIW) accounts for one of the largest parts by weight, and hence designing lightweight car body structure components has become very important for reducing fuel consumption and emissions. Very lightweight structure components can be achieved by using exclusively CFRP materials, which have the disadvantage of high costs and unsuitability for a large-scale, cost-efficient production. Fiber metal laminates (FML) consisting of high- strength steel alloy sheets and a core in CFRP have a high stiffness to weight ratio and display very good damage tolerance compared with mere composite materials. The major disadvantages of using FML are its poor formability and expensive production processes. A promising approach to the automated, large-scale and cost-efficient production of hybrid lightweight automotive structures in FML, which is being adopted at the LUF, is a specially adapted, combined forming and curing process. The paper presents recent experimental and numerical results for the process and material design, together with the measures developed to improve the formability of FML sheets. The influence of the process parameters, the process limits, the necessary tool systems and the process strategies are similarly covered by the paper.

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abst. 2176
Room 1
Wednesday
September 1
14h30

Study of thermally insulated pair of collinear interfacial cracks parallel to a third interfacial crack situated in a composite medium

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The article deals with the problem of thermal stresses produced due to the presence of three thermally insulated interfacial cracks in a composite medium comprises of an orthotropic strip of depth h bonded between two orthotropic half-planes. The present mathematical model contains a central crack at the lower interface and two collinear cracks at the upper interface which are symmetric about the central one. Using integral transform technique, the governing equations are converted into a system of singular integral equations. These Cauchy type Fredholm integral equations of the second kind are solved by using Jacobi polynomials. Numerical values of the Mode-I and Mode-II thermal stress intensity factors (TSIFs) at the vicinity of cracks' tips are found for different particular cases of the considered model. The novelty of the article is the graphical study of depth and offset parallel cracks' interaction through TSIFs.

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abst. 2194
Room 1
Wednesday
September 1
14h50

Shape Distortions in Hybrid Composite Laminates

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abst. 2213
Room 2
Friday
September 3
11h30

Structural shape and 3D printing design for continuous carbon fibre reinforced composite parts

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This study develops a novel procedure combining topology optimisation and fibre placement paths for shape and 3D printing design of carbon fibre reinforced composite parts. First, a two-stage optimisation algorithm based on modified solid isotropic material with penalisation (SIMP), to acquire the optimal topology for confining maximum stress and minimising structural compliance, was developed for a short cantilever and a three-point-bending section with polyamide (PA). Second, based on calculations for the average load transmission trajectories within the optimal topology, continuous carbon fibre (CCF) placement paths were defined for 3D-printing of CCF/PA parts. Last, the effects of short carbon fibre (SCF) and CCF to the pure PA were investigated, with 3D printed PA, SCF/PA (SCF, vol%=15%) and CCF/PA (CCF, vol%=35%) specimens. The results show that the stiffness of 3D printed CCF/PA short cantilever and three-point-bending beam are 1189 N/mm and 2664 N/mm, which are 544% and 328% larger than those of PA parts, respectively.

Multi-level Optimization of Variable-Stiffness Shells with Cutouts based on Isogeometric Analysis

abst. 2216
Room 2
Friday
September 3
11h50

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Composite shell structures are widely used in the aerospace field. For composite shells with cutouts considering multi-component cooperative assembly, how to implement a high-precision and high-efficiency analysis is a hot research issue. The mechanical analysis of shell structures using the Finite Element Analysis (FEA) method often needs very fine meshes to achieve a high-fidelity simulation. The advent of isogeometric analysis (IGA) method provides an alternative, yet efficient and accurate means to model complex shell structures with cutouts. Based on the theory of degenerate shell element, the trimmed structure analysis method (TSA) is applied in the IGA to realize the linear buckling analysis of the complex variable-stiffness shells with cutouts. The improved triangle integration with curved edges is used to improve the calculation accuracy and efficiency. In this work, the formula of geometric stiffness matrix for complex variable-stiffness shells is derived for the first time based on degenerated shell method using IGA, which is the basis of performing linear buckling analysis. In the shape optimization process, in order to further improve the buckling load factor of the structure, the analytical sensitivity of the objective function is derived. And the propagation of analytical sensitivity from design model to analysis model has been realized based on h-refine method. A multi-level shape optimization framework in which the design models and the analysis models are independent is proposed. In doing so, the design model is able to provide enough parameterization for optimization, and, in the meantime, the analysis model ensures efficiency and accuracy for simulation. By conducting numerical examples, the optimization framework greatly improves the shape optimization performance of composite shells with cutouts.

THE EFFECTS OF DILATANCY IN COMPOSITE ASSEMBLIES AS MICROPOLAR CONTINUA

abst. 2219
Room 1
Thursday
September 2
09h40

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Dilatancy is of importance for understanding the micromechanical behavior of materials such as cemented sand, mortar joints, and the interfaces of masonry-like structures. Rough interface contacts are able to result in dilatancy and lead to increase in the material's volume. However, such a vital phenomenon was usually neglected in the previous studies on composite materials. The aim of the literature is to investigate the effect of dilatancy on composite materials with rigid particles connected by rough elastic interfaces. Different hexagonal shapes as rigid particles are considered by a series of geometric parameters. The stiffness properties of the rough interface can be obtained by employing a contact density model. Different roughness is defined for the interfaces to assess the effect of dilatancy by changing the contact density function. A homogenization procedure based on an energetic equivalence criterion is used to generate constitutive parameters. The homogenized continuum is then modeled as a micropolar continuum which has an additional degree of freedom and is known to be able to give an effective result in modeling the behavior of materials with micro-structures. A 2D plane slope composed of material with various roughness interfaces, is analyzed under the effect of dilatancy. This study shows the validity of the micropolar theory when considering the rough micro-structure, which is very essential for capturing more realistic behavior of composite materials.

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abst. 2229
Room 2
Thursday
September 2
11h30

Effect of hydrothermal environment on single-lap shear strength of induction welded CF/PEKK thermoplastic composites

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In this study, the effect of hydrothermal environment on single lap shear strength of induction-welded joints was experimentally investigated. The carbon fibers reinforced the promising aromatic thermoplastic polymer named poly-ether-ketone-ketone (PEKK) was utilized. The current high potential fabrication method for thermoplastic composite is known as induction welding was implemented to create the single-lap joints. Some main parameters of welding were selected according to the literature survey such as the power (2.2 kW), the distance between induction coil and laminate (1 mm), coil velocity (2 mm/s), frequency (250 kHz), roller pressure (150 N). The single-lap joints were kept in the oven under 85% humidity at 85 [U+2103]. The weight of single-lap joint was controlled by measuring for each two weeks until the saturated condition in which the weight change was less than 0.02%. Then, humidity saturated specimens were test under tensile loading at different temperature of 25 [U+2103], 100 [U+2103], 120 [U+2103], 140 [U+2103], 160 [U+2103], and 180 [U+2103]. As the results, shear strength of single-lap joint was nonlinearly decreased under hydrothermal environment. Higher temperature has affected more negatively the shear strength of single-lap joint. In addition, the fracture surfaces were also inspected showing that failure mode of single-lap joint made by CFRP/PEKK composites occurred dominantly at interfacial between adhesive and adherend. Acknwledgement This study was supported by the " Development of Composites Repair Process for Aircraft Winglet" through the Ministry of Land, Infrastructure and Transport (19ACTP-B147766-02)

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abst. 2230
Room 2
Thursday
September 2
11h50

UHF microwave absorbing hybrid folded core sandwich composite structure

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In this study, a lightweight folded core sandwich structure having a good microwave-absorbing performance in the ultra-high frequency (UHF) was designed and fabricated using Ni-coated glass fabric/polyether ether ketone (PEEK) thermoplastic matrix. The electromagnetic properties of pristine glass fabric were modified via an electroless nickel plating, and it was used as a loss material. Sendust particles as ferromagnetic materials were dispersed in polyurethane foam to fill the inside of the core. The signal intensity of the incident electromagnetic wave is effectively reduced due to repeated multiple reflections inside the V-pattern folded core. The UHF RAS related to fabrication possibility was designed by optimal folded core design parameter. The folded core was fabricated by stamp forming having four processes of heating, transfer, forming and consolidation. The sendust particle with the raw material of the polyurethane foam was dispersed by using three-roll-mill. The fabricated structure showed sufficient absorption performance in the UHF band and it was in good agreement with the simulation results. Acknowledgement This work was supported by the Aerospace Low Observable Technology Laboratory Program of the Defense Acquisition Program Administration and the Agency for Defense Development of the Republic of Korea.

Impact behavior of radar absorbing quartz/PEEK folded core sandwich composite structure dispersed with MWNTs

abst. 2231
Room 2
Thursday
September 2
12h10

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In this study, a radar-absorbing sandwich structure was proposed using quartz fabric and polyether ether ketone (PEEK) thermoplastic composites with multi-walled carbon nanotubes (MWNTs). The folded core was designed to improve the absorbing performance considering wall thickness, side lengths, sector angles. The primary principle of the reflection loss in the core was repeated multiple scattering inside the folded core of the V-pattern. The folded core was fabricated by stamp forming of five

processes; heating of the blank, transfer, forming, consolidation, and ejection. Then, the folded core was bonded onto the quartz/PEEK composite skins with the adhesive to produce a sandwich structure. The microwave absorption performance of the fabricated sandwich structure was evaluated using by a free-space measurement system. In the bandwidth of 4.0 GHz to 18 GHz, the proposed RAS exhibited microwave absorption performance of more than 90 %. A low-velocity impact test was conducted to evaluate the impact behavior. The proposed radar absorbing sandwich structure revealed both excellent impact behavior and radar absorption performance in a broad bandwidth. Acknowledgement This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311).

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abst. 2234
Room 2
Thursday
September 2
12h30

Design of radar absorbing structure with cobalt coated quartz fiber/aluminosilicate composite for ultra-high temperature microwave absorption

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In this paper, a radar absorbing structure (RAS) for ultra-high temperature microwave absorption was proposed by using cobalt coated quartz fiber/aluminosilicate composite. The cobalt coated quartz fiber was prepared by cobalt-sputtering coating technique. The cobalt sputtering on the surface of quartz fiber was conducted with different deposition times to improve the electromagnetic properties. The aluminosilicate matrix used in this study, geopolymer based matrix consisting of Al2O3 and SiO2, was selected due to excellent chemical resistance and good thermal stability over ultra-high temperature. The microstructure characterization, phase identification and magnetic properties of cobalt coated quartz fiber was examined by scanning electron microscope (SEM), X-ray diffraction (XRD) and vibrating sample magnetometer (VSM). To design the radar absorbing structure, the dielectric properties of cobalt coated quartz fiber/aluminosilicate composite was measured in X-band (8.2-12.4 GHz) from room temperature to ultra-high temperature. The complex permittivity of cobalt coated quartz fiber/aluminosilicate composite increased significantly after cobalt sputtering deposition on the surface of pristine quartz fiber, and it increased with the increase of temperature. The relationship between complex permittivity and temperature could be explained by Debye theory. To acquire sufficient microwave absorption performance, the double-slab absorber consisting of a pristine quartz/aluminosilicate composite and a cobalt coated quartz was fabricated. The optimal thickness of each layer in the RAS was obtained by a genetic algorithm to achieve maximum microwave absorption performance in the X-band. The microwave absorption performance of fabricated RAS was measured by the free space measurement system at ultra-high temperature. The results showed that radar absorbing structure proposed in this paper can be a promising candidate applicable to ultra-high temperature environments.

Prediction of fatigue life in composite wind turbine blade using Miner and Strength-based model

abst. 2242
Room 1
Wednesday
September 1
15h10

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To predict fatigue life, different methods have been used based on different damage metrics. However, almost all of them involve the same steps as the counting method, S-N curve, and constant life diagram. Miner method and strength-based method are the most common methods, especially in composite wind turbine blades. In the Miner method, the results are converted into a damage parameter that indicates whether a failure has occurred. Also, load sequencing effects are not considered. In the strength-based method, life is predicted by calculating the effect of each load cycle on strength, until the load exceeds the remaining strength. Therefore, load sequencing effects can be included. However, computational and experimental efforts are needed to determine the strength degradation. The purpose of this paper is to establish a process that requires minimal experimental data while reliably predicts the condition of materials. Therefore, in this paper, for the description of damage, two models of Miner and strength-based were investigated on a 13-meter wind turbine blade constructed from glass-fiber reinforced powder epoxy composite material. Comparing the methods show that although the predicted fatigue years are estimated to close to each other, the strength-based method is more reliable. Another reason for the superiority of the strength-based method in this paper is that with the newly introduced approach, the experimental effort is also reduced.

Topology Optimization strategies for continuous fiber-reinforced and functionally graded anisotropic composite structures: A brief review

abst. 2265
Repository

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Among all types of Additive Manufacturing (AM) technology, Continuous Fiber Fused Filament Fabrication (CF4) can fabricate high-performance composites compared to those manufactured with conventional technologies. AM provides the excellent advantage of a very high degree of reconfigurability, which is in high demand to support the immediate short-term manufacturing chain in medical, transportation, and other industrial applications. Additionally, the CF4 capability enables the fabrication of Continuous Fiber-Reinforced Composite (CFRC) materials and Functionally GRaded Anisotropic Composite (FGRC) structures. The current expedition in AM allows us to integrate Topology Optimization (TO) strategies to design realizable FRC and GFRC structures for a given performance. Various TO strategies for attaining lightweight and high-performance designs have been proposed in the literature, which exploits AM's design freedom. Therefore, the paper attempts to address works related to TO strategies employed to obtain optimal CFRC and FGRC structures. This review intends to overview, compare existing strategies, analyze their similarities and dissimilarities, and discuss challenges and future trends in this field.

Self-Reinforced Polyethylene Composites with Gamma-Irradiated Dyneema Fibers

abst. 2271
Room 1
Wednesday
September 1
15h30

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Self-reinforced composites are all-polymer composites in which the reinforcement and the matrix are composed of the same polymer, or polymers of the same polymer family [1]. These thermoplastic composites have a great importance nowadays, because the ease of their recycling via melting, and the shorter cycle times compared to that of their thermoset counterparts. The processing of such composites is simple (by compression molding, thermoforming or rotational molding, extrusion, etc.), but it must be gentle, because the fibers must keep their fiber form, while the matrix must melt [2]. The melting temperature of the fibers must be shifted (different crystal forms, tacticity, branching, additives, etc.) in order to be able to avoid the melting of the fibers. When using the same or similar polymeric material it is challenging. The fibers can undergo molecular relaxation (i.e. orientation decreases) and also their surface can melt and become a matrix that in not favorable [3]. It is difficult to apply high performance polyethylene (HPPE) fibers in composites because they form a poor adhesion with most of the common matrix materials [4]. Placing these HPPE fibers in a similar, polyethylene matrix resolves this issue. The different polyethylenes have different melting temperatures that way we can protect the fibers from melting. In this study, we made Dyneema (HPPE) reinforced high density polyethylene (HDPE) composites. To enhance the themal stability of the fibers, we cross-linked those by gamma-irradiation with a dose of 100, 200 and 300 kGy. The differential scanning calorimetry shown that the crystal melting temperatures decreased slightly as a function of the dose. On the other hand, we were not able to melt the fibers even at 200 °C, crosslinking occurred. Subsequently, we compounded these fibers with the HDPE by a twin-screw extruder. The gamma-irradiated fibers kept their structural integrity during the compounding. We were able to injection mould standard tensile specimens from these compounds. The fibers were able to withstand the high temperature and pressure of processing, while the non-irradiates samples did not. The 200 kGy irradiation dose resulted in a 70% higher tensile strength, almost 30% increase in the modulus and a slight increase in the hardness. References: 1. Ákos Kmetty, Tamás Bárány, József Karger-Kocsis: Self-reinforced polymeric materials: A review, Progress in Polymer Science, 35(10), 1288-1310 (2010). 2. Yao, S.-S., Jin, F.-L., Rhee, K. Y., Hui, D., Park, S.-J.: Recent advances in carbon-fiber-reinforced thermoplastic composites: A review. Composites Part B: Engineering, 142, 241–250 (2018). 3. Gao, C., Yu, L., Liu, H., Chen, L.: Development of self-reinforced polymer composites. Progress in Polymer Science, 37(6), 767–780. (2012). 4. L. Gilson, A. Imad, L. Rabet, F. Coghe: On analysis of deformation and damage mechanisms of DYNEEMA composite under ballistic impact, Composite Structures, 253, 112791 (2020).

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abst. 2273
Repository

Dynamic behavior of three dimensionally printed functionally graded foams

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In the present work functionally graded foam (FGF) based beams are three dimensionally printed (3DP) using fused filament fabrication (FFF) process. These foams are manufactured by reinforcing hollow spherical particles such as glass micro balloon (GMB) in high Density Polyethylene (HDPE) matrix. 3DP FGFs are investigated for its mechanical buckling response using experimental technique. Mechanical buckling load of the FGFs are evaluated using double tangent method. The results show that among all graded composites, foam having 20-40-60 gradation exhibited better performance. Moreover, for FGFs at first mode natural frequency decreases in the pre-buckling region and started increasing in the post buckling region. Comparative results of FGF with plain core shows that FGFs exhibited higher mechanical buckling load. These concurrently printed graded foams might pave away new venues in realizing complex structures having jointless leakproof and integrated component geometries in weight sensitive regime.

A novel concept for realizing multi-stable periodic FRP structures

abst. 2284
Room 1
Wednesday
September 1
15h50

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Multi-stable structures show a high potential for use in shape adaptation. In fact, when designing lightweight shape adaptable structures, multi-stable components are favorable due to their ability to maintain multiple stable shapes without the need for a continuous power supply. In the last decades, intensive research has been conducted to investigate and model the stability behavior of thin laminated fiber-reinforced polymer (FRP) composites. Despite multiple concepts having been proposed, several challenges are limiting the implementation of such elements into real-world applications. High coupling of the multi-stable property with the shell boundary conditions, complex manufacturing techniques, and the partial suppression of the multi-stability when extending the shell design by periodicity are common drawbacks. The present research illustrates and characterizes a novel mold-less manufacturing technique for the fabrication of multi-stable composite structures with complex 3D topologies. Combining thin FRP composite shells with pre-stretched membranes generates elastic instabilities that result in out-of-plane buckling of the shells. With the use of periodicity, this shape-forming mechanism enables the manufacturing of periodic structures that show potential for the realization of shape adaptable structures. Prototypes show that a single cell structure possesses eight stable modes and that the multi-stability of the unit cell is preserved in the periodic structures. Moreover, the periodic structures possess further stable configurations not observed in the unit cell. The influence of several design parameters on the multi-stability of the structures is investigated in this work. Particularly, both finite element analysis and experimental results show that the multi-stability property depends on the level of anisotropy of the laminate employed for manufacturing the structures. Highly anisotropic laminates strengthen the multi-stability while isotropic materials suppress it. A parametric study illustrates the dependence of the multi-stability on the geometry of the shell and the laminate layup. Results highlight that laminates with a high ratio between the longitudinal bending stiffness and the torsional stiffness show the maximum number of stable states. There are two major benefits when realizing multi-stable structures with the proposed approach. First, the concept enables the realization of multi-stable shells with a comparably easy fabrication technique. Second, the periodic extension of the presented concept is not only preserving the multi-stability, but rather enhancing it. To conclude, the concept can be adopted to augment the functionality of FRP structures, allowing the manufacturing of highly multi-stable components and showing potentials for the integration of highly anisotropic composite elements into shape adaptable mechanical metamaterials.

Design of a Type III Pressure Vessel Considering Through Thickness Stress Gradient and Experimental Validation

abst. 2286
Repository

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Accurate stress and strain state predictions along a composite pressure vessel are of utmost importance in the design stage of the structure. Conventionally, a finite element analysis is due after the generation of the pressure vessel profile to assess the finalized design accurately. It is common to generate such vessel profiles based on the load balance across the cylindrical region, ignoring the variation of stresses through thickness direction which may eventually cause premature failure of the vessel. In this paper, the design process is extended to include stress variations in thickness of a composite pressure vessel with a metallic liner including elastoplastic deformation, resulting in a design methodology that considers both the load balance and maximum stresses on the vessel. Resulting pressure vessel was modelled in Abaqus commercial finite element software environment. Proposed design process was validated through finite element analysis. Comparison of vessel generated by conventional method and the proposed method is given. Vessels designed by using both methods were manufactured, and employed

in burst test. Strains were monitored at certain locations of both vessels. Results of burst pressure and strain measurements were shown to agree with results of the given finite element analysis and the proposed method. According to the results of the finite element analysis and experiments, the proposed method offers a design approach that satisfies the burst pressure criteria for composite pressure vessels that may exhibit large stress variations through its thickness.

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abst. 2292
Repository

Homogenization of shape memory polymer composite based nonperiodic corrugated structure

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In this work, a homogenization scheme for shape memory polymer composite based nonperiodic corrugated structure has been proposed. Corrugated design is lighter, has anisotropic properties, low cost, easy manufacturability and adaptability and are used in several engineering applications like roofs, cardboards etc. Shape memory polymers and its composites are a kind of polymer having shape memory properties. They can undergo large deformation and can hold on to it in the absence of load under certain external condition. To analyze such a design, a homogenization procedure is needed. A homogenization scheme based on equivalence of strain energy has been used in this work. Corrugation parameters like thickness, number of corrugation elements, composite lay up, orientation of corrugation elements affect structural behaviour and this has been accounted for in the homogenized model. Based on overall structural requirements, corrugation parameters can be deduced from the homogenized model. Model validation has been carried out with direct comparison with finite element based simulation. Result has been compared and discussed.

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abst. 2299
Room 1
Wednesday
September 1
16h10

Dynamic stability of thin-walled FML profiles with implemented delamination

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Under analysis is the dynamic stability of thin-walled channel section column subjected to axial compressive pulse loading made of Fiber Metal Laminate. Columns consist of seven layers – three layers of aluminium sheets and four layers of glass-fibre reinforced composite prepregs. Three different layer arrangements - each symmetrical with respect to mid-plane, were investigated. Dynamic structure response was studied based on Finite Element model previously validated in static experimental tests. This numerical study was performed in ANSYS - the FEM software. In the investigations, the column with initial imperfections corresponded to the lowest buckling mode, subjected to rectangular-shape pulse loading was considered. The delamination failure was implemented with the application of the Cohesive Zone Method in the region revealed by failure analysis. Location of that region corresponds to greatest failure factor values thus of the highest probability of debonding occurrence. The delamination zone was modelled in the column flange between the aluminium outer sheet and the glass-fibre composite layer. The whole analysis was performed in three steps which included: the linear buckling analysis - to determine the critical buckling load and buckling mode; the modal analysis - to obtain the period of natural vibration and finally, the transient analysis to assess a critical dynamic load factor. Two types of criteria were implemented to determine the dynamic buckling stability: dynamic stability criteria and failure criteria. Implementing the failure mechanism and the delamination possibility allows detecting all forms of failure (as aluminium yielding, fibre and matrix cracking in GFRP and delamination itself). The effect of the delamination failure on the structural dynamic response under pulse loading was investigated.

Design and Testing of a CFRP Frame for an Innovative Railway Running Gear

abst. 2300
Room 1
Thursday
September 2
10h00

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There is a strong interest from the global railway industry in composite materials. This is motivated by a demand for increasing the structural efficiency and decreasing the weight as this will result in reduced energy consumption, reduced track wear, increased load/passenger capacity and improved operability. In modern rail vehicles, composite materials are mostly used for interior semi-structural applications and front nose, whereas the primary structures producing most of the vehicle's weight are typically made of metals. In a conventional passenger vehicle, the largest mass contributor is the running gear, adding up to 40% of the total tare weight. The running gear is a highly loaded component and has a large effect on the dynamic performance of the vehicle. By that it must meet strict design requirements on its strength and stiffness properties. Carbon Fibre Reinforced Polymers (CFRP), with their high specific mechanical properties and high fatigue strength have a great potential as structural materials for the running gear elements, specifically for the running gear frame. The frame is the primary structure of the running gear connecting the carbody with the wheelsets through the suspension elements. In a classical design, the running gear frames are made of steel and perform mainly a structural function – carrying various static and dynamic loads. The static loads are mostly result from the weight of the carbody and passengers, and the dynamic loads result from vehicle vibrations and curve negotiations. Whereas the vibration attenuation is traditionally performed by the suspension elements e.g., springs and dampers. The suspension is crucial for the vehicle's dynamic performance as its responsible for shock and vibration attenuation and anti-roll function. There are a few examples of the running gear (bogie) frames made of CFRP, which demonstrated significant weight saving potential. However, their topologies were similar to traditional metallic frames, hence they were designed to perform the structural function - transferring the loads, whereas the suspension functions were kept by the conventional suspension elements. This study presents a design and testing of CFRP running gear frame with integrated anti-roll functionality. The integration of the anti-roll functionality in the running gear frame eliminates the anti-roll bar in the suspension system. This in combination with high mechanical performance of the CFRP frame allows to considerably increase a structural efficiency of the running gear.

Composite structures in civil engineering

abst. 2008
Repository

Strength, toughness and microstructure of high performance concrete reinforced with steel-polypropylene hybrid fibers

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This article investigates the effect of blending hybrid steel-polypropylene fibers on the behavior of high performance concrete (HPC). The uniaxial compression, splitting tension and bending tests of HPC specimens were performed for different dosages of steel-polypropylene fibers. The flexural toughness parameters were determined from results obtained from the Digital Image Correlation (DIC) system with the ARAMIS software. In addition, optical-microscopic imaging analysis were performed to identify the presence of various compounds and microcracks in the HPC with hybrid fibers. The results indicate that concrete containing a fiber combination of 1% steel fibers and 0.1% polypropylene fibers can be adjudged as the most appropriate combination to be employed in HPC for compressive strength, splitting tensile strength, flexural strength, elastic modulus and flexural toughness. Furthermore, the results show that the addition of hybrid fibers promotes build stronger interfacial transitional zones (ITZs) and alters the failure pattern in the HPC.

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abst. 2070
Room 3
Thursday
September 2
15h30

Ultimate Strength of Web-Flange Junction in Pultruded Composites: A Random Lattice Modeling Investigation

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Pultruded glass fiber reinforced polymers (GFRP) are gaining increased attention in the structural engineering field, as a result of the advantages they bring when compared to classical construction materials, such as light weight, high strength-to-weight ratio, electromagnetic transparency. Being relatively new to structural applications, much research is still needed to characterize the failure mechanisms of these elements, to provide statistically relevant data to guide their design. One aspect of particular concern in the design of these elements is the ultimate strength of the Web-Flange Junction (WFJ) in slender GFRP profiles. This is the main focus of the present work, in which both experimental and numerical investigations on the ultimate strength of WFJ in pultruded GFRP structural elements are presented. First, a set of experimental tests is discussed, in which specimens with different geometrical arrangements have been tested to quantify the strength of WFJs. Based on these observations, a novel random lattice modeling approach is proposed and validated. Such numerical model was then employed to simulate the tests and parametrize the response of the WFJ under different geometrical and loading conditions. The results of the simulations can shed light on the mechanical behavior of the web-flange junctions at failure and help guide the design of pultruded GFRP elements. The main lessons learned and directions for future research will be discussed in the conclusions.

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abst. 2088
Repository

Compressive behavior of FRCM strengthened pre-damaged columns

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The main objective of this paper is to study the effects of strengthening newly cast low strength reinforced concrete short columns with PBO-FRCM. A total of five columns were cast with concrete that had a compressive strength of 18 MPa. All columns had a reinforcement ratio of around 0.015. Also, all columns were transversely reinforced with 6 mm ties spaced at 180 mm. The main varied parameters in this study were the number of PBO-FRCM layers used in strengthening the columns and the degree of pre-damaging. All columns had a circular cross-section that had a diameter of 200 mm and were reinforced with 6 10 bars. 2 columns were strengthened with 2 PBO-FRCM layers, 2 columns were strengthened with 4 PBO-FRCM layers and the fifth column was not strengthened and served as control. For the strengthened columns, half were strengthened prior to any loading and were loaded to failure while the other half were pre-damaged to ultimate capacity, unloaded, wrapped with PBO-FRCM, then loaded to failure. To ensure all columns behaved as short columns and no moment was to be induced, all columns had a height of 800 mm according to the ACI 318 code requirements for the maximum allowable height for short columns. Standard compression tests using a Universal Testing Machine (UTM) were conducted on all columns where a monotonic load increased incrementally until failure. Results showed that for un-pre-damaged specimens, columns strengthened with 2 and 4 PBO-FRCM layers had a capacity increase of around 36% and 74%, respectively. Also, strengthened columns subjected to pre-damaging had almost the same capacities as their unstrengthened counterparts, indicating the efficiency of PBO-FRCM.

Shear Center Identification for Composite Structures via the Finite Volume Method

abst. 2090
Room 3
Thursday
September 2
16h30

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The finite volume method is an established technique in the homogenization and localization of periodic composites [1]. The recent review article by Cardiff and Demirdzic [2] provides an exhaustive summary of the method's numerous applications to solid mechanics problems, including homogenization and localization of heterogeneous materials and structures. It is apparent that limited work on the application of this technique to structural engineering problems involving both homogeneous and composite materials has been reported, providing a rich area for future research and structural engineering applications. Chen et al. 3,4] were the first to apply the finite volume method to torsion of rectangular and arbitrarily shaped homogeneous and composite cross sections, illustrating the method's accuracy, applicability, and potential in reducing warping through appropriately laminated constructions. In this contribution, we further extend our finite-volume based approach to the solution of flexure problems of arbitrarily shaped homogeneous and composite cross sections with the aim of producing an efficient methodology for identifying the shear center. Following the finite-volume based solution to torsion problems, an elasticity based semi-inverse approach is employed to reduce the flexure problem to two potential theory problems solved using the finite volume technique. The developed approach is verified using known elasticity solutions and employed, in conjunction with an optimization algorithm, to identify shear centers of technologically important cross sections, illustrating the effect of composite construction on the shear center location. Using the developed technique, we also assess the approximate identification of shear centers for thin-walled structures as a function of the wall thickness to identify the limits of applicability of numerous engineering formulae found in advanced mechanics of materials monographs. Keywords: finite volume method, flexure, shear center, composite cross sections [1] Pindera, M-J., Khatam, H., Drago, A. S., and Bansal, Y. Micromechanics of spatially uniform heterogeneous media: A critical review and emerging approaches. Composites B, 40(5), pp. 349-378, 2009. [2] Cardiff, P. and Demirdzic, I. Thirty Years of the Finite Volume Method for Solid Mechanics. Archives of Computational Methods in Engineering (2021, in press). [3] Chen, H., Gomez, J., and Pindera, M-J. Saint Venant's torsion of homogeneous and composite bars by the finite volume method. Composite Structures, 242, 112128:1-19, 2020. [4] Chen, H., Gomez, J., and Pindera, M-J. Parametric finite-volume method for Saint Venant's torsion of arbitrary shaped cross sections. Composite Structures, 256, 113052:1-16, 2021.

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abst. 2106
Room 3
Thursday
September 2
15h50

Three-dimensional stress and free vibration analysis of steel-concrete composite beams using high order theories and closed-form solutions

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This paper applies high order theories and closed-form solutions based on Carrera unified formulation (CUF) to analyze the stress and free vibrations of steel-concrete composite beams. Bilinear, cubic, and fourth-order Lagrange polynomials are adopted to discretize the cross-sectional kinematics. Then, the governing differential equations are formulated in terms of fundamental nuclei via CUF. The differential problem can be solved in analytical form by imposing simply supported boundary conditions. To assess the proposed method, steel-concrete I-girder and box-girder are studied and results are compared with those from previous published work and also checked by ABAQUS. From this research, it is clear that the proposed approach can give 3D-like numerically exact stresses and free vibrations of steel-concrete composite beams with a significant reduction in the computational costs, which is innovative and worth promoting.

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abst. 2107
Room 3
Thursday
September 2
16h10

Numerical modelling of recycled glass particle–polymer resin structural composites

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Structural composites comprising recycled glass particles bound together by a thermoset polymer resin offer multifunctional lightweight construction materials that combine structural resistance with enhanced thermal and acoustic insulation. Although these composites behave in a brittle manner under compression, experimental results indicate that particularly thin specimens can exhibit densification hardening accompanied by a regain in strength, similar to that seen in compressible foams; the ratio between the specimen depth and the glass particle diameter has an influence on this phenomenon. given that the composite constituents are thoroughly mixed during fabrication and thus evenly distributed, assuming isotropy at the macroscale can be considered rational. However, the volume of air voids entrapped during the fabrication process can contribute towards significant variations in material density and composition when examining the composite at lower scales. Thus, although the stress state at the macroscale can usually be assumed with some degree of confidence, localised stress distributions are greatly influenced by factors such as void distribution and local geometry, with previous experimental results indicating a considerable edge effect in composites containing 4–8 mm glass particles. In this study, finite element analysis is applied firstly to assess the accuracy of various material models in simulating the behaviour of recycled glass particle–polymer composites at the macroscale, with comparisons made to existing experimental results. Then, more detailed models incorporating air voids and local geometric features are formulated in order to assess the impact of the volume and distribution of air voids on localised stress distributions and hence the assumption of isotropy and the manifestation of densification hardening at the macroscale.

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abst. 2158
Repository

3D Textile Reinforced Cementitious Composites for Permanent Formwork to Achieve Fast Construction without Environmental Waste in Concrete Construction

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Concrete is one of the most popular construction materials using tremendous amounts of usage per year in the world. One of the advantages of concrete materials used in construction projects is that the use of formwork on site makes it easy to make the desired shape. Even though concrete has all the merits as the construction material, the formwork is the one of throw backs. Usually, plywood plates have been used long time for a temporary formwork until system formwork was invented and used. However, utilization of system formwork can reduce to use of temporary formwork, but the majority of concrete construction work is still utilization of the traditional method. This traditional method takes a lot of construction period because assembly and de-molding are intensive labor works. and it also generates large amounts of environmental waste. Therefore, in order to develop a permanent formwork that takes less construction time than the existing construction method and can reduce environmental waste, many studies using fiber-reinforced cementitious composite (FRCC) are being conducted. However, in most of the methods, short fibers or woven fibers were applied. In FRCCs using short fibers or woven fibers, it is very difficult to control the distribution and orientation of fibers during mixing and casting. In order to minimize the problems mentioned above, 3D textile reinforced cementitious composites (3D-TRCCs) were applied to the permanent formwork. The 3D-TRCCs panel was fabricated by applying a 3D mesh fiber, and its mechanical properties were confirmed through experiments. 3D-TRCCs can be controlled to be more uniformly distributed than short fibers, and ductile behavior can be obtained with a small amount of fibers. The workability and quality of permanent cementitious composites are verified by constructing concrete box culverts on site. The purpose of this study is to propose the new formwork by comparing the existing formwork and cementitious composite permanent formwork method based on cost and construction period.

Design and test verification of connections between FRP deck panels and conventional girders in road bridges

abst. 2160
Room 1
Thursday
September 2
15h50

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The constant interest in the use of FRP composite elements in civil engineering is currently observed. Material and cost limitations mean that the use of fully composite bridges is not a common solution. The hybrid system, in which the directly loaded deck slabs are made of composite panels supported by conventional concrete or steel main girders, is much more effective. The weak point of these structures is the connection between these two elements. One of the most common ways of avoiding this problem is the use of flexible connections that make the two work independently. However, this is not an economic solution. Therefore, the authors, after developing a new system of road bridge decks with a sandwich structure, proceeded to solve the problem of connecting them to the girders. Preliminary analysis identified six ways to connect FRP panels with the most commonly used concrete and steel girders. All six concepts were subject to advanced numerical analysis, and on its basis, the two least promising solutions were rejected. Then, the production of four types of prototypes began: two joints for both types of girders, follow by the destructive laboratory tests carried out on three samples of each connection. The obtained laboratory results combined with the results of numerical simulations allowed for a reliable assessment of each type of connection, which in turn made it possible to select the best connection with the concrete and steel girder.

Enhancement of the adhesion between epoxy resin coating and cement-based substrates by using limestone powder sourced from quarry wastes

abst. 2189
Repository

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Epoxy resins have many advantages, making them a very attractive material. Epoxy resin coatings are characterized by very good mechanical properties and excellent chemical resistance. However, the components of epoxy resins are very harmful to the environment, including are toxic to aquatic life, cause skin and serious eye irritation and even serious eye damage and may cause allergy or asthma symptoms. Bisphenol A is a particularly harmful component of epoxy resins, as it has been confirmed to be carcinogenic and toxic to reproduction. But due to the excellent properties provided by epoxy resin and bisphenol A, and the lack of good alternatives, they are still used in flooring. Considering the above, there is a need to find a solution to reduce the total mass of epoxy resins used to make the coatings. It seems that the best solution is to replace part of the epoxy resin mass with a materials currently considered waste, e.g. waste limestone powders. This would allow recycling of these materials. It should be emphasized that the addition must not reduce the pull-off strength of the epoxy resin coating below 1.5 MPa. Achieving a pull-off strength value above 1.5 MPa is crucial to the durability of the epoxy resin coating. Summarizing, the aim of these research were to reduce the total mass of epoxy resin in the coating, thereby reducing the mass of the harmful components of the epoxy resin and to reduce the amount of waste limestone powders stored in heaps. The main aim of the research was to find an amount of waste limestone powder that would improve or at least not deteriorate the adhesion between epoxy resin coating and cement-based substrates. The tests were carried out on a concrete substrate 15 cm thick, which was divided into two areas. The first half of the substrate surface was patched after concreting to obtain a patched surface. The other surface of the substrate was mechanically grinded to obtain a ground surface. The entire surface of the substrate was divided into measurement squares with dimensions of 0.20 m x 0.18 m. The measurement squares were located 15 cm from the edge of the substrate to eliminate the edge effect. The substrate surface was vacuumed and a bonding agent was applied to all squares. Then, after 24 hours, epoxy resin coating was applied with the addition of waste limestone powder. Two reference squares (one on the patched surface and one on the ground surface) were covered with an epoxy resin coating without additive. An epoxy resin coating with a gradually increasing content of the selected waste limestone powder (from 7 to 29%) was applied to 10 measuring squares (5 squares for both types of surfaces). After the epoxy resin coating had hardened, pull-off tests were performed in accordance with ASTM D4541. On the basis of the obtained results, graphs of the relation between the content of the waste limestone powder and the pull-off strength of coating were created. The microstructure at the interface between the epoxy resin coating with waste limestone powder and the substrate was analyzed using a scanning electron microscope and X-ray micro CT. Finally, on the basis of the obtained data, graphs of the fractional share of pores along the sample's height of the subsurface zone were obtained. The aim of the research was achieved and the adhesion between the epoxy resin coating and the substrates was improved by using waste limestone powder. The addition of waste limestone powder made it possible to reduce the total mass of the epoxy resin needed to make the coating.

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abst. 2209
Repository

Simulation of Concrete-filled Square Steel Tubular Columns Stiffened with Encased I-Shaped CFRP Profile under Lateral Impact with a Fixed-fixed End

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The concrete-filled steel tubular (CFST) column is widely used in practical engineering for its high compressive strength, good plasticity, and excellent seismic performance. To further improve the performance of CFST columns, our research group has proposed a new-typed composite column, concrete-filled square steel tubular (CFSST) columns stiffened with encased I-shaped CFRP profile, and its static performances have been studied in depth in previous research. In this paper, the lateral impact resistance of the new-typed composite column under fixed-fixed end was studied through finite element analysis. Parametric analysis was conducted to investigate the effects of the impact velocity, slenderness ratio and axial compression ratio on the dynamic performances of the columns. Based on the simulation results, for a constant impact energy, compared with traditional CFSST columns, the decrement of deflection and the increment of energy consumption in the column stiffened with encased I-shaped CFRP profile is 8% and 15%, respectively. These indicates that the introduction of CFRP to CFSST columns can significantly increase the impact load and deformation resistance of the component. Additionally, the increasing of the impact velocity, which leads to the increase of the impact energy, will result in the rise of the deflection at mid-height of component. As the impact energy increased from 24.5kJ to 40.5kJ, the mid-height deflection rose by 43%. As for slenderness ratio, the impact resistance of CFSST columns stiffened with encased I-shaped CFRP profile reduces with the increasing slenderness ratio. When the slenderness ratio increased from 23.1 to 32.5, the platform value of the impact load time-history curve has reduced by75%, and the mid-height deflection has increased by 57%. In contrast, the influence of axial compression ratio on the mechanical performances is non-monotonic. The rising of axial compression ratio has a promoting effect on the dynamic responses of the column for an axial compression ratio lower than 0.3, while the axial compression ratio has an opposite influence on the dynamic responses of the column when it exceeds 0.3. Hence, it is recommended to design the CFSST columns stiffened with encased I-shaped CFRP profile within the critical value of the axial compression ratio in practices.

Lateral impact behavior of concrete-filled square steel tubular beam stiffened with encased I-section CFRP profile

abst. 2210
Repository

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I-section carbon fiber reinforced polymer (CFRP) added to concrete-filled steel tubular (CFST) can improve the mechanical performance of CFST and reduce the cross-section of CFST. This paper reveals the dynamic response of the CFST beam stiffened with encased I-section CFRP profile under simply supported conditions, through analyzing the stress-strain, time history curve of impact force and deflection, and energy dissipation of each component of CFST beam stiffened with encased I-section CFRP profile. Based on the above research, the effects of I-shaped CFRP profile, impact energy, impact momentum, impact height and concrete strength on the impact resistance of CFST beams stiffened with encased I-section CFRP profile were analyzed. It was found that compared with CFST members, the I-section CFRP profile added to the CFST beams can significantly increase the impact force and deformation resistance of CFST beams stiffened with encased I-section CFRP profile under the lateral impact. With the increase of impact height and impact energy, compared with CFST members, the deflection reduction ratio of the CFST beam stiffened with encased I-section CFRP profile at the impact position increases, and the maximum deflection reduction can reach 22%. Under the same impact energy, the impact duration and the peak value of impact force of the CFST beam stiffened with encased I-section CFRP profile increase with the increase of the momentum of the impact object, but the impact force plateau value and deflection change little. With the increase of impact energy, the ratio of CFST beam stiffened with encased I-section CFRP profile energy consumption to impact energy increases, but the overall energy consumption is maintained at about 83%. With the increase of impact height, the deflection of CFST beams stiffened with encased I-section CFRP profile becomes larger, and the whole impact duration increases.

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abst. 2253
Room 3
Thursday
September 2
16h50

Moment-Rotation Based Model for the Coupled Buckling Analysis of pGFRP Members

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The use pultruded glass fiber-reinforced polymer (pGFRP) material in construction industry has gained attention due to its advantages over traditional materials, such as strength-to-weight ratio, enhanced durability when exposed to harsh environments and versatility in geometry. On the other hand, the combination of a relatively low modulus of elasticity of the material with slender and thin-walled structural members makes the strength to be controlled by buckling, with possible coupling between global and local modes. To analyze pGFRP structural members, two main approaches have been currently adopted: i) lower-bound strength curves calibrated for experimental results; and ii) non-linear finite element analysis including imperfections with shapes derived from main buckling modes. While the former consists in a straightforward design procedure, it may lead to conservative strength predictions and only for pre-qualified cross-sections. For the latter case, the use of specific finite element packages is required, which may be not readily available for designers. The present work aims to present a moment-rotation-based alternative strategy for the analysis of non-linear buckling mode interaction of pGFRP members subject to compression. First of all, a representative prism is defined based on the critical local buckling length and, based on an assumed deflected shape and constitutive relations, corresponding moments can be derived for given rotations of the prism. In a second step, the structural member is divided in segments and a Mohr's analogy is adopted to obtain the deflections with loading. The model is validated against experimental and numerical results available elsewhere in literature and it is shown that the model can be a useful tool for the analysis of pGFRP structural members. A study is also carried out to assess the influence of different parameters, such as imperfections, material properties, local and global slendernesses and end conditions, confirming trends previously observed in literature. Finally, the model is adopted to derive lower-bound strength curves.

Composites in Innovative Applications

FRP-confined desert sand column: concept and compressive behavior

abst. 2028
Repository

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This paper presents the conceptual structural form incorporating fiber reinforced polymer (FRP) and uncemented desert sand. The main feature of this FRP-confined desert sand (FCDS) is the direct use of uncemented desert sand without additional binder. To investigate the compressive behavior of FCDS, a total of 15 specimens with an inner diameter of 150 mm and a height of 300 mm have been prepared and tested. Test variables included the type and thickness of the exterior FRP container while the unscreened desert sand kept constant. Test results showed that both the compressive strength and axial deformation of FCDS are larger than that of the simple sum of the FRP tube and uncemented desert sand, indicating that the confinement provided by exterior container is effective. Moreover, these FCDS specimens with polyethylene naphthalene (PEN) and polyethylene terephthalate (PET) FRP exhibited a superior compressive behavior compared with their counterparts covering the CFRP tube. This FCDS column provides an effective option for underground convergence controlling in the desert zone. In addition, it can be also used in some infrastructure construction where the stiffness of the structural form is not the main concern.

Determination and enhancement of bonding properties of hybrid steel-GFRP composites

abst. 2108
Room 3
Thursday
September 2
17h10

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Glass fiber reinforced polymers (GFRP) are versatile and promising materials that have made their appearance in bridge construction more than a decade ago. Due to their high strength to weight ratio, low maintenance requirements and ease of installation on site, these materials show an important potential for bicycle and pedestrian bridges and for road bridges for light and moderate traffic. But this material also has great potential for expansion projects and the renovation of existing bridges. The design of GFRP bridges is typically based on service limit state (SLS) requirements, such as the deflection under uniformly distributed load and the natural frequency in unloaded and loaded state [2], whereby the stiffness of the GFRP material has a large contribution. However, this stiffness-dominated design will mean that for larger spans ($>$ 30 m) large construction bridge deck depths are required in the design of a GFRP bridge in order to avoid exercise deflections of the bridge compared to the stiffer steel bridges. As a solution, extra intermediate supports or a double-sided clamping can be used to limit the deflection of the bridge deck. However, it will not always be possible to provide an intermediate support or a double-sided clamping, due to lack of space, the execution of the foundation or the associated costs. In this paper, a new hybrid GFRP material will be investigated, combining the stiffness of steel with the light weight and low maintenance properties of GFRP materials. Here, the adhesive properties between the glass fabric and the steel plate are an important part of the successful implementation of this type of hybrid composite in the future. This paper investigates the bonding properties and enhancement treatments for these hybrid composites. In the first phase, the surface roughness of the steel surface will be investigated with different surface treatments, after which reference measurements with different adhesives will be investigated by means of single lap shear and short beam shear (SBS) tests. After this introduction, the second part will give a brief overview of the materials, surface treatments used and the tests performed in this research. Furthermore, some preliminary results of the research are presented and are briefly discussed. As the research is still ongoing at the time of submission of this abstract, not all results of the described tests are available at this moment.

abst. 2113
Room 3
Friday
September 3
16h50

Optimization stage of a composite quadrupole mass at high-speed rotation using finite element modeling

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This work shows the optimization process of a quadrupole mass at high-speed rotation using the finite element modeling (FEM). Such a mass should compose a gravitational signal generator device, which is intended to use in an experiment to measure the speed of gravity. The device must produce a tidal gravitational signal with a frequency of 3200 Hz. The gravitational wave detector Mario Schenberg is the first option as the detector of the signal. The previous steps of the project are briefly discussed, and the FEM simulations for the quadrupole mass are shown. An analysis of the mechanical stresses produced at high-speed rotation is presented. The most successful FEM simulation yields a favorable geometry for the inclusion of the magnetic suspension of the quadrupole mass. The results indicate the feasibility for the continuation of the project and subsequent construction of the real device.

abst. 2182
Room 3
Friday
September 3
16h30

Developing Innovative Approaches For Joining Structural Composite Parts

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Conventionally used mechanical fasteners not only increase the weight, but also act as a stress concentrator deteriorating the structural capacity of components, cause serious delamination problems, corrode easily, affect electromagnetic properties/radar absorption characteristics, and negatively affect labor cost and manufacturing proces. Thus, alternative joining techniques have become an critical issue in the aircraft industry, etc. In this study, carbon fiber reinforced-epoxy matrix based prepreg composites were interspersed with electrospun polyamide-6,6 (PA 66) nanofibers to improve the bonding behaviour. The coated PA 66 nanofibers were prepared as a 10% by weight solution of PA 66 by dissolving 10 g of PA 66 pellets in 100 mL formic acid/chloroform (75:25 v / v) at room temperature. These nanofibers were deposited directly on prepreg prior to composite production by autoclaving. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were employed to characterize the morphology and properties of the nanofibrous yarns. To investigate the effect of nanofiber field weight density (AWD), various AWD nano interlayers were prepared by varying the electrospinning time. The thermal properties of nanofibers were examined by Differential Scanning Calorimetry (DSC). Alternative adhesive bonding

techniques such as co-curing and co-bonding have been used to join electrospinned prepregs without being subjected to mechanical effects and using metallic elements. Stress analysis and fracture modes of the joint area, the effect of joining techniques on the mechanical, environmental impact, and fatigue performance of composite parts have been investigated. This work will contribute to the aviation industry in many ways, thanks to the production of higher strength and long-lasting composite parts and the reduction of the metal used and the improvement of the junction zone properties. The studies on increasing performance of joining area (fracture toughness, impact strength and mechanical strength) by coating of nanofibers on the surface (prepreg or cured composite skin surface) with electrospinning techniques include the originality of the work. Keywords: Composite material, carbon prepreg, epoxy, joining techniques, nanofibers, mechanical performance

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Influence on the axial stresses values and critical buckling load in a tube made of composite material due to the variability of geometrical and materials properties

abst. 2240
Repository

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One of the main themes of research is inherent in the continuous and progressive lightening of the components by adopting increasingly high-performance materials, or rather materials whose relationship between the fundamental characteristics for the specific application is more positive. An example of this relationship is the ratio between the material ultimate load and its density (which is correlated to the strength of the component) or the ratio between the material Young modulus and its density (which is correlated to the component stiffness i.e. its deformation). Therefore, the higher these values, the greater the weight reduction of the component. For this purpose, there are graphs in the literature (Asby maps) that allow comparing the materials characteristics of the materials not in absolute terms but in terms related to highlighting which ones are more performing for a specific purpose. In this perspective, the composite materials (especially about the type of fibers used), have one of the highest values of the ratio between the breaking load or yielding and the density for all materials that can be used to build a specific component. The sizing of an axial-asymmetrical component subject to axial load and made of isotropic material can be performed by adopting the classic theory of continuum mechanics. Specifically, different effects must be considered, namely the value of the maximum stress and the relative displacement. A further aspect is given by the buckling phenomenon which is closely related to the slenderness of the structure. In the linear elastic field, and with high slenderness values, this phenomenon is well described by a simple equation or by the Euler equation which allows determining the critical load as a function of a few geometric parameters (length of free deflection, geometry of the section) and the material essentially Young's modulus. In the case of composite materials, the formulations become more complex as a consequence of the fact that, in general, the material shows an anisotropic behavior. The study of buckling phenomena for composite materials increase the complexity due to the different aspects like global and local (asymmetric and non-asymmetric deformation). The next step in the design process is to move from a deterministic to a probabilistic approach and this research is part of this field, the purpose of which is to study the variation of the axial stresses and the critical buckling load magnitude as the variations of the parameters that define these values for a column made of composite material. The analytical formulation, in order to determine the variation of the maximum or equivalent stresses, and the critical load of buckling, in relation to the variation of the values of the parameters that define its function, takes place through the use of partial derivatives. These have been determined analytically and implemented in a specific Mathcad software program for their solution. The variability of the values of the parameters adopted was deduced from the normal and usual technological operations carried out for the construction of the component, such as the tolerance on the internal and external diameter of the tube and so on. The choice of a component with a small thickness circular section finds various applications such as pipes, reinforcement elements for civil structures, or even elements of a hydraulic cylinder such as the rod. After the theoretical discussion of the reliability linked to the axle action and buckling phenomenon, the work will be oriented in the application to a concrete case or the rod of a specific hydraulic cylinder. From the preliminary numerical results, it emerges in a nutshell that the deterministic safety coefficient as regards the axial stress is in an almost linear relationship with the component reliability value and that this value is not correlated to the value of the critical load of instability, which is correlated to the effect of the slenderness of the structure (a parameter that is not present in the formula for evaluating the stresses and therefore the stress safety coefficient for the structure). The implications of these conclusions are essentially dictated by the fact that the reliability design of an axisymmetric component in composite material must take into account the two phenomena (safety coefficients with respect to the maximum stress and critical buckling load (global and local)). In fact, there is no correlation between them and the variability on the critical load, depending on the nominal values, which is much greater than the variability on the value of the maximum stress.

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abst. 2259
Room 3
Friday
September 3
17h10

An Investigation on the Mechanical Properties of a 3D Printed TPU/PLA Programmable Filament

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Programmable filament enables end users to customize composite structures with multiple materials using a conventional Fused Deposition Modeling (FDM) 3D printing technique without any hardware updates. The Polylactic acid (PLA) filament is widely used for desktop 3D printing purposes. Although PLA filament possesses exceptional mechanical properties such as high strength and easy-to-store nature at room temperature, its brittleness restricts its use for producing flexible structures. While, Thermoplastic polyurethane (TPU) filament is flexible and commonly used in printing compliant structures. This study focuses on investigating mechanical properties of a 3D printed programmable filament made by combining two biocompatible 3D printing polymer filaments PLA and TPU. The 3D printed programmable filament tested in this work was composed with a PLA/TPU ratio of 60:40 by volume. Dogbone shaped specimens are printed using this programmed filament. The 3D printing parameters such as raster angle, printing speed, layer height, printing temperature and printing flowrate are varied to determine their effect on the mechanical performance of the PLA/TPU composite. Tensile tests are performed on 3D printed PLA/TPU dogbone specimens to determine their mechanical properties compared to homogeneous PLA and TPU specimens. A numerical model is developed to understand the mechanical performance of this 3D printed composite for further prediction with different composite ratios. The responses from the numerical model and experimental tests are also compared. With understanding the influence of printing parameters on the mechanical properties, we prove that programmable filaments with desired properties can be 3D printed without using expensive 3D printers.

DAMAGE SIMULATION OF MECHANICAL PROPERTIES OF COMPOSITE MATERIALS IN GENERALIZED GRADIENT THEORY ELASTICITY

abst. 1022
Room 2
Friday
September 3
13h10

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It is considered a variant of the gradient theory, in which a scalar parameter is introduced, which plays the role of a damage parameter. On the one hand, this parameter, as a global parameter of damage, is associated with the degradation model. On the other hand, the formal use of the variational principle to describe the state of local equilibrium makes it possible to close the problem of modeling damage accumulation and to establish a relationship between the damage macro-parameter and the medium micro-parameters, the role of which is played by the defect fields. It is proposed a variational gradient model of composite material damage, in which the damage parameter can be associated with the gradient behavior of the medium deformations, which is characteristic in the vicinity of the disturbance lines, contact boundaries of various components of the composite, as well as with the microparameters of the medium defectiveness. It is introduced a scalar function, which is a macrocharacteristic of damage and determines the model of degradation of the mechanical properties of the composite components. A continual model of the concentration of scattered damage associated with structural inhomogeneity and the level of stresses in an inhomogeneous material, and a model of damage accumulation, are constructed using a variational formalism that is generally valid for irreversible processes. As a result, the macrodamage is associated with the density level of the integrated part of the potential energy and the dissipation energy density determined by various dissipation channels; it is established a relationship between the damage macroparameter and damage microparameters, the role of which is played by the defect fields. The variational model is based on a modification of the variational model of Mindlin's media and makes it possible to formulate a closed mathematical model of an inhomogeneous medium taking into account the accumulation of damage: a coupled system of equilibrium equations in generalized displacements (or motion) and kinetic equations for macrodamage, as well as a boundary value problem (initial-boundary value) in general case. It is considered an example of a connected problem of diffusion damage and elasticity, in which the defectiveness is determined by free dilation-concentration, and the use of the generalized Mindlin model leads to a gradient generalization of the elasticity equations and the diffusion equation. This example makes it possible to approximately simulate the effects of damage accumulation in the process of moisture saturation of composites. Possible adhesive damage to the phase contact boundaries is taken into account. It is shown that the consideration of adhesion damage can significantly affect the concentration distribution and lead to concentration localization in the vicinity of the inclusion boundaries. The scalar damage function also demonstrates localization around rigid inclusions. The authors would like to acknowledge the financial support of the Russian Science Foundation under the grant 20-41-04404.

The impact of the kissing bonding defects on properties in Fibre Metal Laminates

abst. 2015
Room 2
Friday
September 3
14h30

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The fibre metal laminates (FML) are one of the newest hybrid materials used in aerospace in large scales such as elements of fuselages or other control surfaces in planes. The high quality of FML structures is primary in the manufacturing process. However, some faults can occur and can be hazardous for the reliability of FML structures. One of the most dangerous types of defect is non-detectable zero thickness delamination, named also kissing bonding defects. The kissing bonding is an area at the layer interface where the two surfaces are held together by compressive stress with no molecular forces acting between them. The purpose of the work is the evaluation of NDT techniques appropriate for FMLs in the context of kissing bonding detection and the impact of this type of defect on in-plane and out-of-plane mechanical properties. It was concluded that even sensitive NDT methods are not able to detect the kissing bonding defect in FML constructions. This is because of not only physical contact between the layers. Simultaneously, the kissing bonding impact on out-of-plane properties in FML is significant. In the case of FMLs with the perpendicular fibre orientation to the peel direction, there is one failure pattern. Whereas in the case of FMLs with the direction of the longitudinal fibres to peel direction there occurs two failure pattern. Depending on the poor adhesion area width the interlayer fracture in the composite can be observed until kissing bonding defect area and then transfer the crack to the metal/composite interface through fibres. In the case of low width of poor adhesion area, the two parallel interlaminar cracking can be seen, one at the metal/composite interface in poor adhesion area, the second continuous in the composite layer.

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abst. 2019
Room 2
Friday
September 3
14h50

The mechanical properties and failure analysis of thinply-fibre metal laminates

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Fibre Metal Laminates (FML) are currently under intensive development, especially in aircraft industry. FML possess superior properties of both metals and fibrous composite materials. Fibre metal laminates are characterized by excellent strength and fatigue properties and high damage tolerance including impact damage. The current aim of manufacturing cost reduction and further increase of the properties of FMLs means that new materials or technologies should be used. The research on FML is focused on generating new laminates, for example based on the combination of titanium and magnesium and carbon or glass polymer composites. One of the another solution is the implementation of the thinner plies of metal as well as prepreg in the FMLs. The intensive developing of such structures is because of the much more large design space that they offer, the same like really positive effects of low thickness of layer to affect their performance in various loading conditions.Thin-ply laminates are particular interest due to the in situ effect and their capability of delaying matrix cracking, suppressing delamination and split of thin plies under different loading conditions, and thus delaying the damage of the composite. It might be expected that a combination of hybrid FMLs and thin-ply laminates can improve their properties as compared to that of conventional laminates. The implementation the thinply in FML means that such materials have higher mechanical properties e.g. static and fatigue strength, impact resistance and higher damage tolerance in general. The purpose of the study was the investigation the mechanical behavior and properties of ThinPly Fibre Metal Laminates (TpFML) based on aluminum metal layers and carbon and glass fibres. The thickness of single composite layer in manufactured TpFML was 0.04 mm. The 3/2 laminates were designed. The TpFML was compared to FML based on the same materials but with the thickness of single composite layer of 0.2 mm (as conventional GLARE or CARALL). The final thickness of TpFML and FML was equal. The ASTM standard were used to samples preparation and tests conduction. As a first one a technology and microstructures of TpFML and conventional FML were presented. Then the properties of static tensile, compression, in-plane shear stress/shear strain and interlaminar shear strength were determined. Finally, the conducted research allowed to compare the mechanical properties of TpFML and convenional FML and determine the influence of microstructure and damage mechanisms on the properties of laminates. 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 NUMERICAL ANALYSIS OF COMPOSITE LAMINATES WITH ELASTIC COUPLINGS IN SPLIT CANTILEVER BEAM CONFIGURATION

abst. 2027
Room 2
Friday
September 3
15h10

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Carbon fiber reinforced polymer (CFRP) laminates are widely used in various engineering applications due to excellent material properties like corrosion and fatigue resistance. On the other hand, composite laminates are susceptible to delamination which can follow according to three classical fracture schemes (modes), namely: opening mode I, in-plane shear mode II and transverse shear mode III. Interlaminar delamination resistance in the form of critical strain energy release rate (c-SERR) can be determined by using classical data reduction schemes described in respective ASTM or ISO Standards. In the available literature there is a number of papers addressing to delamination problem in laminates subjected to opening mode I and in-plane shear mode II tests. Nevertheless, much less attention was paid to the mode III delamination. All test methods of mode III fracture toughness proposed in literature cannot totally eliminate contribution of mode II and generate far from uniform c-SERR distributions at delamination front. In addition, those method do not take into account the effect of elastic couplings [1,2] which can cause undesirable behavior of laminate during the test resulting increase of experimental errors. Therefore, subsequent research is still need to better evaluate the mode III fracture toughness. The main goal of this paper is numerical investigation of carbon/epoxy laminates exhibiting elastic couplings. The anti-plane shear (mode III) split cantilever beam configuration were analyzed to validate the mode III strain energy release rate distributions along delamination front. Moreover different boundary conditions as well as applications of different materials in layer configuration were considered. The research has been performed within the framework of the project No. 2016/21/B/ST8/03160 financed by the Polish Science Centre.

The curing effect on fiber bridging phenomena in mode I fracture of laminated composites

abst. 2062
Room 2
Friday
September 3
12h50

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Fiber bridging phenomena play a significant role in the energy dissipation in Mode I fracture behavior of carbon fiber reinforced polymers (CFRP). The bridging phenomena could take 60% of the total energy dissipated during delamination propagation in some cases [1]. Therefore, extensive studies have been implemented to study the origin and development of fiber bridging. Traditionally, the origin of fiber bridging is considered as the nesting of adjacent layers during fabrication, weak interface, voids, fiber-rich zone, and resin-rich zone distribution [2]. Laminates made by thin-ply could have a relatively smooth mode I fracture surface compared to laminates made by thick-ply due to the more homogeneous microstructure in thin-ply laminates [3]. Meanwhile, different thicknesses of laminate could influence the bridging traction decay rate in the fiber bridging zone, which would affect the propagation toughness [4]. However, the sensitivity of fiber bridging due to the curing effect is not fully elaborated in the literature. In this work, we implemented a series of back bonded double cantilever beam (BB-DCB) tests to study the curing effect on the extent of fiber bridging [5]. The baseline sample

was a unidirectional DCB sample [0_8]_s, while the BB-DCB sample contained a middle core and two backing adherends bonded to each side of the core. Three configurations of BB-DCB sample were chosen, which were [0_2 ||[U+3016]0_6][U+3017]_s, [0_4 ||[U+3016]0_4][U+3017]_s, and [0_6 ||[U+3016]0_2][U+3017]_s. The symbol '||' denoted the back bonded position. The total thickness was kept the same as 4 mm; thus the only factor that influences the fiber bridging phenomena comes from the curing process with different thicknesses of core. The experimental results showed that thinner core BB-DCB samples had much less fiber bridging compared to the thicker core BB-DCB samples. Thus, the stable propagation toughness of thinner core BB-DCB samples was much smaller 0.35 N/mm. In contrast, the toughness of the baseline [0_8]_s is 0.68 N/mm, which included energy dissipated from the bridging zone. The reason for different bridging phenomena with different thickness cores was studied. The digital image scanning results indicated that there is no displacement gap in the glue area, which excluded the back bonded influence. Meanwhile, a special configuration test was conducted to further study the curing effect, which is curing the backing adherends and core in the same batch. We put aluminum foil with release agent between the backing adherends and core during hand layer-up the prepregs; thus, the backing adherends and core could be separated easily after curing finished. Then, the same back bonding process was operated. This altogether-cured [0_6 ||[U+3016]0_2][U+3017]_s sample had the same total thickness as the baseline sample [0_8]_s, and the DCB results showed similar bridging phenomena. This additional test further proves that the laminate thickness during curing has a significant influence on the extent of fiber bridging and propagation toughness. [1] M.F.S.F. de Moura, R.D.S.G. Campilho, A.M. Amaro, and P.N.B. Reis. Interlaminar and intralaminar fracture characterization of composites under mode I loading. Composite Structures, 92(1):144-149, 2010. [2] R. Khan. Fiber bridging in composite laminates: A literature review. Composite Structures, 229: 111418, 2019. [3] G. Frossard, J. Cugnoni, T. Gmür, and J. Botsis. Mode I interlaminar fracture of carbon epoxy laminates: Effects of ply thickness. Composites Part A: Applied Science and Manufacturing, 91:1-8, 2016. [4] E. Farmand-Ashtiani, J. Cugnoni, and J. Botsis. Specimen thickness dependence of large scale fiber bridging in mode I interlaminar fracture of carbon epoxy composite. International Journal of Solids and Structures, 55:58-65, 2015. [5] P. Hu, D. Pulungan, R. Tao, and G. Lubineau. Influence of curing process on the development of fiber bridging during delamination in laminated composites. Submitted.

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abst. 2067
Room 2
Friday
September 3
15h30

Computational modeling based on XFEM and cohesive interfaces of the 3D fracturing process in anisotropic layered geomaterials

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In many countries, argillaceous formations are considered as potential host rocks for radioactive nuclear waste geological disposal, due to the very low permeability and high adsorption capacity. Because of the favorable hydro-mechanical properties, the kaolonite-rich Opalinus Clay (OPA) formation is a valid candidate for the Swiss federal deep geological repository of high-level radioactive waste. This shale formation features a very low absolute permeability, and a favourable self-sealing capacity, with a spontaneous reduction of fracture permeability by hydro-mechanical, hydro-chemical or hydro-bio-chemical process. For the sedimentary genesis, this rock can be considered a transversally isotropic geomaterial, as also documented in many laboratory experiments [1-3]. The definition of reliable and robust models for the simulation of the crack growth and propagation in such materials is of paramount importance, such that advanced computational techniques are largely recommended. In this context, the present study proposes the application of a cohesive zone modeling (CZM) [4-6] and the extended finite element method (XFEM) [7,8] to predict the fracture directions of propagation within 3D OPA specimens, by using single and/or mixed-mode fracture mechanics criteria [9]. The proposed computational technique avoids the difficulty of remeshing when tracking the moving interface positions during the craking process. A systematic investigation is performed for notched specimens with different precrack geometries, dimensions, loading conditions, and cohesive interfacial parameters. The numerical results from XFEM are successfully compared to theoretical/experimental predictions available in literature, as

well as to the numerical solutions based on conventional cohesive elements and classical finite elements. This confirms the accuracy of the proposed formulation to treat the fracturing problem, even with a moderate computational demand, despite its complex nonlinear nature. REFERENCES [1] Barpi, F., Valente, S., Cravero, M., Iabichino, G., Fidelibus, C. (2012). Fracture mechanics characterization of an anisotropic geoematerial. Engineering Fracture Mechanics, 84, 111–122. [2] Valente, S., Fidelibus, C., Loew, S., Cravero, M., Iabichino, G., Barpi, F. (2012). Analysis of fracture mechanics tests on opalinus clay. Rock Mechanics and Rock Engineering, 45(5), 767–779. [3] Bossart, P. (2018). Twenty years of research at the Mont Terri rock laboratory: what we have learnt. In Mont Terri Rock Laboratory, 20 Years (pp. 407-413). Birkhäuser, Cham. [4] Dimitri, R., Trullo, M., Zavarise, G., De Lorenzis, L. (2014). A consistency assessment of coupled cohesive zone models for mixed-mode debonding problems. Frattura ed Integrita Strutturale, 8(29), 266–283. [5] Dimitri, R., Trullo, M., De Lorenzis, L., Zavarise, G. (2015). Coupled cohesive zone models for mixed-mode fracture: A comparative study. Engineering Fracture Mechanics, 148, 145–179. [6] Dimitri, R., Cornetti, P., Mantič, V., Trullo, M., De Lorenzis, L. (2017). Mode-I debonding of a double cantilever beam: A comparison between cohesive crack modeling and Finite Fracture Mechanics. International Journal of Solids and Structures, 124, 57–72. [7] Pommier, S., Gravouil, A., Combescure, A., Moës, N. (2011). Extended finite element method for crack propagation. London, UK: ISTE. [8] Dimitri, R., Fantuzzi, N., Li, Y., Tornabene, F. (2017). Numerical computation of the crack development and SIF in composite materials with XFEM and SFEM. Composite Structures, 160, 468–490. [9] Mohammadi, S. (2008). Extended finite element method: for fracture analysis of structures. John Wiley Sons.

ANALYTICAL EVALUATION OF MODE I II FRACTURE TOUGHNESS OF CFRP CURVED BEAMS

abst. 2075
Room 2
Friday
September 3
12h10

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Carbon Fiber Reinforced Plastic (CFRP) is expected to be used in high pressure hydrogen tanks due to its high strength and stiffness. In composite structures with curvature, such as hydrogen tanks, bending moments occur when internal pressures or external loads are applied, which eventually lead to delamination. Delamination is the most important mode of damage in composites because it reduces the stiffness and strength of the composite structure and leads to complete failure if it grows. Delamination is characterized by fracture toughness values, which have been adopted in ASTM standards for characterization of pure mode I and pure mode II delamination in flat specimens by double cantilever beam (DCB) and end-notched flexure (ENF). However, the evaluation method is not yet established for curved beam specimens; there exist some studies that have theoretically evaluated the Mode I energy release rate based on the curved beam theory in DCB testing. On the other hand, there are no studies that theoretically evaluated the Mode II energy release rate of ENF for curved beams. Therefore, in this study, DCB and ENF analysis of CFRP curved beams are conducted. Based on the theory of curved beams, Mode I and Mode II energy release rates are evaluated theoretically. Also, we attempt to evaluate the effect of curvature on Mode II crack propagation in commercial finite element software, Marc.2017, by applying cohesive zone model.

Development and fabrication of two-matrix composites: materials characterization and fracture mechanics

abst. 2087
Room 2
Friday
September 3
15h50

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Demand of new innovative products is constantly increasing in today's global manufacturing environment. Such trends can be seen in the airspace, wind energy, medicine and other specific industries, where additional requirements for the products are met. Composite materials are traditionally used in mentioned industries because of lightweight, low-cost and high performance. However, there is continuous need of new composite materials with enhanced mechanical properties or functionality. For fabrication of new materials traditional and advanced production technologies can be used. Additive manufacturing (AM) is very well known technology for production of unique, complicated products. Traditionally AM was used for parts production from various polymers. Today AM can be used for production of parts from polymers, metals, ceramics and even composite materials. Combination of technological possibilities of AM and ability to fabricate composite materials can be very important in the global manufacturing environment. In this study two-matrix composite materials were developed and tested. Fused deposition modelling (FDM) technology for production of composite materials was used. FDM is material extrusion based technology where molten polymer is extruded through nozzle and deposited on platform. For the production of composite material modified FDM principle was used which allow to print polymer as a matrix material and continuous carbon fiber as a reinforcement material. In this study polylactic acid (PLA) and 1K carbon fiber tow T300B were used. FDM is very well known technology, however it has some disadvantages among them is porosity of produced product. Usually porosity cannot be avoided, but can be reduced by changing printing parameters such as printing layer height and extrusion width. In this study, was decided to print two groups of specimens with 1 mm and 1.2 mm extrusion width. However to eliminate porosity completely composite parts were impregnated with epoxy resin in the vacuum chamber. For the analysis of mechanical properties, tensile and flexural tests according ASTM D 3039 and ASTM D 7264 standards respectively were performed. During tests, slow motion camera was used in order to identify failure modes and fracture mechanism in the composites. The obtained results confirmed that adjustment of printing parameters can be used for improvement of mechanical properties. Smaller extrusion width allows to print less porous composite structures. However, after analysis of impregnated structures it was found that higher porosity parts can absorb more epoxy resin and this can lead to significantly improved mechanical properties. Composite specimens printed with 0.3 mm layer thickness and 1.2 mm extrusion width showed 203 MPa tensile strength before impregnation. Meanwhile composite specimens printed with the same printing parameters showed 265 MPa tensile strength after impregnation process. During analysis of results after flexural tests, even more clear trend was observed. Composite specimens demonstrated 140 MPa and 294 MPa flexural strength before and after impregnation respectively. It can be stated that two-matrix composite materials has significantly better mechanical properties in comparison with PLA/CF composites. The results can be applied for the fused deposition modelling process to predict mechanical properties of composite parts. Moreover, combination of FDM and impregnation processes are very promising because can help to reduce porosity and increase mechanical properties significantly.

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abst. 2103
Room 1
Thursday
September 2
11h30

INTERLEAVING AS A PRACTICAL ROUTE TO MAKE PSEUDO-DUCTILE HYBRID COMPOSITES MORE SUITABLE FOR INDUSTRIAL APPLICATIONS

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One of the most significant worldwide challenges of the 21st century is to reduce the emissions of CO2 in the atmosphere. The transport sector is responsible for 45% of the total emission in Europe [1], which are mainly due to fuel consumption. The efforts to decrease the carbon footprint of transportation have a beneficial effect on the environment, and the main actions concern the weight reduction of vehicles (e.g. airplanes, ground transport, etc.). Therefore, progresses into lighter materials with high mechanical performance are essential. The weight reduction in vehicles allows for reduced fuel consumption and make engineering structures more efficient. Fibre-reinforced polymer composite (FRPC) materials have been used largely in the last decades in high-performance engineering structures and are particularly attractive for their high strength-to-weight ratio. The main drawback of FRPCs is their inherent tendency to fail catastrophically, without sufficient warning before their final failure. The recent studies on hybrid composites and pseudo-ductility [2] opened new possibilities to design composite structures which showed, a gradual fracturing and stable delamination before the final failure of the material, under tensile loads. This way, composites may be provided with the safety margin, usually missing in the traditional FRPCs. Czél et al. [2] have studied the parameters which control pseudo-ductility in uni-directional (UD) hybrid composites. The thickness of the plies used in the hybrid laminate plays an important role in eliminating unstable damage modes, i.e. catastrophic delamination, and promoting the gradual fragmentation of the carbon/epoxy layer leading to the pseudo-ductile behaviour. Thin carbon-epoxy plies were particularly suitable for getting fragmentation and design pseudo-ductile hybrid composites. On the other hand, thin-ply prepregs are expensive and difficult to manufacture, and their use may inhibit the introduction of pseudo-ductile hybrid composites in industrial applications. We will present the possibility to achieve pseudo-ductility in hybrid composites using standard-thickness plies and explore the routes to eliminate the unstable damage modes which have characterised the baseline configuration, i.e. without interleaves. The strategy for suppressing delamination and increasing the mode II interlaminar fracture toughness (GIIC) is interleaving thin layers of thermoset or thermoplastic films and nanofibrous layers between the unidirectional composite layers of the interlayer hybrid composite plates. Interleaving has been shown in literature to be an efficient way of introducing toughening effects in composites. They make composites more damage tolerant and delamination resistant with the introduction of energy absorption mechanisms like crack arresting and deflections. The work presented here focuses on hybrid composites made by standard-thickness IM7 carbon/epoxy and S-glass/epoxy plies. Tensile tests on this hybrid configuration resulted in unstable damage mode due to catastrophic delamination. The interleaf layers of epoxy or thermoplastic films and PA6 electrospun nanofibrous layers promoted the gradual fragmentation of the carbon/epoxy layer and localised, stable delaminations around the carbon/epoxy fragments. The observed failure mode fulfils all requirements for pseudo-ductile behaviour. Acknowledgement The research has been performed within the framework of the HyFiSyn project (European Union's Horizon 2020 research and innovation programme, Marie Skłodowska-Curie grant agreement No. 765881) and supported by the National Research, Development and Innovation Office (NRDI Office, Hungary) through grant ref. OTKA FK 131882. Gergely Czél is grateful for funding through the Premium Postdoctoral Fellowship Programme of the Hungarian Academy of Sciences. The research has received funding from the European Union in the frames of the project "Modular platform for autonomous chassis of specialized electric vehicles for freight and equipment transportation", Reg. No. CZ.02.1.01/0.0/0.0/16_025/0007293. References [1] González, R. M.; Marrero, G. A.; Rodríguez-López, J.; Marrero, Á. S.: Analyzing CO2 emissions from passenger cars in Europe: A dynamic panel data approach. Energy Policy, 129, 1271–1281 (2019). [2] Czél, G.; Wisnom, M. R.: Demonstration of pseudo-ductility in high performance glass/epoxy composites by hybridisation with thin-ply carbon prepreg. Composites Part A: Applied Science and Manufacturing, 52, 23–30 (2013)

The use of recycled carbon fibres for interlay toughening of composite laminates

abst. 2112
Repository

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This work investigated the potential of using recycled carbon fibres as interlayers of composite laminates to improve the fracture toughness. Two types of nonwoven mats based on 100% recycled carbon fibres and comingled recycled carbon fibres/PPS fibres were used for interlay toughening. The mode-I and mode-II fracture behaviour of toughened carbon fibre composites were studied using a double cantilever beam and an end notched flexure test, respectively. It was found that the addition of recycled carbon fibre/PPS comingle mat significantly enhanced the mode-I and mode-II fracture toughness of the laminates, i.e. the maximum improvement in the mode-I and mode-II fracture energy was observed to be 220% and 123% respectively. This was mainly attributed to the PPS fibre bridging and pulling-out/peeling-off of recycled carbon fibres. However, interlaying pure recycled carbon fibres had negligible effects on the mode-I and mode-II fracture toughness of the composites. The main fracture mechanisms were observed to be pulling-out/peeling-off of recycled carbon fibres. While this mechanism contributed to energy dissipation, the presence of recycled carbon fibre interlayer also prohibited the fibre delamination and damage of the continuous carbon fibres observed for the reference laminate. Accordingly, it failed to enhance the overall interlaminar fracture toughness.

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abst. 2150
Room 1
Thursday
September 2
11h50

Reinforced crack in a prestressed and prepolarized piezoelectric ceramic material

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We formulate and solve the mathematical problem for an antiplane reinforced crack in a prestressed and prepolarized piezoceramic material with static initial fields, assuming the initially deformed configuration of the body is locally stable [1]-[2]. Using the boundary conditions of the reinforced crack [3]-[4], we get the homogeneous and a nonhomogeneous Riemann-Hilbert problems. Nonhomogeneous linear complex differential equations having the unknown complex potential are obtained. For constant value of the applied incremental forces can be obtained the complex potentials, incremental displacement and stress fields corresponding to the third mode of the classical fracture. Generalizing Sih's strain energy density criterion [5], for prestressed and prepolarized piezoelectric ceramic materials, we study the crack propagation. References [1] Cristescu, N., Craciun, E.M., Soos, E., 2004, Mechanics of Elastic Composites, CRC Press, Chapman and Hall, Boca Raton, FL. [2] Craciun, E.M., Baesu, E., Soos, E., 2005, General solution in terms of complex potentials in antiplane states in prestressed and prepolarized piezoelectric crystals: application to Mode III fracture propagation, IMA J. of Appl. Math., 70, 39-52. [3] Bigoni, D., 2012, Nonlinear Solid Mechanics, Bifurcation Theory and Material Instability, Cambridge University Press, New York. [4] Bigoni, D., Movchan, A.B., 2002, Statics and dynamics of structural inter faces in elasticity, Int. J. Solids Struct., 39, 4843-4865. [5] Zuo, J.Z., Sih, G.C., 2000, Energy density theory formulation and interpretation of cracking behavior for piezoelectric ceramics Theor. Appl. Fract. Mech., 34, 17-33.

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abst. 2198
Room 2
Friday
September 3
12h30

Crack propagation in Hyperelastic material using phase field method

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Fracture in materials is a very complex phenomena involving various mechanisms. Although a lot of research has been done to address the same, fracture or damage in hyperelastic material and its study has limited reach. In this work we study the crack propagation path and its dependency on various material parameters of a hyperelastic body. The crack is modelled as a diffused crack in a phase field framework and coupled with the mechanical problem in hand. Phase field method has advantage of not defining a crack a priori. The positive part of the strain energy drives the fracture i,e only the tensile part will take part in fracture process. The length scale parameter in phase field is a sensitive material parameter and its effect is studied. In this work we have taken a compressible Neo-Hookean material and studied various aspects of crack initiation and propagation in different boundary condition. The coupled problem solved in a staggered approach to obtain the deformation and damage field at different load steps.

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abst. 2212
Repository

A Nonlocal Phase Field Model for Fracture

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A new nonlocal phase field fracture model is formulated for a brittle material based on the framework discussed from phase field damage model where the order parameter is related to the damage variable from continuum damage mechanics. The free energy functional is of a Helmholtz type including gradients of the non-conserved order parameter. The Euler form of the Helmholtz free energy functional with respect to the damage variable gives the Allen-Cahn equation. This Allen-Cahn equation defines the evolution equation for damage process. A suitable energy degradation function and interpolation function is chosen. The existing Arc-length methods quadratic equation is linearised such that we obtain a unique root for the load increment factor instead of the two obtained when using the quadratic equation. This modified Arc-length algorithm is used in a staggered approach for the numerical implementation. The capability of the derived model is checked by solving a few standard fracture examples.

Phase-field modeling of brittle fracture with inertia effects

abst. 2238
Repository

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Modeling cracks in dynamic cases based on a discontinuous description is difficult because it needs additional branching and widening criteria. Being able to deal with complex crack patterns like branching, merging and fragmentation, phase-field models are promising in the computational modeling of dynamic fracture in solids. In this study, ABAQUS software is used to solve the phase-field dynamic problem in staggered way. User-defined element subroutine (UEL) is used to solve for the phase-field variable and user-defined material subroutine (UMAT) for the displacement field variable. Micro inertia is incorporated into the phase-field model for dynamic fracture as proposed in the literature and solved for one example to account for the rate-dependent effect under high-rate loading. Keywords: Phase-field method, Dynamic brittle fracture, Micro inertia, Abaqus implementation.

Development of pseudo-ductile and repairable high-performance hybrid composites

abst. 2270
Room 1
Thursday
September 2
12h10

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High-performance fibre reinforced polymer composites are an excellent choice for lightweight structural components. They have outstanding strength to weight ratio, and their corrosion and fatigue resistance are also appreciated in several demanding fields. Still, their usually catastrophic failure mode limit their spread towards safety-critical high volume applications such as automotive and transportation. Unlike metals which can be repaired using the wide selection of welding technologies, composites suffer from the lack of intrinsic repairability. The lifetime of partially damaged structures can only be extended by removing material from the deteriorated zones and apply bonded repair patches to restore the original load-bearing capacity. This is a rather complicated and laborious technique with limited scope. The failure mode of composites can be made safer, similar to that of ductile metals, by introducing pseudo-ductility through hybridisation of, e.g. glass and carbon fibres in the same thermosetting polymer matrix [1]. Czél et al [2] demonstrated earlier that the use of a unidirectional (UD) discontinuous carbon/epoxy (CF/EP) layer in sandwich hybrid laminates together with UD continuous glass/epoxy (GF/EP) layers could provide a linear-plateau-linear type tensile stress-strain response. In this case, the CF/EP plies do not fracture during the benign damage process. The material's stiffness is degraded gradually by delamination between the discontinuous CF/EP and the continuous GF/EP layers before the final failure triggered by the fracture of the GF/EP layers. This well-controlled damage

mechanism also enables the tailoring of the mechanical response to the requirements through careful design of the material architecture. This study aimed to combine pseudo-ductility and repairability, providing two desired features to high-performance composite materials for structural applications.UD prepreg plies were selected for manufacturing the laminates, and autoclave curing was utilised for the best reproducibility and quality. A novel approach to enable repairability was used in the discontinuous hybrid laminates. Stable, pseudo-ductile tensile stress-strain response was demonstrated in the first step. Then, partially damaged samples were generated and repaired. The achievable stiffness recovery of the samples will be presented. [1] Czél G., Jalalvand M., Wisnom M. R.: Design and characterisation of advanced pseudo-ductile unidirectional thin-ply carbon/epoxy-glass/epoxy hybrid composites. Composite Structures, 143, 362-370 (2016) [2] Czél G., Jalalvand M., Wisnom M. R.: Demonstration of pseudo-ductility in unidirectional hybrid composites made of discontinuous carbon/epoxy and continuous glass/epoxy plies. Composites Part A (Applied Science and Manufacturing), 72, 75-84 (2015)

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abst. 2279
Room 1
Thursday
September 2
12h30

3D stress state failure analysis of thin-walled GLARE column subjected to axial loading in postbuckling range

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This study deals with the failure analysis of thin-walled GLARE columns subjected to axial compression. Considered GLARE structure is a hybrid composite that consists of alternating thin aluminium layers and unidirectional glass fibre-reinforced prepregs. Comparative study was performed for different open cross–section profiles - mainly on top-hat channels. Various 3/2 symmetrical lay-ups were investigated for which 7 stacking sequences were distinguished based on fibres alignment in the composite layer. The compression failure test was performed in laboratory by a universal electromechanical strength testing machine of Instron upgraded with Zwick/Roel control software. Simultaneously, numerical simulations by FEM were performed to predict the damage of the multi-layered GLARE structures in a post-buckling state. Post-buckling numerical analysis was initially carried out based on nominal stress state in non-degraded structure but there was a slight discrepancy when compared to results from experimental tests. Hence, another step included a description of the damage evolution law to determine the progressive failure model. Material property degradation method (MPDG) was used and damage variables were determined to describe stiffness reduction in the area where failure was initiated [1]. Failure initiation was monitored in MPDG method by means of failure factors (FF) determined by Hashin and Puck failure criteria. The application of progressive failure model to post-buckling analysis of top-hat-shaped GLARE samples provided high agreement with experimental tests. Previous study allowed to draw a conclusion that the failure of multi-layered GLARE samples is mainly controlled by yielding of aluminium layers [2]. Therefore, further analysis required the investigation of stress tensor components participation in the failure function of selected criteria. This allowed to determine the failure modes and their continuous development which finally led to material fracture. With regards to comprehensive failure analysis, separate failure modes of various composite material constituents are already identified [3] but there is still considerable uncertainty with regard to their specific interaction. Hence, there is a need to consider various determinants of stress tensor that participate in the failure progression and post-failure behaviour. The aim of this study is to perform post-buckling failure analysis of top-hat open-cross section columns subjected to axial compression with a detailed analysis of stress tensor components contribution into material damage progression. Acknowledgments The author has obtained funding as part of financing a doctoral scholarship from the National Science Center, No. UMO-2019/32/T/ST8/00605. [1] D. Banat and R.J. Mania, "Progressive failure analysis of thin-walled Fibre Metal Laminate columns subjected to axial compression". Thin-Walled Structures, Vol. 122, pp 52–63, 2018. [2] D. Banat and R.J. Mania, " Damage analysis of thin-walled GLARE members under axial compression – Numerical and experiment investigations ". Composite Structures, Vol. 241, pp 112102, 2020. [3] S.L. Lemanski, J. Wang, M.P.F. Sutcliffe, K.D. Potter and M.R. Wisnom, "Modelling failure of composite specimens with defects under compression loading". Composites Part A: Applied Science and Manufacturing, Vol. 48, pp 26–36, 2013.

A meso-scale approach for delamination and transverse cracking in cross-ply curved carbon-reinforced laminates

abst. 2304
Room 2
Friday
September 3
16h10

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The onset and propagation of damage in the matrix of carbon-reinforced composites may be characterized by complex patterns in the presence of three dimensional stress states, which can originate both matrix cracking and delamination. A case can be represented by curved composite laminates with multi-directional reinforcements where matrix transverse cracking can occur and interact with the onset and propagation of delamination [1]. In this paper, a set of experiments are performed on unidirectional and cross-ply curved laminates made of AS4/8852 unidirectional plies. The application of a bending moment leads to the onset of delamination in the curved zones of the laminates. The experimental observations indicate that delamination and the development of intralaminar transverse cracks interact in the cross-ply specimens, in agreement with the results shown in [1,2]. The analysis of such phenomena by using FE models developed at the meso-scale level is complicated, due to the need of representing with an adequate accuracy the through-the-thickness stress distribution in each ply as well as the development of interacting discrete cracks. Several elements in the thickness of each ply may be required, with the introduction of zero-thickness cohesive elements in the mesh [1]. Alternatively, special elements can be developed to represent crack migration [3]. In this work, the problem is studied by applying a meso-scale bi-phasic model, where the idealized fibre phase of the plies is represented by membrane elements embedded in a solid mesh characterized as an effective medium that models both inter- and intra-laminar matrix-dominated responses [4]. Interacting cohesive zone models are embedded in the constitutive law that characterizes the solid elements, so to represent both delamination and transverse crack, and their mutual interaction, without requiring high mesh refinement levels. The approach is applied to model both the 0° oriented specimens and cross-ply specimens, including the effects of thermal residual stress. The results show that the effects of transverse cracking development on the strength of interlaminar layers and the crack migration phenomena can be effectively represented by adopting the modelling technique proposed. References. [1] Dongfeng Cao, Haixiao Hu, Qingfeng Duan, Peihao Song, Shuxin Li, Experimental and three-dimensional numerical investigation of matrix cracking and delamination interaction with edge effect of curved composite laminates, Composite Structures 225(2019). [2] K. Cinar, I. Guven, N, Ersoy, Effect of residual stress on the bending response of L-shaped composite laminates, Composite Structures 246(2020). [3] N.V. De Carvalho, B.Y. Chen, S.T. Pinho, J.G. Ratcliffe, P.M. Baiz, T.E. Tay, Modelling delamination migration in cross-ply tape laminates, Composite Part A 71(2015), 192-203. [4] A. Airoldi , C. Mirani, L. Principito, A bi-phasic modelling approach for interlaminar and intralaminar damage in the matrix of composite laminates. Composite Structures. 234(2020).

Hybrid Toughening in Carbon/Epoxy Composite Laminates to Enhance Interlaminar Fracture Response under Mode-I Loading

abst. 2317
Repository

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Carbon fibre reinforced epoxy composites offer relatively high mechanical properties (e.g. specific strength and stiffness, tailorability, good corrosion resistance and fatigue properties) over metallic materials. Composite laminate structures have been widely used in lightweight critical applications such as aerospace, defence and renewable energy industries. However, vulnerability to interlaminar failure (i.e. delamination) of composite laminates threatens the structural integrity of composite laminate structures. In this regard, enhancing the interlaminar fracture performance of composite laminates is essential to address the issue of poor delamination resistance of composite laminates and thus maintain the structural integrity of composites during their service life. Interlaminar veil toughening (e.g. presence of tough, ductile thermoplastic fibres at interlaminar regions as an additional layer) has recently been shown as an effective strategy to enhance interlaminar fracture behaviour of composite laminates. The areal weight of veils is a significant parameter leading to the fracture performance of veil toughened composite laminates, which results in a reduction in in-plane properties of composite laminates as decreasing the reinforcing fibre volume fraction, especially for micro-fibre based veils. Therefore, this study investigates a hybrid toughening approach (i.e. interlaminar veil toughening together with bulk resin toughening with core-shell rubber particles (CSR)) to achieve further improvement in interlaminar fracture energy. In this study, un-toughened laminates were manufactured with a low viscous two-part epoxy resin (i.e. Araldite LY 564 and Aradur 2954 supplied by Huntsman) and uni-directional carbon fibre non-crimp fabric with an area weight of 314 gsm (supplied by Saertex). Polyphenylene Sulfide (PPS) veils were with an areal weight of 10 gsm (supplied by TFP, UK) and Albidur EP 2240 masterbatch (supplied by Evonik, Germany) containing 40% core-shell-rubber particles (near-spherical particles with diameters varying from 0.1 to 3 μm) were used for hybrid toughening. During the fibre stacking process, a film insert was located at the symmetry plane to introduce a pre-crack with a length of 55 mm and 2 layers of PPS veils with 10 gsm were introduced behind the film insert. Composite laminates with/out PPS veils and core-shell rubber particle presence were manufactured with vacuum infusion and out-of-autoclave curing. The mode-I fracture energies of the manufactured composite laminates were characterised following ASTM D-5528. The hybrid toughening route was developed with the combination of interleaving of PPS veils with 20 gsm areal weight and CSR bulk resin toughening with 10 wt% presence. The mode-I fracture energies for initiation and propagation of the hybrid toughened laminates were observed to be significantly higher (by 245% and 275%). It is shown that the presence of CSR particles in PPS veil interleaved interlaminar region (i.e. PPS veils include greater resin-rich regions compared to the aligned unidirectional continuous carbon fibre) could result in enlargement of the fracture process zone ahead of the crack tip in the hybrid toughened laminates under mode-I loading by altering energy dissipation mechanisms due to gained ductility in the epoxy resin with CSR particles and extensive fibre bridging mechanisms. Fractographic observations indicated that the carbon fibre-matrix interface with CSR particle presence is relatively higher compared to adhesion achieved adhesion between the PPS fibre-matrix, which inhibited the crack diversion from veil toughened interlaminar region to the carbon fibre-matrix intralaminar region. The hybrid toughening strategy provided further improvement in the mode-I fracture energies for the composite laminates, especially for the crack propagation, by keeping the thickness of composite laminates similar to counterpart veil toughened composite laminates. References [1] N. Sela, O. Ishai, Interlaminar fracture toughness and toughening of laminated composite materials: a review, Composites. 20 (1989) 423–435. https://doi.org/10.1016/0010-4361(89)90211-5. [2] D. Quan, F. Bologna, G. Scarselli, A. Ivankovic, N. Murphy, Interlaminar fracture toughness of aerospace-grade carbon fibre reinforced plastics interleaved with thermoplastic veils, Compos. Part A Appl. Sci. Manuf. 128 (2020) 105642. https://doi.org/https://doi.org/10.1016/j.compositesa.2019.105642. [3] D. Quan, R. Alderliesten, C. Dransfeld, N. Murphy, A. Ivanković, R. Benedictus, Enhancing the fracture toughness of carbon fibre/epoxy composites by interleaving hybrid meltable/non-meltable thermoplastic veils, Compos. Struct. 252 (2020) 112699. https://doi.org/10.1016/j.compstruct.2020.112699. [4] ASTM D5528 - 13 Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites, (n.d.). https://www.astm.org/Standards/D5528.

DOPED POLYANILINE FILM COATING FOR LIGHTNING STRIKE PROTECTION

abst. 2035
Room 3
Thursday
September 2
09h40

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Metal mesh/foil-based lightning strike protection (LSP) systems are commonly used in most aircraft due to their high mechanical and electrical properties. However, the weight penalty, repairing cost and galvanic corrosion are the severe concern of these systems. Therefore, this work aims to develop a conductive film coating for structural composites to protect against a lightning strike, easy to repair and corrosion resistive. Doped polyaniline (PANI), an intrinsically conductive polymer, has been chosen due to its high electrical conductivity, low weight and cost-effectiveness. Damages under the different film coating thicknesses will be studied and compared with the metal mesh/foil LSP system. Introduction: Carbon fiber reinforced polymers (CFRP) composites are widely used structural materials in the aerospace industry due to their high specific strength/stiffness, lightweight, fatigue strength, and corrosion resistance compared to conventional metallic materials. However, low electrical conductivity makes these materials vulnerable to lightning strike damages. The direct and indirect effects of the lightning strike damages have severe consequences on the aircraft composite structures. The direct damage includes matrix resin decomposes, delamination, fiber breakage. At the same time, the indirect effect could fail the electronics system due to electromagnetic waves. Therefore, it is crucial to protect these materials from lightning strike damages, commonly known as the LSP system. The commercially available metal mesh/foil LSP system contributes weight penalty and is prone to galvanic corrosion, low adhesion at the metal-polymer interface, uneven surface, etc. Therefore, it is crucial to address these issues and develop low weight, repairing and cost-effective LSP systems. Our group has been working on the polyaniline-based composite development in the last several years and reported its potentiality as a multifunctional structural material. A continuous study has been going on to optimize its properties. In this research, different thickness of the doped PANI film coating will be fabricated on top of CFRP composites to qualify under simulated peak lightning current of 40 kA. Further, the coating film's effectiveness will be evaluated in terms of residual strength of composites after the lightning strike, internal damage evaluation using the ultrasonic test, and cross-section observation under a microscope. Sample fabrication: For CFRP composite fabrication, the vacuum-assisted resin transfer molding (VARTM) technique was used. Eight layers of plain-woven carbon fiber fabrics (TR3110M, TR30-3K fibers, 200 GSM, Mitsubishi Rayon Co. Ltd.) and XNR/H6815 epoxy resin (Nagase ChemteX Corp.) were used to fabricate the CFRP composites. The square panels with a side of 150 mm will be used for lightning strike tests. The film coating consists of an emeraldine-base (EB) form of PANI, which doped with dodecylbenzene-sulfonic acid (DBSA), were purchased from Regulus Co. Ltd, Kanto Chemical Co. Inc. respectively. The PANI-DBSA (PD) was mix with a weight ratio of 1:2; this ratio was calculated based on the molar ratio. A centrifugal mixing machine was used to prepare a homogeneous PD mixture. Further, the homogeneous PD mixture coated on top of CFRP composites with a coating tool. Further, the coating was heated from 23 C to 130 C at a rate of 10 C/min and hold for 10 minutes to cure. A protecting layer of epoxy resin was also fabricated on top of PD coating film to protect it from mechanical damage. Experimental procedure: Three different thicknesses (0.2, 0.3 and 0.4 mm) of film coating were chosen to optimize the LSP system under 40 kA simulated peak lightning current. The test will follow according to SAE ARP 5412 stander, with modified Component A. All samples will be tested before and after the lightning strike to evaluate the lightning damages, followed by a cross-section view under a microscope. Further, to evaluate the proposed LSP system's effectiveness, residual strength and stiffness of the CFRP composite will be evaluated and compared with the metal mesh/foil-based LSP system. Results and discussion: Coating characterization: To evaluate the doped PANI coating film's conductivity, glass fiber reinforced polymer (GFRP) composite was chosen as an insulating base material. The conductivity of the film coating was estimated as 260 S/m with a thickness of 0.22 mm. The density of the film coating was also measured to be 0.78 g/cm3. LSP qualification: We will discuss after lighting tests are carried out.

abst. 2162
Repository

A study on mechanical behavior of Liquid Crystalline Polyester (LCP) under high temperature condition for designing electronic devices

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Liquid Crystalline polyester (LCP, SUMITOMO CHEMICAL-SUMIKASUPER) composed of short and long fibers with polyester is suitable for thermoforming of complex shaped structures. Therefore, this composite material is used in various electronic industries like display technology, optical memory devices and performance testing devices for semiconductors. In this paper, a connector which is used for the performance testing machines for semiconductor chips under environmental conditions was designed with three different LCPs according to the composition of fiber types and weight fraction. To characterize the material of the composite materials under room temperature (23°C) and high temperature (160°C) environments, static tensile and fatigue tests were carried out. Static tensile strength under each temperature condition including stress-strain relationships was experimentally investigated. For about fatigue test the stress ratios were determined using some specific rates of static strength and under 40% of static strength condition the fatigue life exceeds one million cycles. Through the fatigue tests with various stress ratios S-N curves under different temperature conditions were determined. These practical data can be used in design stage of electronic devices like connectors under the high temperature service condition and also used for finding any possible material failure due to repetitive loading condition by using fatigue analysis.

abst. 2163
Repository

Advanced modeling technique of a Type III pressure vessel with the consideration of composite layer configuration

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Composite hydrogen pressure vessels are the most economical and safe choice which can be used to store hydrogen gas at high pressure. These vessels are manufactured by the filament winding process which has various winding patterns of the fibers and the covering area of the vessel is changed according to the winding angles. And moreover, the thickness of composite layers is also changed due to many complex processing parameters therefore, accurate estimation of composite configuration should be taken into account for the construction of finite element models. When the filaments are wound at the dome section the winding angle drastically changes due to the change of radius. If the thickness is not accurately calculated during the analysis process, the modeling cannot be accurately performed, and the exact performance of the pressure vessel cannot be calculated. Due to the hoop winding of the cylinder, the fiber cannot be completely wound on the liner which creates the gap at the connection part of the cylinder and the dome. This phenomenon leads to a large error in the thickness prediction at the dome section and affects the finite element analysis (FEA) modeling. In this study, the error caused by hoop winding at the connection part of the cylinder and the dome was calculated and the optimal technique for predicting composite dome part thickness of the Type III hydrogen pressure vessel was proposed.

Ballistic Tests of Material Systems for Bullet Catcher

abst. 2187
Repository

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In forensic tests of weapons, microscopic comparative studies of projectiles fired from high-energy weapons (e.g. rifles) are performed. In order to maintain the necessary quality of the traces of the barrel, such projectiles must be fired from the weapon with full energy and then captured in such a way that they are as little damaged as possible. Most of the hunting bullets are designed to undergo plastic deformation when they hit the animal's body. Deformed projectiles are of limited or no traceability if the deformation extends to a cylindrical guide portion on which barrel marks are left. Currently, there is no effective technology for capturing such penetrators. The research described in the article was aimed at developing a material system that slows down and gently stop a moving projectile in a way that does not cause its deformation or possibly limit it. The solutions of bullet traps that are currently used in forensic laboratories have been analyzed, as well as the system based on composite structure proposed for the current needs. On the basis of the obtained results, it is concluded that in an appropriately selected material system, it is possible to capture the projectile in a form that allows to determine whether the given weapon was used to fire projectile of the same type which was found at the crime scene.

Evaluation of deflection in concrete structural elements prestressed with unbonded FRP bars.

abst. 2192
Repository

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The focus of this work is on the design of concrete structural elements prestresssed with unbonded FRP bars considering the service limit state.. These bars have already been employed in the structural repair of a series of constructions, and the viability of its use as an external prestressing cable has been demonstrated over the last years. In the design, however, the different mechanical properties of these new materials must be considered since they have a linear behavior until the rupture and modulus of elasticity lower than the steel. Prestressed concrete structural elements may undergo larger than expected overloads, or may even be designed to allow for a certain degree of cracking, which results in reduced stiffness of the structural member. The approximate evaluation of deflections in structural elements of reinforced or prestressed concrete is an important step in the analysis of the limit state of service. The objective of this work is the evaluation of simplified method proposed by design code for determination of displacements in prestressed concrete structural elements taking into account unbonded FRP tendons. The study is carry out using experimental results obtained in the literature evaluating the variation of cracked inertia at the various stages of loading and evaluating possible modifications that should be take into account for the good agreement between analytical and experimental results.

Nickel coated radar absorbing structure with lightning strike protection using 3D printing reinforced method

abst. 2233

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Radar absorbing structures (RAS) are significantly vulnerable to lightning strikes. Unlike metallic materials, composites do not easily conduct extreme currents generated by lightning strikes, causing severe damage. Hence, it is essential to consider a lightning protection system to avoid the potential risk of lightning strikes. In this study, RAS reinforced with 3D printing method was designed and fabricated to protect these limitations in terms of the lightning strike impact damage. Plain-weave glass fabrics and electroless nickel plated glass fabric were used as reinforcement in the composite and metalized fibers were employed as the feedstock of 3D printing to reduce lightning strike damage. The 3D printing method was employed to fabricate the composite laminate. The lightning strike was applied to RAS using an impulse current generator according to the SAE standard. Despite the joule heating and damage to the laminates, the measured absorption performance was maintained. Nickel-coated glass fibers provided conductive paths which contribute to direct current, energy dissipation, and LSP effects. The 3D printing method also achieved a sufficient level of conductivity, which limited the damaged area and depth within the surface layer. These findings illustrate that it is a promising candidate as a lightning strike protection.

Durability of composite materials

Experimental results and numerical simulations on the durability of HPFRC beams subjected to freeze-thaw cycles

abst. 2040
Room 2
Wednesday
September 1
16h10

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The use of High-Performance Fiber-Reinforced Concretes (HPFRCs) is getting more and more common in civil engineering field. These materials can be utilised both in realising newly designed structures and in rehabilitation interventions on deteriorated members of existing ones. In both cases, HPFRCs are meant to guarantee superior mechanical properties and durability performance, especially in the case of elements exposed to harsh environmental conditions. Recently, an extensive experimental study has been developed at the Structural Engineering Testing Hall of the University of Salerno (Italy) with the aim to investigate the mechanical behaviour of HPFRC members characterised by a cement matrix of invariant composition and different volume fractions (0.0%, 1.25% and 2.5%) of steel fibers. First, the physical and mechanical characterisation of the materials under consideration was carried out at both fresh and hardened states. Then, HPFRC specimens were subjected to a freeze-thaw cycle protocol and, finally, they were tested in compression and bending with the aim to understand the effect of degradation possibly induced by the aforementioned thermal exposure process. The obtained results revealed a limited degree of degradation in terms of both compressive strength and bending response indices, which confirmed the potential of the tested HPFRC to cope with harsh environmental conditions. The obtained experimental results are, here, employed to drive the extension of a previously formulated non-linear cracked-hinge model capable to simulate the post-cracking response of fiber-reinforced cementitious composites in bending. Specifically, the original formulation of that displacement-based model followed a meso-mechanical approach, which made possible to consider explicitly the random distribution and orientation of the reinforcing fibers. Two main innovations have been introduced in the previous formulation. On the one hand, a transfer length is defined for the matrix contribution that allows considering the possible damage effect induced by the notching process in HPFRC specimens, which, yet neglected elsewhere, can be particularly relevant in high-strength low toughness matrices like the one under consideration. On the other hand, a more detailed description is assumed for the fiber contribution, both in terms of the description in the bond-slip law of fibers and in the definition of an effective volume fraction, which can be of relevance in cases of high amount of steel fibers. In this paper the numerical model is employed for simulating the experimental results, also including the effect of the degradation process observed in bending tests. Specifically, an inverse identification of the bond-slip law is obtained for both the sound specimens and those subjected to the freeze-thaw cycles: this led to identifying the resulting degradation of both the cement matrix and the bond-slip law due to the freeze-thaw process, which can be useful in predicting the mechanical properties of HPFRC with variable amounts of fibers and duration of the freeze-thaw process. Further studies are planned in the future with the aim of obtain other experimental results on a more widely variable composition of the matrix mortar and fiber types: this will lead to a more comprehensive calibration of the numerical model with improved predictive reliability of its numerical simulations.

Effect of pre-loads on the fatigue life of composites with open holes immersed in seawater

abst. 2078
Room 2
Wednesday
September 1
16h30

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This paper aims to study the effect of uniaxial tensile pre-stress histories on fatigue response of notched glass fiber epoxy laminates immersed in seawater. To achieve this goal, in a first stage, rectangular cross-section specimens with a central hole were subjected to different quasi-static monotonic

tensile pre-stress histories, namely 25%, 50%, and 75% of the ultimate tensile strength. Subsequently, specimens were immersed in sea water for 230 and 910 days. Then, fatigue tests were conducted under stress-controlled conditions, using sinusoidal waveforms, with a stress ratio equal to 0.1, and a frequency of 10 Hz. The notch region was monitored in situ, via a digital image correlation setup, to characterize the strain fields and to evaluate the damage accumulation process. After the tests, fracture surfaces were examined by optical microscopy to identify the main fracture micro-mechanisms. The results show that fatigue life is a decreasing function of tensile pre-stress. Regarding the seawater effect, a reduction in fatigue strength was observed for immersed specimens and this decrease increases with the time of immersion. The damage accumulation occurred in a three-step sequential process, consisting of a short initial period with a localized increase of damage around the hole, followed by a dominant period at which the damage climbs slowly in areas more distant from the hole, and a final period characterized by a generalized progression of damage until the total failure. Fractography analyses revealed matrix cracking, fiber failure, delamination, and separation between fiber and matrix.

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abst. 2109
Repository

The effect of vascular self-healing factor orientation on repair efficiency in epoxy-glass fiber composite

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In this study, the effect of vascular self-healing orientation on tensile strength and healing efficiency of epoxy glass composite has been experimentally studied. Hollow glass fiber (HGF) of 450±10 μm diameter and 50%-55% hollowness was produced using an extruder. Following, the HGFs were filled with healing components, and subsequently employed as vascular healing system in composite laminate. The orientations of HGFs were selected at three levels of 0, 45° and 90°. The distance of HGFs was kept at 200 μm. The virgin, damaged and healed specimens were characterized in term of tensile behavior and subsequently the healing efficiency was studied. The results of tensile tests indicated that the presence of blank HGFs in composite has lowered the tensile strength as high as 17, 14 and 21% for HGFs angles of 0, 45° and 90°, respectively. As a damage, a strain of 1.2% was initiated in the tensile specimen and afterward the self-healing process was accomplished at temperature of 70 °C for a time period of 48 hours. Subsequently, the healing efficiency was measured by tensile testing. The results indicated that the best orientation of the filled HGFs was 45°, where the healing efficiency was equal to 42%. The morphology of fractured HGFs and healed zones was studied by employing scanning electron microscopy (SEM).

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abst. 2175
Repository

Improved hygrothermal durability of flax/polypropylene composites after chemical treatments through a hybrid approach

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Plant fibers are well known due to their 'green' origin and high strength. However, these natural fibers absorb moisture and have poor adhesion with polymers. Chemical technique combining alkali and silane treatments is proposed in the current study to modify flax fibers. The changes in chemical composition, microstructure, surface morphology and crystallinity due to chemical treatment were comprehensively characterized using techniques including SEM, FTIR, AFM, XRD, etc. It was found that hemicellulose and lignin at the fiber surface were removed while the crystallinity was increased after chemical treatment. As confirmed by AFM, the surface roughness was increased. Due to these mechanisms, polypropylene composites reinforced by chemically treated flax fibers had better mechanical properties and absorbed less moisture during hygrothermal ageing.

Bleeding of cement pastes and mortars modified with granite powders

abst. 2183
Repository

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Determining of the rate of bleeding of cementitious mixes is especially important for elements formed horizontally (e.g. floors and slabs). As a result of forming this kind of elements water in the mixture begins to float upward, because it is the lightest component of mixes. At the same time, grains of cement and other additives sink to the bottom. It causes a change in the homogeneity of the mixture, as a result, the upper part of the hardened cementitious composite is characterized by lower mechanical parameters (the increased w/c ratio), and its lower part is characterized by higher mechanical parameters (the release of unnecessary water in cement hydration upwards). Bleeding depends on the material composition of the cementitious mixes. Incorrectly selected composition of the cementitious mixture may cause cracking. Cracks on the surface of the horizontal element may damage it (detachment, cavities) what leads to the exclusion of parts of the structure from use. It was found that the increased content of aggregate fine grains (diameter <0.25mm) resulted in the reduction of bleeding of the cementitious mixes. One of the materials that can improve bleeding in cementitious mixes is granite powder. Bleeding research of cementitious mixtures (pastas and mortars) modified with the addition of granite powder were carried out. Thanks to the use of granite powder, the bleeding of the mixture has significantly decreased and its properties have become more homogeneous. There was also no significant change in the mechanical properties of the cementitious composites compared to the reference composites.

The effect of accelerated environmental ageing on the interphase of a glass fibre/vinyl ester composite

abst. 2203
Room 1
Friday
September 3
14h30

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The use of advanced fibre reinforced polymer (FRP) composites in the renewable energy and infrastructure sectors has significantly increased over the last decade, leading to lower raw material costs and the development of more effective production methods. However, the durability and damage tolerance of such materials when exposed to environmental conditions still remain under investigation and their long-term performance cannot yet be reliably predicted. This creates some uncertainty for the introduction and development of FRP composites in these sectors. The assessment of the durability of composite laminates and structures can be assisted by providing a fundamental understanding of the micromechanical performance of the composite fibre-matrix interphase as a function of the environmental history. The fibre-matrix interphase is a critical region of composites materials - the performance of a laminate is directly related to integrity of the interphase. The scope of the present work is to provide a correlation and understanding between the moisture sorption and the mechanical performance of the interphase of a glass fibre/vinyl ester system, intended for wind turbine blade applications. An accelerated ageing study was conducted in order to evaluate the performance of the system in hygrothermal environments. The aim of this study was to accelerate the testing procedure and minimise testing times by increasing degradation conditions, such as moisture and temperature to a higher level than that experienced in real-life operating environments. The micromechanical performance as a function of environmental ageing of the system, has been assessed as a measure of Interfacial Shear Strength (IFSS) change through the microbond test. The reversibility of the ageing effect on the micromechanical performance of the system was also examined by re-drying the test specimens. An estimation of the moisture sorption of each microbond sample has been established by manufacturing thin film neat resin models, with thickness equivalent to the embedded length of a typical microbond specimen (90 - 180 moisture sorption of these films has been measured gravimetrically and has been coupled to results obtained by Fourier-transform Infrared Spectroscopy (FTIR). Additionally, moisture induced degradation has been characterised by recording the change in glass transition temperature (Tg) of

the vinyl ester resin as a function of environmental ageing by a number of thermal analysis techniques. The understanding of material property transferability between the interphase (microscale) and the bulk laminate scale (macroscale) was achieved by measuring the Tg of the matrix as a function of material thickness.

Dynamics of Composite Materials

Elastic waves and electron-phonon heat flow in composite thin films

abst. 1016
Repository

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An ultrathin metal layer deposited on an insulating membrane represents a generic component of ultrasensitive nanosensors, calorimeters, bolometers, electronic on-chip microcoolers [Giazotto, T. T. Heikkila, A. Luukanen, A. M. Savin, and J. P. Pekola, Rev. Mod. Phys. 78 (2006) 217]. When external energy is absorbed in such composite structure the effective temperature of the electron gas in metal rises above that of lattice vibrations (phonons) resulting in a heat flux between the two subsystems. Understanding this process is of vital importance for optimization of the device performance. Experimental studies have found a dramatic change below a thickness dependent temperature T* in the power density of heat transfer: it increases orders of magnitude in thin films as compared to bulk materials while its temperature variation becomes weaker [T. Karvonen and I. J. Maasilta, Phys. Rev. Lett. 99 (2007) 145503; O.-P. Saira, M. H. Matheny, L. Wang, J. Pekola, and M. Roukes, Modification of electron-phonon coupling by micromachining and suspension, J. Appl. Phys. 127, 024307 (2020)]. For a model assuming uniform layers and free boundaries it is shown that this behavior is due to dimensional crossover in the phonon spectrum which strongly modifies the electron-phonon coupling below T* [S. Cojocaru and D. V. Anghel, Low-temperature electron-phonon heat transfer in metal films, Phys. Rev. B 93 (2016) 115405]. The description accounts for the deformation potential interaction with acoustic modes of the Rayleigh-Lamb type. Analytic solution for the long wavelength region of their spectrum is obtained in an explicit form that allows to overview the full range of parameters (elastic moduli, mass densities, thicknesses). The analysis reveals some non-trivial properties of elastic wave propagation in composite nanostructures [S. Cojocaru, Surface adapted partial waves for the description of elastic vibrations in bilayered plates, Wave Motion 92 (2020) 102430]. In particular, contrary to expectation, it turns out that dependence of acoustic properties on material parameters of the added or coating layer can be strongly non-monotonous. Thus, for the lowest frequency mode (the fundamental flexural wave), increasing thickness of the added layer may lead to a sharp increase followed by a drop of the phase velocity with a similar unusual pattern being observed in the low temperature electron-phonon heat flow. In contrast to the single layer case, the wave pattern of Rayleigh-Lamb waves in a composite system is not symmetric and shows a refraction kink on interfaces. However, the obtained solution allows to demonstrate existence of a relation between the spectra of the apparently so different systems. The symmetry characteristics of the natural modes is replaced by the sign value taken by wave amplitudes on the outer surfaces at long wavelengths. The phenomenon of avoided crossing between branches of the spectrum then allows to establish a continuous one-to-one correspondence between surface (Rayleigh and Stonely interface mode) and bulk or volume acoustic waves on one side and fundamental (dilatational and flexural) and cutoff modes (plate resonances) on the other.

Free Vibration of Composite Laminated Cylindrical Shell with Orthogonal Stiffeners

abst. 2031
Room 3
Friday
September 3
14h50

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This paper presents a theoretical approach to analyze the free vibration of composite laminated cylindrical shells with orthogonal stiffeners. Based on the modified Kárman-Donnell shell theory, the effect of the initial curvatures in the circumferential direction of the cylindrical shell is considered. According to the mechanics of composite materials, governing equations for the non-shallow cylindrical shell undergoing out-of-plane vibration and for longitudinal and circumferential ribs are derived, respectively. Due to the undetermined interaction force between the cylindrical shell and the ribs, Rayleigh-Ritz method is used to resolve the free vibration of composite laminated cylindrical shells with orthogonal stiffeners. MATLAB program is developed to obtain the natural frequency of the stiffened cylindrical shell. Furthermore, finite element model of stiffened cylindrical shell was built through commercial software ABAQUS to verify our analytical method. A good agreement between the analytical

solutions and finite element results illustrates the efficiency and accuracy of the proposed approach. With the authenticated model, the influences of different numbers, geometric parameters and material properties of stiffeners on the free vibration of the stiffened cylindrical shell are evaluated. With a series of parametric studies, the phenomenon of free vibration of stiffened cylindrical shell is well-known and the optimization of reinforcement scheme is presented.

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abst. 2081
Repository

Nonlinear dynamics of fluid-conveying nanotubes

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The fluid-conveying nanotube has been widely used in the nano-biological devices and nano mechanical systems for fluid filtration, fluid storage and targeted drug delivery. The flow-induced post buckling, nonlinear forced vibration and low velocity impact dynamic response of FG/ FG-GRC nanotubeare studied. The nanoscale effect, surface energy effect and fluid slip boundary effect are considered. The constitutive model of the nanotubes is established by coupling surface elasticity theory and nonlocal strain gradient theory. Based on a refined shear deformationbeam model, the nonlinear governing equations are derived. The two-step perturbation-modified Lindstedt Poincaré method is proposed. The two-step perturbation-Galerkin method and the two-step perturbation-Runge Kutta method are extended. The semi analytical and semi numerical solutions of the nonlinear amplitude-frequency bifurcation curves, post-buckling equilibrium paths and contact dynamic response of the nanotube are obtained. The influence of fluid flow on the dynamic response is studied. The initial imperfectionsensitivity of the dynamic characteristics of thenanotube at different flow velocities is discussed. The dualinfluences of scale effect, surface energy effect and slip boundary on the nonlinear dynamic responsesin the state of pre-buckling and post-buckling are revealed, and the velocity range sensitive to nano effect is obtained.

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abst. 2083
Room 1
Friday
September 3
11h50

Scattering of elastic waves by a sphere with cubic anisotropy

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Scattering of elastic waves in materials with inhomogeneities is a classical problem in physics and geophysics, and have applications in non-destructive testing, material characterization, medical ultrasound, etc. The classical analytical solution of the scattering by a single isotropic spherical obstacle provides a good approximation and a basis for more complicated problems and gives a deep understanding of the scattering phenomenon. However, plenty of natural and synthetic materials, specifically the grains in a metal, are known to be anisotropic. Recently, the scattering of elastic waves by a circle with cubic anisotropy is studied in 2D by Boström, and Jafarzadeh et al. use the same method to study the 3D scattering problem for a transversely isotropic sphere. The present work is a continuation of these studies and investigates the 3D scattering by a sphere with cubic anisotropy. Consider the scattering of a single spherical obstacle with cubic anisotropy contained in a three-dimensional, homogeneous, isotropic and infinite elastic medium. In the isotropic surrounding the classical approach is used with the displacement field constructed as a superposition of incident and scattered waves, which are expanded in spherical vector wave functions. Inside the sphere the stress-strain relations are given in Cartesian coordinates for the cubic material and these are first transformed to spherical coordinates. These relations then become inhomogeneous in that they contain factors with trigonometric functions in both angular coordinates and the same becomes true also for the equations of motion. To proceed it is useful to expand the displacement into a series of vector spherical harmonics where each coefficient in turn is expanded into a power series in the radial coordinate. It follows from the equation of motion that the coefficients in the power series obey certain recursion relations, thus reducing the number of unknowns inside the sphere. Expressing also the stresses as a series in the vector spherical harmonics, the rest of the unknowns are determined by the continuity of the displacement and traction on the sphere boundary. As a result the transition T matrix elements, relating the expansion coefficients of the scattered wave to those of the incident wave, are calculated. It is, in particular, possible to obtain explicit expressions for the leading order T matrix elements for low frequencies.

Dynamic Analysis of Second Strain Gradient Elasticity through a Wave Finite Element Approach

abst. 2085
Room 1
Friday
September 3
12h10

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In this article, the Second Strain Gradient (SSG) theory proposed by Mindlin is utilized within a Wave Finite Element Method (WFEM) framework for dynamic analysis of one-dimensional Bernoulli-Euler bending beam and torsional bar. Firstly, strong forms of continuum models including governing equations and boundary conditions, for bending and torsion cases, respectively, are derived by Hamilton's principle. New "non-local" Lattice Spring Models (LSM) giving unified description of the SSG models for bending and torsion are expounded, which can be regarded as discrete micro-structural basis of SSG continuum models, and the dynamic equations from LSM are transformed via a Fourier series transform approach, respectively. Weak forms for both bending and torsion are established based on SSG theory. Subsequently, the WFEM is used to formulate the spectral problem and compute wave dispersion characteristics from one-dimensional unit-cell structures. Finally, dispersion relations and forced responses for bending and torsion in micro-sized structures are calculated by SSG and Classical Theory (CT), and some useful conclusions are discussed.

Wave Propagation Analysis in non-local Flexoelectric Composite Material

abst. 2125
Room 3
Friday
September 3
15h10

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In this paper, the effective flexoelectric properties of heterogeneous piezoelectric materials are computed in the context of periodic homogenization, whereby a variational formulation is developed, articulated with the extended Hill macro-homogeneity condition. This framework accounts for higher gradient effects that may be induced by a strong contrast of properties of the composite constituents. The obtained homogenized properties are employed for the determination of the wave propagation attributes of piezoelectric composites. The dynamic equilibrium equations, accounting for higher gradient effects, are formulated to deal with wave propagation in flexoelectric media, considering the Classical Flexoelectric Theory (CFE) and the Non-Local Flexoelectric Theory (NLFE). The obtained dispersion relations show that both piezoelectric and flexoelectric media are dispersive media. Furthermore, it can be observed that the flexoelectric medium becomes more anisotropic when increasing the wavenumber unlike the piezoelectric medium. In addition to that, the influence of non-locality on the frequency of the wave propagation was studied. This study reveals that the frequency of the wave propagation is decreasing when increasing the non-local parameter. This effect can be related to the distribution of the incident energy to not only mechanical energy, but also to electrical energy. References: A. L. Chen, D. J. Yan, Y. S. Wang, Z. Ch., Anti-plane transverse waves propagation in nanoscale periodic layered piezoelectric structures, Ultrasonic, Vol. 65, pp. 154-164, 2015. A C. Eringen, Nonlocal continuum mechanics based on distribution, Int. J. Eng. Sci, Vol. 44(3), pp. 141-147, 2006. Chambion, B., Goujon, L., Badie, L., Mugnier, Y., Barthod, C., Galez, C., Wiebel, S., Venet, C., 2011. Optimization

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abst. 2170
Room 3
Friday
September 3
15h30

Vibration Analysis of Multilayer Double-Curved Structural Systems Containing CNT Patterned Layers in the Framework of Different Shell Theories

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In this study, the solution of the free vibration problem of multilayer structural systems containing carbon nanotube (CNT) patterned layers in the frame of shear deformation theory (SDT) is presented. The basic equations of double-curved composite shells containing CNT patterned layers based on the Donnell-Mushtary type shell theory are derived. Partial differential equations were transformed into the ordinary differential equation by applying Galerkin method and then obtained expression for the frequency of multilayer double-curved composite shells containing CNT patterned layers. From this expression, the formulas of frequencies for multilayer hypar shell, multilayer panel and multilayer plate are obtained as special cases. The results are verified by comparing the reliability and accuracy of the proposed formulation with the results in the literature. In numerical analysis, the frequencies of multilayer structural systems containing uniform and non-uniform CNT patterned layers are discussed comparatively within the framework of SDT and classical shell theory (CST). Finally, the effects of CNT patterns in the polymer matrix layers, number and arrangement of layers, volume fractions and shear stresses on the vibration frequency are investigated. Keywords: Multilayer nanocomposites, CNT, structural systems, vibration, frequency, shell theories References: [1] Iijima S. Helical microtubules of graphitic carbon. Nature 1991;354:56–58. [2] Park SH, Bae J. Polymer composite containing carbon nanotubes and their applications. Recent Patents Nanotech 2017;11(2):109-115. [3] Shen HS, Xiang Y. Nonlinear vibration of nanotube-reinforced composite cylindrical shells in thermal environments. Comput Methods Appl Mech Eng 2012;213:196–205. [4] Vu VT, Tran HQ Tran MT. Free vibration analysis of laminated functionally graded carbon nanotube-reinforced composite doubly curved shallow shell panels using a new four-variable refined theory. J Compos Sci 2019;1-21. [5] Avey M, Yusufoglu E. 2020. On the solution of large-amplitude vibration of carbon nanotube-based doubly-curved shallow shells. Math Meth Appl Sci 2020;1–13: https://doi.org/10.1002/mma.6820. [6] Li H, Pang F, Gao C, Huo R. A Jacobi-Ritz method for dynamic analysis of laminated composite shallow shells with general elastic restraints. Composite Structures 2020;242: 1-18, 112091.

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abst. 2171
Repository

The Experimental and Theoretical Study on the Vibration Characteristic of a Multi-Mode Piezoelectric Energy Harvester

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This paper presents experimental and theoretical investigations on vibration characteristics and performance parameters of the multi-mode vibration energy harvester. The multi-mode vibration energy harvester is a bistable piezoelectric electromagnetic combined power generation structure. Since the magnet, which opposites the piezoelectric cantilever beam, is fixed on the end of the spring, the magnetic distances are self tuned. Therefore, nonlinear dynamic behaviors of the system are more obvious. In order to investigate the stiffness characteristic of the system, the frequency sweep experiment is carried out. Through the variation of the output voltage and the vibration amplitude, the soft spring characteristic of the system is obtained. The influence of the external excitation on dynamic behaviors of the system is studied. The relations of the power generation and the dynamic behavior of the system are analyzed. The influence of the spring on the power generation and dynamic behaviors of the system is investigated. In order to verify the correctness of experiment results, the dynamic equation of the system is established by using Hamilton principle. The first-order discretization and multi-scale perturbation analysis are used to study the dynamic behavior and the amplitude-frequency response of the system. The result of the investigation can be used to analyze related problems of the piezoelectric electromagnetic combined vibration energy harvester.

PRODUCTION OF HIGH-PERFORMANCE ULTRA LIGHT COMPOSITE MATERIALS AND INVESTIGATION OF THE MECHANICAL PROPERTIES AND BLAST MITIGATION EFFICIENCY

abst. 2251
Repository

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In this study, epoxy resin with high-performance properties was used as matrix material. As a reinforcement material, spread tow carbon fiber produced in different weaving designs was preferred instead of woven carbon fiber fabrics widely used. In addition, a single-wall carbon nanotube was added to the resin. Hand lay-up and hot press methods were used together as the production method. The mechanical, physical, and thermal properties of the produced composite plates were investigated. Furthermore, the mechanical properties of sandwich panels obtained by adhering to the produced composite panels on aluminum honeycomb were also examined. Additionally, an experimental study of the behavior of composite plate bonded aluminum honeycomb core sandwiches under blast loads was carried out by using a shock tube setup. Shock pressure was measured with high-precision piezoelectric pressure gauges. The speed and acceleration of the shock pressure wave, the impulse, and momentum values affecting the sandwich panels were calculated. As a result of the mechanical tests, it has been observed that the resistance of the obtained composite plates and sandwich panels against bi-axial stresses is relatively high. Shock tube test results were evaluated depending on the density and type of composites and by comparing the deformations and damage modes of the sandwich panels. Spread tow type carbon fibers can withstand high tensions despite their low weight. For this reason, the spread tow carbon fiber reinforced composites may become widespread in the aviation and space industry, as they are lighter and more resistant.

Dynamics for anisotropic homogenized materials

abst. 2264
Room 3
Friday
September 3
15h50

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Materials such as ceramic and metal composites, poly-crystals, masonry, porous rocks are examples of particle composites: their macroscopic behavior is strongly dependent on the internal microstructure, moreover discontinuities and heterogeneities cannot be neglected. For these reasons, a non-local description is necessary to take into account the microscopic influence on the mechanical response. In this work the goal is to highlight the advantages of a description of these materials as micropolar continua compared to the classical continua. A homogenization technique, based on an energy equivalence criterion, between the discrete model, assumed as the benchmark, and the continuum model, is adopted to detect the anisotropic constitutive characteristics [1]. A possible numerical approach is presented in order to have a right identification of the representative volume element, needful for a correct homogenization [2]. Starting from other works of the same authors where the statics of two-dimensional bodies has been analysed [3-5], this study goes to further enrich the discussion and shows the influences of the material internal length on the dynamic response and consequently the necessity of a micropolar description. Particle composites with an internal microstructure made of three different hexagonal rigid blocks and thin elastic interfaces are considered at three different scale level, the numerical tests bring out how an increasing in the level of material anisotropy affect both frequencies and mode-shapes. References: [1] P. Trovalusci and R. Masiani, "Material symmetries of micropolar continua equivalent to lattices," Int. J. Solids Struct., vol. 36, no. 14, pp. 2091–2108, 1999, doi: 10.1016/S0020-7683(98)00073-0. [2] M. Colatosti, N. Fantuzzi, P. Trovalusci, and R. Masiani, "New insights on homogenization for hexagonal-shaped composites as Cosserat continua". Meccanica, 2021. https://doi.org/10.1007/s11012-021-01355-x. [3] N. Fantuzzi, P. Trovalusci, and R. Luciano, "Multiscale analysis of anisotropic materials with hexagonal microstructure as micropolar continua," Int. J. Multiscale Comput. Eng., vol. 18, no. 2, pp. 265–284, 2020, doi: 10.1615/IntJ-MultCompEng.2020032920. [4] N. Fantuzzi, P. Trovalusci, and R. Luciano, "Material symmetries in homogenized hexagonal-shaped composites as cosserat continua," Symmetry, vol. 12, no. 3, pp. 1–21, 2020, doi: 10.3390/sym12030441. [5] L. Leonetti, N. Fantuzzi, P. Trovalusci, and F. Tornabene, "Scale effects in orthotropic composite assemblies as micropolar continua: A comparison between weak and strong-form finite element solutions," Materials, vol. 12, no. 5, 2019, doi: 10.3390/ma12050758.

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abst. 2274
Repository

MECHANICAL FORCED VIBRATION OF THE SYSTEM CONSISTING OF "ELASTIC + PZT" BI-LAYERED PLATE, COMPRESSIBLE VISCOUS FLUID AND RIGID WALL

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The present work studies the mechanical forced vibration of the hydro-piezo-elastic system consisting of "elastic + PZT" bi-layered plate, compressible viscous fluid and rigid wall. It is assumed that the PZT layer of the plate is in contact with the fluid and the time-harmonic lineal located forces act on the free surface of the elastic-metal layer. The motion of the plate is described within the scope of the piece-wise homogeneous body model by utilizing the exact equation and relations of elastodynamics and elasto-electrodynamics for piezoelectric materials. The flow of the fluid is described by the linearized Navier-Stokes equations for the barotropic compressible Newtonian viscous fluid. The plane-strain state in the plate and the plan flow in the fluid take place. It is assumed that between the layers of the plate the complete contact conditions satisfy. Moreover, the impermeability conditions on the rigid wall and the compatibility conditions between the piezoelectric layer and the fluid satisfy. For the solution to the corresponding boundary-value problem the Fourier transform with respect to the space coordinate on the axis directed along the plate laying direction is employed. The analytical expressions of the Fourier transform of all sought values of each constituent of the system are determined. The originals of the sought values are determined numerically, according to which, numerical results on the stresses and fluid flow velocities on the fluid and plate interface plane are presented and discussed. It is analyzed the influence of the piezoelectricity of the plate layer material on the mentioned stresses and velocities. It is also analyzed the influence of the problem parameters, such as plate thickness, fluid depth and etc. on the frequency responses of the interface stresses and velocities.

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abst. 2294
Room 3
Friday
September 3
16h10

Design Optimization of Dynamic Scaled Wing Models using Multi-Material Topology Optimization

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The dynamic behavior of an aircraft can be investigated using computational and experimental models. To validate their designs, engineers perform experiments that are usually expensive and time consuming. In order to reduce the development cost, topology optimization can be used to produce scaled models with similar dynamic behavior compared to the full scaled models made possible by novel additive manufacturing techniques. The goal of this work is to design and manufacture a scaled model that has similar dynamic behavior of the full scaled model. Multi-material topology optimization method is used where the material properties are defined using the Solid Isotropic Material with Penalization (SIMP) method. The Modal Assurance Criterion (MAC) is selected as the optimization constraints to track and synthetize modes between the full scale and the scaled designs. Eigenvector derivatives are calculated using Dailey's method in order to prevent errors in case of repeated eigenvalues. The optimal topologies of a wing with multi materials are designed for different materials and the results for the scaled and full scaled models are compared and evaluated.

Mechanical response of 3D printed honeycomb based structures made from BASF Ultrafuse 316L filament under various loading conditions

abst. 2309
Room 1
Friday
September 3
12h30

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Contemporary development in leading-edge industry branches causes a growing demand for new multifunctional materials. Scientists and engineers, inspired by nature, pay their attention to cellular structure materials which demonstrate specific mechanical properties with respect to low density. Over the last two decades, a great number of studies have been undertaken in order to improve methods of their manufacturing, evaluating mechanical response under various loading scenarios. The additional impact of the growing interests of regular cellular materials is caused by new available methods their production based on additive manufacturing. The main goal of this work is a presentation of the investigations results concerned on mechanical behavior of 2D honeycomb based structures under compression loading with consideration the temperature and strain rate effects. Regular honeycomb and four additional variants with gradually changed topologies were manufactured additively with the use of FFF (Fused Filament Fabrication) 3D printing technique. The material used during fabrication process was BASF Ultrafuse 316L which demonstrate a specific mechanical properties. It is a composite consists of 80% stainless steel and has a 20% polymer content which allows for easy printing on many open FFF desktop printers. The manufacturing process with the use of mentioned filament is similar to MIM (Metal Injection Molding) process. The adopted investigation methodology included a manufacturability study, strength tests of the base material and experimental compression tests of developed regular cellular structures with consideration two loading scenarios. The first one, refers to quasi-static tests. The other approach, related to dynamic compression tests was carried out with the use of split Hopkinson pressure bar laboratory set up in a direct configuration. Furthermore, mechanical response of proposed structure topologies were studied based on the results of computer simulations. Based on carried out experimental tests it has been found that applied BASF Ultrafuse 316L material indicate a high mechanical strength and high range of plastic deformation. Dynamic compression tests of regular honeycomb and four variants with gradually changing topologies revealed that buckling and bending were the main mechanisms responsible for the deformation of developed structures. Adopted initial boundary conditions in numerical analysis reflected the conditions of experimental tests under

quasi-static as well as dynamic compression tests. Proposed by the authors numerical models were successfully validated and allow for further optimization studies.

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abst. 2315
Repository

Experimental investigation of the dynamic characteristics of wrapped and wound fiber and fiber/metal reinforced composite pipes

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This paper experimentally investigates the effect of the manufacturing method and metal reinforcement option on the natural frequency and damping behavior of five polymer and Fiber Reinforced Polymer (FRP) composite pipes. The five pipes are made of polymer, roll-wrapped woven glass FRP, metal-reinforced roll-wrapped woven glass FRP, filament-wound glass FRP, and metal reinforced filament-wound-up glass FRP. The composite pipes can replace conventional pipes in oil and gas industries and conventional metallic shafts in many applications. Logarithmic decay, logarithmic decrement, and random frequency excitation methods were employed to identify the damping ratio and the natural frequency of the different composite materials. Tests were conducted using a CVMSL electrodynamic shaker (M437A/BT500M) and a triaxle vibration measurement instrument. The results revealed that the metal-reinforcement option outperformed the rest of the reinforcement options in terms of dynamic characteristics, as it resulted in higher natural frequencies and damping ratios. In addition, the filament-wound-up manufacturing method demonstrated superior dynamic characteristics over the woven roll-wrapped method. The metal/filament-wound-up reinforcement increased the logarithmic damping decrement from 0.1165 to 0.1231 and the natural frequency from 36.5 Hz to 70 Hz.

Electrical conductivity of MAX phases-based composite coatings and bulk material

abst. 2047
Repository

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The objective of this paper is to investigate the chemical and phase composition effects on high temperature long-term oxidation resistance and electrical conductivity of bulk and film MAX phases based materials of Ti-Al-C system. The paper presents the results of variations of structure, oxidation resistance, and electrical conductivity of highly dense Ti-Al-C composite bulks and vacuum-arc deposited 6 µm thick coatings before and after heating at 600 degrees C in air for 1000 h. Ti-Al-C coating is highly resistant toward oxidation with $\Delta m/S = 0.07mg/cm2$, its high electrical conductivity of $1.3\dot{1}0^6 S/m$ was preserved after long-term heating in air. The specimen surface layers of MAX-phases Ti3AlC2 and Ti2AlC based bulks and chromium-containing Crofer 22APU steel become semiconductors as a result of high-temperature long-term oxidation at 600 degrees C. Moreover, high values of nanohardness of H (10 mN)= 9.5±1.5 GPa and Young modulus $E = 190 \pm 10GPa$ were obtained. High oxidation resistance and electrical conductivity of the vacuum-arc deposited Ti-Al-C coating, along with its good mechanical characteristics make it very promising for various applications, especially for interconnects of solid oxide fuel cells (SOFCs).

Electro-thermal multi-function deicing airfoil composite with nickel-plated carbon fabric

abst. 2226
Room 3
Thursday
September 2
14h30

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This study proposed an electro-thermal de-icing system for the airfoil structure using nickel-plated carbon fabric. Ice formation on the surface of aircraft is a serious issue for aircraft operation. Moreover, ice accretion on the wing, propeller, and rotor blades affects lift loss, and changes in moment characteristics. Accordingly, it is very important to ensure the safety condition for aircraft by reducing the ice formation. Recently, many studies have been focused on a high potential solution namely electro-thermal anti/de-icing system by using multi-functional composite materials such as carbon fabric. In this study, an electro-thermal de-icing system for the airfoil structure with new materials of nickel-plated carbon fabric was introduced. The electroless plating method was conducted for coating nickel onto carbon fabric expecting to improve the electro-thermal properties of the pristine carbon fabric. Afterward, the heating performance of the fabricated airfoil structure using nickel-plated carbon fabric was experimentally and numerically accessed. The good agreement between the coupled electric-thermal in FEM simulation and experiment was obtained. Furthermore, interlaminar shear strength test (ILSS) was performed to identify the structural integrity of the airfoil structure. In addition, multiphysics de-icing simulation, which could be analyze the ice accretion and de-icing performance, was conducted for the practical approach. The results confirmed that the proposed electro-thermal de-icing system for airfoil structure can be a good solution as a multifunctional composite for de-icing performance.
Acknowledgements This work was supported by the development of the IPS functional composite structure of the Korea Aerospace Industries, LTD. (CT20050855RND2020). This work was supported by the research on material durability evaluation according to long-term exposure natural and operational environment condition of the Korea Aerospace Industries, LTD. (FA84WB0026). This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311).

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abst. 2244
Room 3
Thursday
September 2
14h50

Multifunctional behaviour of PLA conductive composites. Dependence on infill rate and printing orientation

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Additive manufacturing (AM) techniques allow the fabrication of complex geometry pieces with polymeric smart composites. In this work, a wide characterization of 3D printed PLA composites reinforced with Carbon Black have been implemented through combined mechanical and electrical tests. For this proposal and to obtain a correlation between the physical response and the printing parameters, different specimens were manufactured, varying printing orientation (longitudinal; transverse; oblique), infill rate and length. Tensile and compression quasi-static mechanical tests were carried out, and its results will be used to develop a structural optimization of a three-point bending behaviour. For longitudinal configuration, values of elastic modulus confirm adequate bending mechanical response. Furthermore, thermo-electrical DC experiments using different configurations were taken place, finding inferior conductivity in samples with transverse orientation. Moreover, electro-mechanical AC tests

varying the signal frequency from 30 Hz to 30MHz were considered, to characterize impedance electrical behaviour. Results show that PLA conductive composites hardly contains capacitance component. Besides, it can be proved that by reducing the infill rate of the samples, the resistivity tends to increase until a convergence point, caused by the intrinsic conductive paths of the external wall of the specimen. Finally, it has been observed that increasing of infill rate leads to the improvement of the sinterization process between filaments and layers. This fact promotes the global homogenization of the specimen, decreasing the dependence on the printing direction. By the structural and electrical point of view, it is displayed a substantial progress in the linear behaviour consistent with the quality of the impression associated to infill rate and sinterization process. Keywords: Additive manufacturing (AM), polylactid-acid (PLA), Carbon Black (CB), PLA conductive composites, Fused Deposition Modelling (FDM), electro-mechanical coupling, multiphysics characterization Bibliography: [1] I. Tirado-García, D. García González, S. Garzón Hernández, A. Rusinek, G. Robles, J.M. Martínez-Tarifa, A. Arias. Conductive 3D printed PLA composites: On the interplay of mechanical, electrical and thermal behaviours. Composite Structures 2021. 265. [2] R. Thiago Luiz, I. Cardoso, T. Assis, D Bürger. Experimental characterization and micrography of 3D printed PLA and PLA reinforced with short carbon fibres. Composites Part B 2017. 124:88-100. [3] N. Maqsood, R. Rimašauskas. Characterization of carbon fiber reinforced PLA composites manufactured by fused depositgion modeling. Composites Part C: Open Access 2021.

Experimental Methods

abst. 2012
Room 1
Thursday
September 2
13h10

Influence of geometrical imperfections on damage process of real L-shaped thin-walled columns under axial shortening

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Damage process of thin-walled laminated structures made of modern laminates can be tested using experimental or numerical methods. It is difficult to achieve high repeatability and accuracy of the real thin-walled structures during the production process. The real column in experimental studies is not perfect, whereas its numerical model of the samples is perfect. Therefore, it is difficult to compare the experimental and numerical results. The solutions obtained by both methods can be differ significantly. Additionally, incompatibility of damage mechanism can be found in many cases of experimental studies. The main aim of this study was prepared FEM model of the real structures and simulations its collapse process. Therefore, the 3D Atos core scanner and special GOM soft was used to prepare the geometrical model of the real structure. Additionally, this software allowed to estimate surface inaccuracies, geometric dimensions of the real objects. Next, experimental collapse analysis of tested thin walled columns on a Zwick Z100 static materials testing machine was performed. The real samples were subjected to uniform axial shortening. The tested columns were loaded with the load from 0 to the maximal load, which allowed one to observe the column behavior until its collapse. Experimental tests were performed at a constant velocity of the cross-bar equal to 1 mm/min. All analyzed samples were made with carbon-epoxy laminate using autoclave technique. The lay-up configurations of the laminate was [60,02,-602,603,-602,03,-602,0,602]T, where direction 0 was along the length of the column. Material parameters of laminate were Young's modulus along the fiber direction: 170000MPa and along the fiber transverse direction: 7600MPa; shear modulus: 3520MPa; Poisson's ratio: 0.36. The length of the column was 300 mm. Thickness of the column was 0.81mm and its width of the flanges was 40mm. Non-linear numeric simulations were performed by the Newton-Raphson method until ultimate failure of the structure using Abaqus software. Composite material damage was described with a progressive damage model. Whereby, it was possible to identify the mechanism of damage. Finally, all obtained results for real structures were compared. The influence of geometrical imperfections on failure process of the real column and its mechanism of collapse were discussed. The present study was supported by statutory resources allowed to the Department of Applied Mechanics, the Lublin University of Technology under "The Grant for Young Researchers" no. FNM 30/IM/2020.

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abst. 2051
Repository

Fatigue Behavior and Damage Evolution of Additively Manufactured Short Carbon Fiber Reinforced Thermoplastics in the VHCF Regime

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Additive manufacturing is becoming more and more reliable, so that the change from prototypes to series products is consistent. Supporting this switch to high performance applications, additional application-driven testing approaches and conditions are needed. The special focus is on the fatigue

behavior and damage evolution of short carbon fiber reinforced polymer in the high cycle (HCF) and very-high cycle fatigue (VHCF) regime. Process-induced defects result in highly anisotropic material behavior with its obvious weakness in the interlayer contact area. The process parameter layer height has a major impact on the interlayer capability and manufacturing productivity. Therefore, a capability- and economy-oriented variation is investigated in this test series. The high-frequency tests were performed using a newly-developed resonant testing system at 1 kHz. The non-destructive quality assessment was executed by micro-computed tomography and 3D laser scanning microscopy resulting in the internal and external quality evaluation. The capability-oriented variation achieves a higher amount of lifetime for equal loadings compared to the economy-oriented. The internal and external quality assessment and quantification indicates an increasing primary surface profile and void volume content for increasing the layer height.

Reduce of the variability in the measured impact energy of epoxy unnotched specimens with carbon-nanofillers

abst. 2104
Repository

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The surface energy of a material is defined as the energy required to create a new free surface and is directly related to its fracture strength. This document describes the procedure used to estimate the surface energy of a material from impact tests on unnotched specimens. The utilisation of specimens without notch provides dispersed values of the energy involved in the fracture process. This variability is reduced if the surface energy per unit of fractured area of the material is estimated. This work focuses on an epoxy resin employed in the wind industry, studying how the introduction of a low percentage of carbon-derived nano-reinforcements exfoliated in the presence of melamine influences the polymeric system. With this purpose, the energy absorbed during a Charpy impact test and the mechanical response under quasi-static three-point bending are analyzed. The elastic properties are obtained by combining the so-called Homogenized Section Technique and the deformation field acquired by Digital Image Correlation.

Assessing the thermal degradation of PEEK after excessive heating and its impact on PEEK's interfacial adhesion with carbon fibre

abst. 2122
Room 3
Friday
September 3
11h30

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Poly-ether-ether-ketone (PEEK) and its reinforced composites are increasingly used in high-temperature applications due to their chemical resistance and thermal stability. Especially in the aerospace industry, carbon fibre (CF) reinforced PEEK consists an important candidate for replacing the metallic alternatives in an aircraft. Several studies have examined the decomposition mechanisms of the PEEK matrix but most of them have examined the response of the material after long-time isothermal heating. However, considering its increased use in applications where incresed heating rates are applied it is important to examine the response of the material in these conditions. ne of the main issues that could occur with high-temperature processing of PEEK is the activation of the decomposition mechanisms of the polymeric material. The resulting thermal degradation could lead to the deterioration of the mechanical properties of the matrix as well as the deterioration of the interfacial adhesion between the fibre and the matrix. Therefore, to assess the thermal degradation of PEEK after high-temperature processing, attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy is applied and a thermal

degradation assessment methodology is established. Initially, the decomposition mechanisms of PEEK are investigated up to full decomposition with thermogravimetric analysis (TGA) in heating rates up to 100 [U+25E6] C/min. Then, in static air conditions PEEK samples are partially degraded in the controllable heating conditions of the TGA furnace and the slightly degraded samples are examined with ATR-FTIR spectroscopy. Through this process, a new fluorenone peak is detected that is directly linked with the process of degradation. Overall, a correlation between the peak's intensity and the decomposition of the material takes place in the examined heating rates between 5 and 100 [U+25E6] C/min. The results showed that the intensity of the peak can be safely used for detecting the extent of decomposition after an applied heating process with heating rates up to 100 [U+25E6] C/min. Finally, the effect of excessive heating on the interfacial adhesion between PEEK and CF is examined by performing single fibre pull-out tests (SFPTs) on samples that have been slightly degraded after several heating programs. In all, a detection technique is suggested that can identify whether decomposition has taken and can identify the approximate extent of the resulting decomposition after high-temperature processing of PEEK. Finally, the effect of the thermally induced damage on the interfacial properties between the PEEK matrix and the embedded carbon fibre is investigated with SFPT tests and the effect of thermal degradation on the interfacial shear strength (IFSS) of the two constituents is examined.

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abst. 2168
Repository

Influence of laser generated micro- and nano-structuration of surface of intrinsic bonded hybrid system CFR-EP-EN AW 6082-T6 on its corrosion properties

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The utilization of hybrid materials in the mobility sector is a promising approach to increase efficiency of lightweight structures due to their beneficial strength-to-weight ratio and potential for material saving, which contributes to reduction of CO2 emissions. Modern vehicles are multi material designed, in what hybrid composites have proven to be notably well performing. Compared to monolithic aluminum alloys (AA), hybrid AA composite structures with carbon fiber-reinforced epoxy (CFR-EP) offer a high lightweight potential with increased damage tolerance and resistance to fatigue loads. While being advantageous for mechanical applications, contact corrosion due to potential differences between AA and CF reduces the benefit. This is further promoted by environmental conditions, such as temperature, humidity and corrosive media in automotive applications. Estimating the influence caused by corrosion is difficult since the contact area between AA and CF is variable. Using an adhesive bonding technique enables the reduction of the surface area and thus, in comparison to frictional bonding, minimizing gaps. For electrochemical investigation, a hybrid model system was used. The system consisted of EN AW 6082 in heat treatment state T6, commonly used in the automotive industries, intrinsic bonded with unidirectional CFR-EP via epoxy resin E201. In order to optimize the bonding properties and minimize the susceptibility to corrosion, the AA surface was laser pretreated with varying parameters and subsequently adhesive bonded with CFR-EP by crimping. Investigations of the single components of the system by use of potentiodynamic polarization (PDP) in 0.1 mol/l NaCl solution against a silver/silverchloride reference electrode show distinct differences in corrosion current density as well as the open circuit potential (OCP). In addition to that, varying surface conditions of the AA (electrolytically polished, rolled (manufacturing condition) and laser structured) were compared. Analogously, differences in corrosion reaction were determined. From these results, the most promising laser parameters, regarding corrosion and mechanical properties, were identified and chosen for manufacturing of the hybrid composite system used for further corrosive investigations. Besides evaluating electrochemical parameters, the surfaces were controlled pre and post testing for microstructural changes by means of light and scanning electron microscopy (SEM). It was found, that defined nanostructures in comparison to polished and non-treated surfaces promote a localization of corrosion phenomena on the surface. Additionally, the resin helps reducing the contact corrosion due to separation of carbon fibers and AA-surface. For volume investigation with regard to delamination and process defects of AA-CFR-EP

bonding, computed tomography (CT) was used. These investigations were enhanced by using a temperature controlled, integrateable in situ stage. Thus, it was possible to detect delaminations caused by different application of catalyst, used for an enhanced curing of resin. The application of in situ methodology is used for the mechanism-based description of the damage progression. The transfer of established short-term fatigue testing methodology to hybrid and asymmetric specimens enables the analysis of a process-structure-property relation, as well as evaluating macro- and microstructural damage of the hybrid composite. In the course of further research, specially developed in-situ corrosion chambers will allow the combination of mechanical and medial loading in addition to contact corrosion.
Keywords: EN AW 6082, corrosion, materials testing, PDP, CFRP, CFR-EP, in situ testing, fiber metal hybrid

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Computed tomography-based characterization of impact and fatigue after impact behavior of carbon fiber reinforced polyurethane

abst. 2169
Repository

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With the increasing use of fiber-reinforced polymers (FRP) in many safety-critical applications, detailed investigations of material behavior under various mechanical loads are mandatory. Since carbon fiber-reinforced polyurethane (CFR-PU) can often be found in aerospace and automotive industries, good impact resistance is required for potential crashes and bird strikes. Besides the determination of characteristic values from impact and fatigue tests, the impact damage detection and observation in subsequent tests via non-destructive testing, such as computed tomography (CT) or thermography, is of prime importance. Especially the performance after impact of these materials is highly significant, as such components often cannot be replaced immediately or damages are only detected within the inspection intervals. These ongoing loadings may include tension, compression and fatigue after impact (TAI, CAI and FAI). In order to achieve qualified knowledge of dynamic properties of CFR-PU, microstructure-oriented investigations of initial state and after impact damage were carried out. Thus, different methods for detecting voids and delamination inside the specimen were developed. By optimizing the mechanical testing strategy, reproducible impact and high-speed puncture tests could be performed. The specimens were manufactured by micro-waterjet cutting from a quasi-isotropic CFR-PU with symmetrical layer setup [+45/-45/0/90]2s. The impact tests were performed at 10, 15 and 20 Joule. The investigation of the impact damage was realized by means of non-destructive testing for determining damage modes and damaged area. This also ensures the possibility of subsequent mechanical testing in form of TAI and FAI. The specimen geometry was specially designed for impact and following tensile and fatigue testing. The fatigue tests, tension-tension with $R = 0.1$, were performed as constant amplitude tests (CAT) at $f = 10$ Hz with a servo-hydraulic testing machine and monitored via digital image correlation (DIC). The results from the impact and fatigue tests were divided into quantitative and qualitative observations. For the quantitative characterization, mechanical parameters were used as a basis for defining impact resistance and strength after impact. In doing so a decrease in tensile strength of 33 % with impact energies between 0 and 20 Joule could be detected. Furthermore, energy-based parameters were used in order to enable the connection between impact and fatigue testing. Consequently, specimen energy absorption serves as key parameter for comparing and accumulating the damage, since the remaining energy input potential can be estimated The qualitative characterization is done with the help of additional methods providing optical images: light microscopy, CT, DIC. Thus, the influence of damage development and propagation can be classified with respect to the overall failure of the specimen. With the correlation of these results, the damage size and modes were evaluated and their effect on residual strength in fatigue tests could be assessed. Moreover, critical and non-critical damage modes could be identified. With regard to this, the predominant impact damage mode is delamination, which is due a certain level of bending of the specimen. With increasing impact energies, fiber breakages additionally occur, which can be estimated as more critical, especially with delaminations closing up while tension loading. As a consequence, the performance of CFR-PU in highly-stressed components is shown and offers clear indication for improving existing

components for more efficiency. Keywords: fiber-reinforced polymers, CFR-PU, computed tomography (CT), delamination area, impact-loading

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abst. 2173
Room 3
Friday
September 3
11h50

Fast assessing out-of-plane shear stress-strain behaviour for thick-section composite materials using a combination of neural network based optimization and digital image correlation

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Neural network is a data-driven computing method, which is widely used in the field of fuzzy prediction. The analytical solution of transverse shear stress for the glass fibre reinforced epoxy matrix composite plate with thick section cannot be obtained due to the complexity of the stress form in the torsion test of small plates. In this paper, On-line neural network is used to predict the shear stress in the gauge region of a small plate torsion specimen. The off-line finite element model of small plate torsion test was established under predetermined size, and 8400 sets of data were obtained by changing load, elastic modulus, Poisson's ratio, shear modulus and nonlinear parameters of transverse shear stress strain behaviour. Gradient-descent method, Fletcher-Reeves conjugate gradient method and BFGS quasi-Newton method were used to train the neural network according to these data, and 912 groups of back-to-back test results were used to verify the neural network. The results show that the Fletcher-Reeves conjugate gradient method is better than the other two methods in data training, with an average error of 4%. Material stress-strain constitutive relationship is relying on the out-of-plane shear strain components, and on iterative neural network updating based on the least regression algorithm for minimization of least squares error between the DIC-measured and the neural network - predicted strains. Results of two interlaminar stress-strain curves simultaneously captured for a practical glasss/epoxy tape material system.

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abst. 2188
Repository

Determination of CFRP Intralaminar Fracture Properties in the Calibration of a Non-Local Damage Model for Crash Application

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The in-plane fracture resistance of fibre-reinforced laminated composites is several orders of magnitude higher than the resistance against delamination. This type of failure is utilized advantageously in crush applications, where elevated kinetic energies must be dissipated through material fracture and fragmentation. In simulation, due to the complexity of the crush event, advances have been made discarding a continuum, physically-based implementation in favour of smeared-crack methods, where the damaging material is modelled using volume averaged fracture energies accounting for several micromechanical phenomena. These Non-local Damage Models (NDM) overcome stress localization issues and offer superior mesh independence than conventional continuum-based damage models. In this work, the NDM derived from Waas-Pineda, implemented in the commercial software ESI-VPS is described and a procedure to calibrate such model against experimental coupon tests is proposed. The intralaminar fracture properties of a carbon fibre/epoxy material are obtained from Compact Tension (CT) and Compact Compression (CC) tests, and several data reduction methods for the tests are compared. Single element simulations are used as first building block level to assess the basic working of the damage model. Here, the fracture energy inputs are calibrated to obtain the correct value of strain energy to

failure. The CT and CC coupon tests are simulated using calibrated inputs, comparing the load output with experiments. Finally, a sensitivity study is carried out to evaluate the influence of several model parameters on the output load.

Characterisation and analysis of intraply shear and interply friction for UD prepreg forming: A critical review and roadmap for future studies

abst. 2280
Room 3
Friday
September 3
12h10

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Intraply shear behaviour of uncured composite plies plays a key role to influence the component quality in advanced manufacturing processes such as prepreg compression moulding (PCM) and double diaphragm forming (DDF). Accurate understanding and characterisation of the in-plane intraply shear behaviour of prepreg plies helps to avoid wrinkling defects during composite forming. Intraply shear property of Unidirectional (UD) prepreg is frequently confused with its interply friction behaviour mainly to achieve the macroscale deformation behaviour of UD prepregs during experimental forming. Essentially, this work aims to address two aspects of the related issues: a) a critical review of the relevant research literature to evaluate the characterisation methods and align the understanding of the mechanics of deformation of UD prepregs during in-plane shear, b) propose a new approach to characterise and analyse the intraply shear property of a thermoset UD prepreg for advanced forming techniques. Further, a complementary work on intraply friction behaviour of the same UD prepreg at relevant processing conditions is characterised to differentiate quantitatively the two major deformation mechanisms (intraply and interply) during composite forming

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Experimental Study on fluid-structure interaction of dilatant fluid and circular cylindrical shell under harmonic axial load

abst. 2297
Room 1
Thursday
September 2
12h50

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The presented experimental investigation illustrates the preliminary results of the project FAR2020 Mission Oriented “Fluidi non-Newtoniani e Interazione Fluido Struttura / InterFlu” (Non-Newtonian Fluids and fluid-structure interaction) funded by the University of Modena and Reggio Emilia. The activity will focus the attention on the complex dynamic phenomena that arise from the interaction between the thin walls of the cylindrical shell, in conditions of non-linearity: large displacements, and the change in viscosity of the non-Newtonian fluid analyzed. The circular cylindrical shell under seismic excitation is filled with fluid and the dynamic has been investigated experimentally. A Polyethylene terephthalate (P.E.T.) thin shell with an aluminium top mass is harmonically excited from the base through an electrodynamic shaker in the neighbourhood of the natural frequency of the first axisymmetric mode. The dilatant fluid is composed of a cornstarch-water mixture with 60% cornstarch and 40% water of total weight. The preliminary results show a strong non-linear response due to the coupling between the fluid and structure and the shaker-structure interaction that leads to a very interesting dynamic response of the system. The specimen is a polymeric circular cylindrical shell: an aluminium cylindrical mass is glued on the shell top edge; conversely, the bottom edge of the shell is clamped to a shaking table. The following sensors have been adopted: three triaxial accelerometers placed on the top mass at 120°, a monoaxial accelerometer at the base of the shell, a laser vibrometer to measure the lateral velocity on the mid-height of the shell. The test article has been excited in the axial direction

through a harmonic load, with a step-sweep controlled output, the voltage signal sent to the shaker amplifier is closed-loop controlled; to avoid interaction between the control system and the specimen under study, no controls have been used for controlling the shaker base motion. The harmonic forcing load consists of a stepped-sine sweep of the frequency band 100-500 Hz with a step of 2.5 Hz, at different constant amplitude levels. All the tests have been performed with the shell full filled with quiescent fluid and with open-loop control. The dynamic scenario is carefully analyzed through time histories, spectra, phase portraits and Poincaré maps. The experiments show the onset of complex dynamics: subharmonic, quasiperiodic and chaotic responses. The amplitude-frequency diagrams of two runs at 0.34 Volt and 0.48 Volt, in both upwards and downward direction, shown a rise in energy to the lateral motion at increasing of the base excitation. Moreover, there is a slight decrease in the peak frequency, showing a slight softening behaviour. The bifurcation diagram of the radial velocity and top acceleration of the downwards test at 0.48 Volt and the bifurcation diagram of the radial velocity of the upwards test at 0.34 Volt shows clearly that the dynamic scenario of the shell is strongly nonlinear. In addition to the main instability region around the first axisymmetric mode between 235Hz and 300Hz, the bifurcation diagram of the lateral velocity shows a second interesting region between 366Hz and 442Hz, where a subharmonic response is predominant, confirmed by the spectrum of the lateral velocity in the upward 0.34V case at 400Hz and the branches of the diagram separate and rejoin several times, showing a strong dynamic instability with a period-doubling behaviour. The Poincaré maps and phase diagrams of the vertical acceleration of the top mass and the radial velocity of the shell shows a 4T subharmonic motion progress to chaotic states at 250Hz.

Failure of Composites

Failure analysis of thin-walled composite structures using independent advanced damage models

abst. 2014
Repository

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In the presented paper, the phenomenon of failure of thin-walled composite structures was analysed. The tested thin-walled structures were made of carbon-epoxy laminate using the autoclave method. Experimental tests on actual structures and advanced numerical calculations using the finite element method were conducted. The numerical calculations were carried out in the ABAQUS® software. The study were conducted in the full load range, taking into account the failure phenomenon. During the experimental tests, post-critical equilibrium paths were recorded. This approach made it possible to carry out further analysis of the failure status of the composite material. Numerical simulations were conducted using independent advanced damage models. The first damage model is model associated with progressive failure analysis (PFA), based on the failure initiation (Hashin's criterion) and the damage evolution (energy criterion). Second damage model is cohesive zone model (CZM) which was used in numerical studies in order to predict the delamination phenomenon. Additionally, the extended finite element method (xFEM) was used to predict crack initiation and propagation. Both numerical and experimental studies were carried out until the total loss of load-carrying capacity.

A Multilateral Study on the FRP Composite's Matrix Strength and Damage Growth Resistance

abst. 2025
Room 2
Thursday
September 2
14h30

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In the paper, fiber reinforced polymer (FRP) composite's matrix damage resistance was evaluated based on a mechanical behavior of selected materials. Four materials were selected to scientific investigation. Epidian 5 epoxy resin and Epidian 53 epoxy resin were cured using the curing agents with various chemical composition: Z1 triethylenetetramine curing agent and PAC polyaminoamide curing agent. Tensile tests were conducted to obtain strain-stress characterizations, as well as Charpy dynamic impact tests and quasi-statical three-point bending tests were performed to calculate both dynamic and static fracture toughness (KID and KIC, respectively). The relation between the values of fracture toughness and other mechanical properties was discussed. The literature review in the field of polymer materials and adhesives reveals that there is a lack of scientific publications considering the testing results of that type. Therefore, the results obtained from the conducted research brings far-reaching benefits for the practical use of them in these branches of industry where technology based on adhesion phenomenon is dominant or significant. Aerospace and space industry, as well as automotive are the branches of engineering directly interested in the obtained results. The specific motivation of this multilateral matrix-characterization research framework is a need to calibrate the acoustic- emission-based elastic wave frequency analysis used in damage identification in composite laminates (FRPs), where matrix cracking and delamination phenomena take place. Acknowledgements: This paper was financially supported by the Ministerial Research Project No. DEC-2016/21/B/ST8/03160 financed by the National Science Centre, Poland.

Failure mechanism of 3D printed continuous carbon fibre reinforced polymer composites with optimised topology and fibre orientation under three-point bending

abst. 2044
Room 2
Thursday
September 2
14h50

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This study experimentally and numerically investigates the failure mechanism of topology-optimised, 3D printed continuous carbon fibre reinforced polymer composite structures. A sequentially coupled optimisation of structural topology and fibre orientation is presented, in which topology optimisation determines the geometry while continuous fibres are placed along the identified principal stress trajectories. Case studies are performed with the classical Messerschmitt-Bolkow-Blohm (MBB) beam under three-point bending, wherein four cases with different volume fraction constraints and geometric complexity are considered to evaluate the effect of optimisation parameters on the failure pattern. Fused filament fabrication (FFF) 3D printing technique together with post-printing treatment is used to produce the curved fibre composites. Finite element (FE) models are also established using the real printing paths of fibres to predict the damage evolution. Failure analysis from the FE models is correlated with experimental data of digital image correlation (DIC) to reveal the failure mechanism.

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abst. 2071
Room 2
Thursday
September 2
15h10

Bending damage evolution from micro to macro level in thick CFRP laminates studied by high-frequency ultrasound microscopy and acoustic emission

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The results of the experimental investigation of the bending damage evolution in the volume of laminate with a stacking sequence of [0°/90°]4S and thickness of 4.5 mm were presented in this work. Damage formation under the step-by-step loading (three iteration) was detected by acoustic emission and was visualized by high-frequency acoustic microscopy. The acoustic emission method revealed the moments of the fiber breakage, formation of cracks and delaminations in the process of bending. AE activity and energy of AE pulses were related to drops and slope of the loading curves which corresponded to the damage in the composite volume. The layer-by-layer ultrasound imaging revealed the location of matrix cracking, fiber fracture and interlayer delaminations. Experimentally it was found that initiation of bending damage started in the orthogonal 90° plies of the tensile region under 0.7-1.0% deformation of the outer plies. The following bending provided the fiber breakage under the indenter. Further damages developed both in the compression and tensile region. Growth of matrix cracking in orthogonal (90° plies) was visualized in the tensile zone and formation of small delaminations around the fractured fibers was detected in compression area. Specimen lost strength stability after the appearance of extended interlayer delaminations. The scheme of step-by-step damage development in the laminate volume was presented. The reported study was funded by RFBR according to the research project № 18-29-17039.

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abst. 2095
Room 2
Friday
September 3
10h20

Low-velocity impact and residual compression performance of carbon fiber reinforced composite stiffened plates

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Carbon Fiber reinforced composites (CFRP) have been widely used in the aeronautical structure design due to its high specific strength and stiffness, great designability. The composite stiffened structures have attracted much attention of the aviation, automobile and energy industries. When the composite stiffened structures are impacted by objects during the application process, serious damage will occur inside it. These damage will occur damage extension when the composite structures are bearing the load, the specific manifestation is that the impact damage area increases gradually, which seriously affects the service life of the structures. It is necessary to discuss the impact damage caused by low-velocity impact and the residual compressive strength after impact of the structures. In this study, three groups of tests were designed for the possible impact positions of the carbon fiber reinforced composite stiffened structures during actual use, and each set of tests impacts one position. The first type of impact position has no stiffener under the impact position; the second impact position is directly above the midpoint of the longitudinal stiffener; the third impact position is directly above the intersection of the transverse and longitudinal stiffeners. The impact test uses a drop-weight testing machine to apply the impact load; the compression test uses a universal testing machine to apply the axial compression load. Through visual inspection and ultrasonic C-scanning system to detect the surface damage and internal damage of the test specimens and the size of the damage area, compare the difference of damage after impact at different positions. Then, after the impact test, perform an axial compressive test and observe the failure modes of the test pieces and test the remaining compressive strength of the test pieces. The commercial software ABAQUS is used to simulate the impact tests and compressive tests after impact of the composite stiffened structures. The strain-based three-dimensional Hashin failure criterion is introduced through the Vumat subprogram interface to simulate the failure process of fiber and matrix, and the cohesive force model is used to simulate the delamination damage extension of composite stiffened plates. Through experimental results and finite element simulation results, the mechanism of impact damage formation of composite stiffened plates and the damage propagation and extension process under compressive load are analyzed. The results show that when there is no stiffener below the impact position, the main impact failure modes are fiber fracture and internal delamination of the skin, and the damage area is large. But it has little effect on the bearing capacity of the structure, the bearing capacity decreased by 15.09%; when the impact position is directly above the midpoint of the stiffener, the fiber and matrix damage area in the skin is small, and the main failure mode of the stiffener is that the stiffener is peeled from the skin, which will obviously affect the remaining bearing capacity of the structure, the load-bearing capacity drops by 22.25%; when the impact position is directly above the intersection of the transverse and longitudinal stiffeners, the fiber and matrix damage area in the skin is also small the main failure mode of the stiffener is that the stiffener is peeled from the skin, which will seriously affect the remaining bearing capacity of the structure, the load-bearing capacity decreased by 44.74%. Therefore, special attention should be paid to the damage of the contact part of the stiffener and the skin during the use and maintenance of the composite stiffened plate.

Experimental study on low-velocity impact and residual compressive properties of composite grating after damp-heat aging

abst. 2098
Room 2
Friday
September 3
10h40

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Carbon fiber composite materials have the characteristics of specific strength, high specific stiffness and strong design, and have been widely used in the design of aerospace structures. Lightweight and large-scale structures are the development trend of aircraft structure design. Composite reinforced structures have the characteristics of high axial load-bearing capacity, high strength and high rigidity, and are valued by aviation, automotive and wind power industries. The impact of foreign objects on composite materials during the application process will cause serious damage to the structure. These damages will expand when they are loaded in actual applications, resulting in a gradual increase in the impact damage area, which seriously affects the service life of the structure and limits the composite The application of material-reinforced structures in various industries.For composite material structures with a hot and humid environment storage period, as time goes by, moisture will enter the composite material, and the structure will be damp and heat aging, and mechanical damage will be caused. This damage gradually accumulates, and the gradual accumulation of micro-cracks in the composite material leads to damage. The absorption of water increases, which further reduces the integrity of the composite interface. In this paper, the impact performance and residual compression performance of composite grid panels after damp and heat aging are studied. First, perform damp and heat aging treatment on the composite grid plates and record the moisture absorption rate. Observe the internal damage of the specimens after 0, 45, and 90 days of damp heat aging through the ultrasonic C-scanning system. Second, carry out low-velocity impact test and compressive test after impact on the specimens treated with damp heat aging for 0 days, 45 days and 90 days and observe the damage of the specimens after 0, 45, and 90 days of damp-heat aging through the ultrasonic C-scanning system. ; The test results show that the damp and heat aging has little effect on the mechanical properties of the test pieces, and the ultimate load-bearing capacity of the 45 day and 90 day damp and heat aging test pieces decreases by 8.05% and 13.94% respectively. Under the action of impact load, stratification defects will occur inside the specimen. The impact at the center of the skin mainly produces stratification inside the skin. The failure modes are obvious stratification and buckling failure of the skin, and compression failure of the ribs; the impact at the position of the longitudinal stiffener and the impact at the intersection of the longitudinal stiffener and the transverse stiffener mainly produce stratification defects at the interface between the skin and the stiffener and inside the stiffener. The failure mode is mainly the fracture of the stiffener. The fracture causes local stratification of the skin; the impact at the position of the longitudinal stiffener and the impact at the intersection of the longitudinal stiffener and the transverse stiffener have a greater impact on the bearing capacity than the impact at the center of the skin. The compression failure mode of the specimen after impact is similar to the compression failure mode of the unaffected specimen. During the loading process, the skin buckles locally at the weakest section position, and then the laminate fracture along the 45° direction occurs at the buckling position. When it reaches the specimen under the ultimate load, the reinforcement ribs of the specimen were broken, the skin was stratification in a large area, and the specimen lost the bearing capacity. The study found that the deformation of each type of specimen during the test is similar, and the impact damage has little effect on the strain change of the specimen. The damp heat aging test will destroy the interface between the resin matrix and the carbon fiber. As time increases, the surface of the fiber adheres to the matrix gradually decreases, and micro-cracks appear between the fiber and the matrix, which reduces the adhesion of the interface and causes damage to the test piece.

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abst. 2127
Room 2
Thursday
September 2
15h30

Assessment of Cuntze and Puck inter fibre failure criteria in simulation of CFRP plates subjected to low velocity impact

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This paper presents the implementation and assessment of a Continuum Damage Mechanics (CDM) based material model to predict the damage and mechanical response of Carbon fibre reinforced polymer (CFRP) composites subjected to low velocity impact. Cuntze and Puck inter fibre failure (IFF) criteria are employed in combination with non-linear shear behavior and damage evolution using a user-defined material model or VUMAT in Abaqus/Explicit to account for the progressive damage in laminated composites. The capability of the numerical model was stablished through a set of benchmark simulations on Representative Volume Elements (RVE) and tensile specimens. The 3D models of low velocity impacts were validated against experimental tests with three different energy levels of 8 J, 10 J and, 12J. A good correlation has been observed from the comparison of experimental and numerical results of force-time histories, force-displacement curves, and energy-time histories as well as delamination, which indicates the capability of both IFF criteria in predicting the intralaminar damage in CEFP composites.

Combined compression-torsion fatigue failure of unidirectional carbon fiber reinforced composites

abst. 2167
Room 2
Friday
September 3
09h40

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Compression strength of composites is its design limiting criteria. It is also known that the compressive strength of unidirectional composites degrades significantly with superposed shear loading. Previous work in literature (Yerramalli and Waas 2003) has studied the combined compression-torsion response under static loading. Fatigue response of unidirectional composites under combined compression-torsion loading is absent in literature. As part of this study a combined micromechanics based modeling approach and an experimental program has been conducted to obtain the fatigue failure behavior of unidirectional carbon fiber reinforced composites under fatigue loading. A total of three compression/shear ratios were chosen along with the pure compression and pure torsion load cases for this study. The specimens were loaded in torsion to three different levels of shear stress and then the compression load cycles were performed to obtain a relation between the compression fatigue life and the superposed shear. The analytical model results for the compression fatigue life predictions were compared with the experimental data.

Microstructure-based analysis of residual stress concentration and plastic strain localization followed by fracture in metal-matrix composites

abst. 2214
Room 2
Thursday
September 2
15h50

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Experimental-numerical study is performed to investigate the deformation and fracture in aluminum matrix – carbide particle composites. Al-TiC and Al-B4C cylindrical speci-mens are fabricated by solid-state sintering during hot pressing and then subjected to compression and tension tests for investigating the fracture by electron microscopy. The method of step-by-step packing is adopted to generate 3D model microstructures of metal-matrix composite materials, and a technique for computer simulation of three-dimensional structures of materials with reinforcing particles of complex irregular shapes observed in the experiments is proposed, which assumes scale invariance of the natural mechanical fragmentation. The dynamic and quasistatic boundary-value problems are solved numerically by the finite-element method using ABAQUS. Constitutive models describing the mechanical behavior of the matrix and particle materials, where isotropic strain hardening is included into consideration and a fracture criterion is used, are implemented in the FE calculations through a user-defined subrou-tine. The interrelated plastic strain localization in the aluminum matrix and crack origination and growth in ceramic particles are investigated under compression and ten-sion, as well as during cooling followed by compression or tension of the composite. A detailed analysis is performed to evaluate the residual stress concentration in local regions of bulk tension formed under all-round and uniaxial compression of the composite due to the concave and convex interfacial asperities. The work was supported by the Russian Science Foundation (grant No. 18-19-00273, https://rscf.ru/en/project/18-19-00273/).

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abst. 2215
Repository

Influence of Cracks and Voids on the Responses of Composites

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In this presentation, numerical study on influence of parameters related to cracks and voids on the responses of the composites under tension, compression, and shear de- formation is conducted by extended finite element method (XFEM). Under tension, the maximum stress of composites changes less than 5% when crack orientation, fiber orientation, and void distance change. The maximum averaged stress could differ by 10% when the crack location and crack length change. In the multi-crack composites, there is difference by 10% in maximum stress due to relative crack location. Under shear deformation, crack orientation affects the maximum averaged shear stress sig- nificantly when compared to the same composites under tension. The difference of maximum averaged shear stress is more than 15% when fiber orientation changes. The void distance results in 5% difference on the maximum stress of composites. In the multi-crack composites, the relative crack location could result in 10% difference in maximum averaged shear stress. Crack length also could result in significant differ- ence in maximum stress of composites under shear deformation. Under tension and shear deformation, one crack is always the dominant crack and its propagation path determines the strength of the multi-crack composites. Unlike in tension and shear deformation, single crack in the composites under compression doesn't result in the failure of composites even when the strain is 0.03. That is, no kinking and geometric buckling occurs for the single crack composite under compression. Noticeable crack propagation starts in multi-crack composites under geometric buckling, which result from the existence of multi-cracks and their interaction in the composites.

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abst. 2220
Room 2
Friday
September 3
10h00

Modeling the interaction of interface with the anisotropic crack using cohesive zone model in a composite system

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Composites are widely applied as they offer high strength and high stiffness for low weight when compared to traditional materials. The material properties of the composite material can be tailored according to the specified purpose. As composites are made up of two or more constituents, there exists an interface between the constituents which play a vital role in defining the mechanical response of the system. The failure in a composite system can be due to the failure of individual constituents or the interface. The crack can initiate and/or propagate along any of the constituents or the interface. In the present work, a nonlocal diffused approach is proposed and implemented to model a composite system and understand the interaction of crack with the interface. A coupled cohesive zone law is adopted to define the constitutive behaviour of the interface. Parametric studies are conducted to understand the effect of relative fracture toughness of the interface to that of the bulk on the crack propagation and mechanical response of whole system. The proposed model is illustrated through numerical examples to understand various failure mechanisms in a composite system.

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abst. 2239
Room 1
Wednesday
September 1
17h10

High-fidelity modelling of single-edge notched cross-ply tensile laminates

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The failure mechanics of composite materials exhibit a variety of complex damage and failure modes such as intra-ply cracks (matrix and fiber failure) and inter-ply delamination, including their interactions. Due to the micro-structure of composites, matrix cracks can occur between the fibers and are usually considered sub-critical damage. In the presence of notches, however, matrix splits can initiate and develop into critical cracks. For example, in a notched cross-ply [90_2/0_2]s tensile laminate, the splits occur in the 0 ply and extend to the grips with increasing loading. Likewise, dominant matrix cracks arise in the 90 plies near the notch, but additional distributed transverse cracking develops throughout the entire specimen length. Furthermore, the discontinuities in the plies trigger delamination at the ply interfaces, dictated by the growth of the intra-ply cracks. Finally, the fiber strength in the 0 plies is reached and the specimen breaks. In our talk, we will describe a virtual testing framework using a novel finite element method (FEM) - based model. The newly developed "semi-discrete" method aims to unify features that are seen in existing methods in the literature to solve a wide range of challenging problems, such as unnotched, open-hole, notched cross-ply and angle-ply tensile specimens. It combines high predictive fidelity due to semi-discrete meshing features and high computational efficiency by using continuum damage crack band methods. The method comprises of a novel and efficient meshing strategy and physically consistent material constitutive models that is able to separate the mechanisms of failure into bulk dissipation and sharp cracks (strong discontinuities modeled through a smeared approach). In order to do so, the model consists of thin strips of elements, that are evenly spaced and aligned along the fiber direction in each ply. These elements are used to capture sharp matrix cracks. In order to capture the progression of transverse cracks (crack density), we ensure a random material property distribution. Randomized transverse and shear strength and toughness properties are assigned to the matrix-split strips, while fiber and interface properties can be randomized throughout the entire structure to simulate an actual fabricated specimen. In our presentation, we aim to demonstrate, explain and predict the physics of failure and the mechanisms by which composite structures dissipate energy while progressively damaging and failing when subjected to mechanical loads, by studying the single-edge notched cross-ply tensile laminate. The model is capable to capture the dominant and distributed matrix cracks, as well as interactive delamination and fiber tensile failure. The predictive results are validated against experimental studies.

Linking tensile strength of carbon fibre composites to strength of single fibres: An experimental, probabilistic and micromechanical approach

abst. 2272
Room 1
Wednesday
September 1
16h50

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Tensile strength of unidirectional composites is strongly governed by the strength of the reinforcing fibres. Most of the commercially used fibres (e.g. carbon and glass fibres) are brittle in nature, and exhibit a scatter in strength due to the presence of flaws introduced during their manufacturing and handling. Under increasing loading of the composites, the fibres start failing at their weak locations, and the resulting loss in stress carried by the broken fibres is taken up by the surrounding intact fibres. Different probabilistic models can be used to analyse the strength distribution of brittle fibres, where the Weibull model is by far the most widely used one. The Weibull model is based on a weakest-link theory assuming that a given volume of material fails at the location of the most detrimental defect, and that there is no interaction between defects. With respect to the determination of strength distribution of fibres, one challenge is the need for testing a large number of fibres under controlled conditions, and with a minimum interference from manual handling. Another challenge is accurate measurement of the cross-sectional area of fibres. In this study, tensile testing of carbon fibres was performed with a semi-automated single fibre testing machine, with a built-in vibroscope system for cross-sectional area measurements. The fibres were tested with sample sizes of 150 fibres at eight different gauge lengths in the range 20 - 80 mm. The two-parameter unimodal Weibull distribution was used to analyze the experimental data of fibre strengths, leading to good linear fit (R2 $\approx$ 0.99) of the log-log relations for all gauge lengths. The average Weibull modulus was determined as 6.7 $\pm$ 0.7, and characteristic strengths were determined in the range 3800 – 4500 MPa for different gauge lengths. Tensile testing of unidirectional carbon fibre reinforced vinyl ester composites (67 % fibre volume fraction) was performed using protected x-butterfly shaped specimen [1] to ensure failure in the gauge section. The ultimate tensile strength of the composites was measured to be 2700 $\pm$ 100 MPa. A correlation between experimental strength values of single fibres and composites was established using the micromechanical model of Curtin [2]. The model includes the effects of (i) fibre strength distribution i.e. Weibull modulus and characteristic strength, (ii) load transfer from broken to unbroken fibres, (iii) interfacial shear strength. Thus, the Curtin model covers the fundamental probabilistic and micromechanical mechanisms governing failure in fibre reinforced polymer composites. Altogether, the study presents a connecting link from strength of single fibres to strength of carbon fibre composites.

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abst. 2287
Room 1
Wednesday
September 1
16h30

An approach to damage tolerance assessment for composite structures based on the Hashin criterion

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Modern aircraft structures are manufactured with increased presence of polymer composite materials. Usage of such materials bring some new functionalities but on the other hand have some limitations. Composites are sensitive to impacts that can lead to damage. Evaluation of structural integrity of the composite structure is based on the results of non-destructive testing. If damage presence is detected in the structure, it is referred to the structural implications. For new aircraft, the damage size limitation is determined based n strength tests results. The Polish Armed Forces operate aircrafts that operate based on service life extensions programms Also due to the safe life concept failure mode size restrictions concepts has not bee implemented. Service life extension programmes enforced the migration to condition based maintenance approach for aircraft operation. The article presents a implementation ofmethod for determining the critical failure mode size determination based on numerical calculations. Especially the impact of failure mode configuration on the mechanical properties of the composite structure was analyzed using the finite element method and the Hashin criterion. For a quasi-isotropic material, the influence of the damage surface on the stiffness of a typical aeronautical structure made of composite was investigated. On this basis, a method of estimating the boundary damage surface of the composite skin has been proposed. As a result of the analysis, relation of the influence of the failure mode configuration on the structure durability and elaboration of the guidelines for damage size criteria elaboration.

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abst. 2318
Repository

Influence of elastic pads on the post-buckling state of the thin-walled L-profile column

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Determining the boundary conditions of the structure is a very important aspect in the failure analysis. In experimental tests, the method of compressed composite samples significantly influences the obtained results. In numerical studies, there is a problem of correctly defining the boundary conditions applied in real object. The present paper includes study to determine the influence of the elastic pads on the thin-walled laminated angle column under shortening. Analyzed samples are made with carbon-epoxy laminate using the autoclave method. The configurations of laminate layers are: [60,02,-602,603,-602,03,-602,0,602]T, where direction 0 is along the length of the profile. The buckling and the post-buckling states of the columns were investigated experimentally and numerically. Firstly, a simply supported angle columns subjected to uniform shortening are tested experimentally. Due to the stress concentration between the real sample and the grips, flexible pads were used. Experimental tests are carried out on the universal testing machine. The deformations of columns were measured by using the non-contact Aramis System. The composite material condition was monitored by AE (acoustic emission) using the Vallen Systeme with piezoelectric sensors. Next, the numerical calculations in Abaqus software based on the FEM (finite element method) are performed. To determine the influence of an elastic pads, two numerical models of the system with and without flexible pads are developed. In order to estimate damage initiation load in numerical models, a different damage criteria (Tsai-Hill,

Tsai-Wu, Azzi-Tsai-Hill, Hashin) are used. Based on the results specified that the model with elastic pads more accurately reflects the actual behaviour of the L-profile element under shortening. It was supported, i.a. by good agreement of flanges deflection (the equilibrium paths) with experimental results. A qualitative and quantitative agreement of damage initiation load was obtained using Hashin criteria. The present study was supported by statutory resources allowed to the Department of Applied Mechanics, the Lublin University of Technology under "The Grant for Young Researchers" no. FNM 30/IM/2020.

FRP in concrete, steel and composite steel/concrete structures

abst. 2032
Repository

Technological Peculiarities of Strengthening RC Members with Prestressed FRP Laminates

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There is a general agreement on the benefits of using FRP materials for structural retrofitting. Full potential of this high strength materials can be implemented by the process of prestressing. However, prestressing has a number of nuances and can be compromised. Therefore, based on the results of a recent experimental study and the experience of other authors, the peculiarities and issues of application FRP reinforcements are summarized. Current paper includes the steps from the surface preparation, anchoring to commissioning. Also, a novel prestressing system for retrofitting of reinforced concrete members with externally bonded FRP laminates is disclosed. The proposed system consists of three main items: a clamping unit, a light frame for hydraulic jack and anchoring plates. The new approach to the use of tempered steel grips for efficient clamping of FRP laminates is presented. Usually, the result of using corrugated surface steel grips would be fractured laminate, therefore plane surfaces are common in commercially available prestressing systems. The advantage of the proposed system lies in the fact that efficient corrugated surfaces are employed for compression of FRP reinforcement.

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abst. 2066
Repository

Effects of seawater immersion on shear performance of BFRP and GFRP bars embedded in seawater sea-sand mortar

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This study focused on the durability of basalt fiber-reinforced polymer (BFRP) and glass fiber-reinforced polymer (GFRP) bars used for reinforcing seawater sea-sand concrete (SSC) structures in ocean engineering. An experimental study was conducted to investigate the long-term shear performance of SSC-coated BFRP and GFRP bars immersed in seawater environment. The immersion temperatures were set at room temperature (26 °C), 40, and 60 °C. A series of horizontal shear tests and transverse shear tests of bare,10 mm and 20 mm SSC-coated BFRP and GFRP bars were performed. The redisual horizontal and transverse shear strength of BFRP and GFRP specimens after exposure to a 180-day immersion were analyzed. These findings indicate that the degradation in horizontal shear strength and transverse shear strength of SSC-coated BFRP bar generally increased as the coating thickness increased from 10 mm to 20 mm. This degradation could be attributed to the fact that the negative effect of the alkaline environment in concrete pore was dominant rather than the coating protection as the SSC coating thickness became bigger. It is noted that GFRP bars exhibited a better long-term shear performance than BFRP bars, regardless of the SSC coating thickness, especially for the horizontal shear strength. For example, the horizontal shear strength retentions of BFRP and GFRP bars with 20 mm SSC coating were 17.7% and 90.4%, respectively. This finding may be due to that glass fiber is more stable and the excellent interface bonding property between glass fiber and resin matrix. Keywords: BFRP bar, GFRP bar, Seawater sea-sand concrete, Seawater environments, Durability, Shear strength The authors gratefully acknowledge the financial support provided by the National Natural Science Foundation of China (Nos. 52078141 and 12072078), the Guangdong Basic and Applied Basic Research Foundation (Nos. 2019A1515011431 and 2019B151502004)

Behavior of concrete-filled FRP tube columns internally reinforced with FRP-steel composite bars under Axial compression

abst. 2114
Repository

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Capitalizing the advantages such as ease of construction and excellent compression behavior, concrete-filled FRP tube columns (CFFTs) have become increasing popular. However, the CFFTs in isolation has an inferior bending performance than the compressive performance. This paper proposes novel Concrete-Filled FRP Tube columns internally reinforced with FRP-steel Composite Bars (referred to as CFFT-CB columns), in which longitudinal reinforcing steel-FRP composite bars (SFCBs) and an SFCB spiral are employed as internal reinforcement. The axial compression behavior CFFT-CB columns is studied via experimentation in this paper. The effects of the spiral types (FRP bars, SFCBs), the spiral pitches (50mm, 100mm), and the thickness of FRP tubes (0, 1, 2, 3-layer) are carefully investigated and the test results confirm the viability of the proposed columns. The stress-strain curves of test columns are compared with existing stress-strain models, with the confining stresses from both the FRP tube and the SFCB spiral being accounted for. The comparison demonstrates that the existing models provides reasonably accurate predictions of the test specimens.

Compressive and Transverse Shear Behaviour of Novel FRP-UHPC Hybrid Bars

abst. 2116
Repository

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Fibre-reinforced polymer (FRP) bars have become increasingly popular as internal reinforcement in reinforced concrete (RC) structures due to their excellent corrosion resistance. However, FRP bars under compression are likely to suffer damage due to fibre micro-buckling, and their transverse shear performance is much inferior to steel reinforcement due to their low elastic modulus. To this end, novel FRP-UHPC hybrid bars, which consist of an outer FRP confining tube, a central FRP bar and a layer of ultrahigh performance concrete (UHPC) (without steel fibres) in the annular space between them, have been proposed whist limited studies have been carried out on their basic mechanical properties. In this study, the compressive and transverse shear behaviour of FRP-UHPC hybrid bars are investigated via experimentation. The key test variables were fibre winding angle of the FRP tube, type of fibres of the FRP tube, the FRP tube thickness and the diameter of central FRP bar. The test results confirm the validation of the novel hybrid bars: i) the compressive behaviour of FRP in hybrid bars are superior to the compressive behaviour of FRP bars in isolation; ii) the transverse shear performance of hybrid bars is much better than the pure FRP bars due to the contribution of FRP-confined UHPC section.

Effects of fire insulation scheme and anchorage system on fire performance of insulated CFRP-strengthened RC beams

abst. 2172
Room 3
Wednesday
September 1
12h50

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Fire performance of reinforced concrete (RC) beams externally bonded with fiber-reinforced polymer (FRP) laminates is an important issue and should be adequately considered in the strengthening design process. Existing studies have indicated that the cable mechanism of FRP laminates at elevated temperatures can significantly enhance the fire resistance of FRP-strengthened RC beams. This paper aims to propose a feasible method to realize the cable mechanism of carbon FRP (CFRP) sheets under fire through the combined use of appropriate fire insulation schemes and the mechanical anchorage system. A total of seven beams were prepared and constructed: three beams were tested at ambient temperature to determine the load-bearing capacity, while the other four beams were subjected to ISO 834 standard fire exposure. The parameters varied between tests include the mechanical anchorage system of the EB CFRP sheets, the load ratio and the fire insulation scheme. The test results show that the mechanical anchorage system of the EB CFRP sheets can enhance the strength and deformation capacities of the strengthened beam tested at ambient temperature, and can also reduce the deflection responses of the beam after the occurrence of the bond failure at the EB CFRP-to-concrete interface during fire exposure. Also, the thick insulation layer provided for two anchorage zones of the EB CFRP sheets can significantly delay the temperature growths at the CFRP-to-concrete interface, which leads to smaller deflection increases of the strengthened beam after the bond between CFRP and concrete at the middle zone is lost. This is because the EB CFRP strengthening system acts as an external "cable" held by the two anchorage zones during fire exposure. In addition, the load ratio has a significant effect on the mid-span deflection responses of the insulated CFRP-strengthened RC beams. A relatively large fire load ratio leads to rapid deflection growths of the strengthened beams during fire exposure.

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abst. 2195
Room 1
Thursday
September 2
16h10

The influence of the recycled carbon fibres reinforcement on the load bearing capacity of eco-firendly, self-compacting, fibre reinforced concrete.

Ostrowski, Krzysztof Adam (krzysztof.ostrowski.1@pk.edu.pl), Cracow University of Technology, Poland

Fibre-reinforced concrete (FRC) belongs to the group of special concretes, which, apart from their strength, are characterized by special properties. In recent years, this concrete has been modified with advanced admixtures, techniques and content, which has affected the behavior of the stress-strain behaviour. Self-compacting concrete (SCC) plays an increasingly important role in the design of new structural components due to the rheological parameters of its fresh concrete mixture. At present, the problem of waste management is a very important issue. The possibilities of using waste materials in construction, concrete technology and composite structures are increasingly being sought. In this research, self-compacting, fibre-reinforced concrete (SCFRC) reinforced with recycled carbon fibres was analysed. The composition of the concrete consisted of recycled concrete aggregate, waste tire aggregate and recycled steel fibers. The recycled carbon fibers were in the form of scraps. They were obtained from the recycling of structural concrete elements reinforced with carbon fiber mats. During this research, 20 cylindrical concrete specimens were reinforced with one, two and three layers of recycled carbon fibres, and then subjected to a uniaxial compressive test. The load-bearing capacity was examined. It has been shown that the stress-strain characteristic depends on confinement pressure. The test results showed that it is possible to achieve significant reinforcement of SCFRC using recycled carbon fibers.

FRP reinforced concrete structures

Numerical behavior of externally CFRP prestressed beams with FRP/steel rebars

abst. 2021
Repository

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In externally post-tensioned members, the provision of a certain amount of bonded rebars is required to ensure favorable flexural performance and crack pattern. Conventional steel reinforcement is subject to corrosion damage, which can be overcome by replacing it with Fiber reinforced polymer (FRP) composites. In addition to their non-corrosive property, FRP composites are high-strength, light-weight and non-magnetic. These composite materials are increasingly used for strengthening or reinforcing concrete elements. Different types of FRP composites are available, such as aramid, carbon and glass FRPs (AFRP, CFRP and GFRP). Unlike steel reinforcement with ductile characteristic, FRP composites are linear-elastic materials without yielding. In addition, the FRP modulus of elasticity is usually lower than that of steel reinforcement. Hence, some concerns on the use of FRP reinforcement instead of steel reinforcement may arise. This study examines the influence of using FRP bonded rebars instead of steel ones on the flexural performance of prestressed concrete beams with external CFRP tendons. A finite element model for the full-range nonlinear analysis of externally prestressed concrete beams is introduced. Two typical FRP (carbon and glass) rebars and conventional steel rebars are adopted for a comparative study. Various rebar areas are considered. Comprehensive aspects of behavior of the beams are analyzed. The results indicate that FRP rebars lead to significantly different structural response compared to steel rebars.

Stress-strain behavior of thermally damaged concrete columns confined with FRP composites

abst. 2174
Room 3
Wednesday
September 1
13h10

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Externally bonded fiber-reinforced polymer (FRP) composites are increasingly used to confine concrete columns as an effective strengthening technique. Some experimental investigations have been conducted to extend the FRP strengthening technique to repair thermally damaged concrete columns after a fire incident. The existing experimental results have indicated that the FRP confinement effectively restores the load-bearing capacity of thermally damaged concrete columns. Both the compressive strength and axial deformation capacity can be significantly enhanced. However, all existing concrete confinement models (i.e., stress-strain models) have been proposed to predict the compressive behavior of FRP-confined concrete at ambient temperature, and their applicability in FRP-confined thermally damaged concrete is still uncertain. This paper collects available test data on FRP-confined thermally damaged concrete columns in the literature. Some typical concrete confinement models are also reviewed, and their applicability in predicting the compressive behavior of FRP-confined thermally damaged concrete columns, including compressive strengths, ultimate axial strains and axial stress-strain relationships, are evaluated. The comparisons between test data and model predictions have indicated that as the exposure temperature increases, the accuracy of each model prediction is significantly reduced. Finally, a new stress-strain model is proposed for the FRP-confined thermally damaged concrete by appropriately considering the degradations of the mechanical properties of the thermally damaged concrete and the relevant confinement mechanism.

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abst. 2208
Repository

Full-Range Axial Load-Strain Model for GFRP-RC Columns

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Fiber-reinforced polymer (FRP) bars reinforced concrete (RC) structures (referred to as FRP-RC structures) have become increasingly popular. However, existing confinement models have been heavily relied on models of steel-confined concrete and the calculation of the longitudinal contribution of FRP reinforcement remains unclear. Moreover, there is a lack of full-range axial load-strain model for FRP-RC columns, which is fundamental for the design and advanced analysis of FRP-RC structures. To this end, comprehensive assessments of existing confined concrete ultimate axial stress (or strain) models (including models for glass FRP spiral-confined concrete (GFSCC) and models for FRP partially confined concrete (FPCC)) against a newly established database are conducted in this paper. In the final section of the paper, a new design-oriented full-range axial load-strain model is proposed for circular GFRP-RC columns by accurately considering the behavior of the three components in FRP-RC columns (i.e., the confined concrete core, the FRP longitudinal reinforcement and the concrete cover). The comparisons demonstrated that the proposed model provides satisfactory predictions of FRP-RC columns.

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abst. 2302
Repository

Confinement of concrete columns with composite materials: FRP vs. TRM design and modelling

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Rehabilitation and Maintenance (RM) of existing structures represent a relevant amount of the whole construction industry activities in Europe, where the 26% of the existing buildings was built between 1945 and 1696. As a matter of fact, before COVID-19 crisis, the costs for RM were about 28% of the total investments in constructions, while the market of new buildings represented only 21.6% of the total resources. For decades, the scientific community is involved in the enhancement of the mechanical performance of existing buildings for the safeguard of Cultural Heritage and, in this field, the stability of columns is an issue of paramount importance. Among the numerous confinement techniques, in the last twenty years, Fibre Reinforced Polymers (FRP) have been widely studied and adopted and, since about ten years, also the use of Textile Reinforced Matrix (TRM) composites has been investigated as alternative to FRP systems for confinement of concrete columns. This paper presents a critical comparison between the efficacy of FRP vs. TRM confinement systems, based on a dataset of experimental results available in the literature on the enhanced bearing capacity and ductility of confined concrete columns. The most well-established analytical models available in research studies and in the codes are considered for the prediction of the confined response in terms of peak stress and ultimate strain. Among them, the models proposed by Spoelstra and Monti [1], Campione and Miraglia [2], Wu et al. [3] and Teng et al. [4] are used for FRP confinement. Moreover, the code provisions for FRP systems suggested in CNR-DT 200 [5] are considered. As for TRM strengthening, the model proposed by Colajanni et al. [6] and the code provisions of CNR-DT 215 [7] and ACI 549 [8] are employed. All formulations originally conceived for FRP systems are also used for the interpretation of the results of TRM confined columns. A parametric analysis is thus conducted for highlighting the criticisms and limits currently present in the analytical reference models when used for interpreting the results of TRM-confined columns. Moreover, the results of the analyses are used for remarking the most significant design parameters which affect the efficacy of FRP vs. TRM confining system, considering the variation of stiffness and strength of the reinforcing grid, the number of reinforcing layers, the concrete and mortar grade and the cross-section shape. References [1] Spoelstra MR, Monti G. FRP confined concrete model. J of Compos for Constr 1999; 3(3):143-150. [2] Campione G, Miraglia N. Strength and strain capacities of concrete compression members reinforced with FRP. CemConcr Compos 2003; 23:31-41. [3] Wu G, Lu ZT, Wu ZS. Strength and ductility of concrete cylinders confined with FRP composites. Constr Build Mater 2006;20(3):134–48 [4] Teng JG, Jiang T, Lam L, Luo Y. Refinement of a design-oriented stress–strain model for FRP-confined concrete. ASCE J Compos Constr 2009;13(4):269–78 [5] CNR-DT 200 (R1 2013). Guide for the design and construction of externally bonded FRP systems for strengthening existing structures. Rome: Italian Council of Research (CNR); 2013. p. 1-144. [6] P. Colajanni, F. De Domenico, A. Recupero, N. Spinella, Concrete columns confined with fiber reinforced cementitious mortars: experimentation and modelling. Constr. And Build. Mat., 52, 375-84, 2014. [7] CNR-DT 215 (2018). Guide for the Design and Construction of Externally Bonded Fibre Reinforced Inorganic Matrix Systems for Strengthening Existing Structures. Rome: Italian Council of Research (CNR); 2018. p. 1-91. [8] ACI 549.6R-20 American Concrete Institute. Design and construction of externally bonded Fabric-Reinforced Cementitious Matrix (FRCM) systems for repair and strengthening concrete and masonry Structures. 2020.

Sustainable confinement of concrete columns using Natural-FRP composites: efficacy of current design provisions and analytical models

abst. 2303
Repository

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The scientific research in the field of construction industry is widely devoted to the rehabilitation of existing structures aiming at the safeguard of the Built Heritage. Fibre reinforced Polymer (FRP) composites are the most widely adopted strengthening systems for concrete structures, even though the growing concern on sustainability increased the interest towards products with low environmental impact for promoting recycle and circular economy approaches in the field of structural interventions. In recent years, efforts have been done to replace the most common composites by materials less harmful to the environment, as natural fibres, for developing compatible and sustainable rehabilitation techniques for concrete members. This paper presents the most recent studies available in the literature on the use of natural fibres as reinforcing textile and/or ropes in novel composite materials with organic matrix made of epoxy resin and adopted as strengthening systems for axially loaded concrete columns. The performances of natural and classical FRP systems are compared in terms of effectiveness in the enhancement of compressive strength and ductility of columns. The comparison is performed exploiting some of the experimental results currently available in the literature on Natural-FRP confined concrete members [1-4]. The experimental data are interpreted using the most well-established analytical models [5-7] currently available for classical FRP systems, including few more recent theoretical modelling of the response of FRP strengthened columns [8-10]. Parametric analyses are conducted for highlighting the criticisms and limits of the reference models used for interpreting the results of Natural-FRP confined columns. The analysis results also allow the detection of the most relevant design parameters which affect the efficacy of natural vs. classical FRP confining systems, in terms of stiffness and strength of the reinforcing fibres, number of reinforcing layers, concrete grade and the cross-section shape. References [1] Padanattil, A., Lakshmanan, M., Jayanarayanan, K., Mini, K. M. (2019). Strengthening of plain concrete cylinders with natural FRP composite systems. Iranian Journal of Science and Technology, Transactions of Civil Engineering, 43(3), 381-389. [2] Hussain, Q., Ruangrassamee, A., Tangtermsirikul, S., Joyklad, P. (2020). Behavior of concrete confined with epoxy bonded fiber ropes under axial load. Construction and Building Materials, 263, 120093. [3] Ghorbel, E., Limaiem, M., Wardeh, G. (2021). Mechanical Performance of Bio-Based FRP-Confined Recycled Aggregate Concrete under Uniaxial Compression. Materials, 14(7), 1778. [4] Madhavi, K., Harshith, V. V., Gangadhar, M., Kumar, V. C., Raghavendra, T. (2021). External strengthening of concrete with natural and synthetic fiber composites. Materials Today: Proceedings, 38, 2803-2809. [5] Spoelstra MR, Monti G. FRP confined concrete model. J of Compos For Constr 1999; 3(3):143-150. [6] Wu G, Lu ZT, Wu ZS. Strength and ductility of concrete cylinders confined with FRP composites. Constr Build Mater 2006;20(3):134–48 [7] Teng JG, Jiang T, Lam L, Luo Y. Refinement of a design-oriented stress–strain model for FRP-confined concrete. ASCE J Compos Constr 2009;13(4):269–78 [8] Pham TM, Hadi MNS, Youssef J. Optimized FRP wrapping schemes for circular concrete columns under axial compression. J Compos Constr, ASCE 19 (6) (2015) 04015015. [9] Wang WQ, Sheikh MN, Albaali AQ, Hadi MNS. Compressive behaviour of partially FRP confined concrete: Experimental observations and assessment of the stress-strain models.

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Functionally graded materials and structures

Free Vibrations Analysis of Composite and Hybrid Axisymmetric Shells

abst. 2033
Room 1
Wednesday
September 1
12h30

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The formulation to carry out the free vibrations of laminated composite (C) and hybrid (F/C/F) axisymmetric shell structures is the objective of this work. The hybrid structures are made by laminas of composite material sandwiched by two functionally graded material laminas (FGM). The numerical solution is obtained by expanding the variables in Fourier series in the circumferential direction and using conical frustum finite elements in the meridional direction. The implemented finite element is a simple conical frustum with 2 nodal circles, with 10 degrees of freedom per nodal circle. This model needs a reduced number of finite elements to model the geometry of this type of structures, the integration procedures uses one Gauss point, and the through the thickness properties variation in FGM is modelled by only 20 virtual layers. From the combination of these three proposals, a very small computational time is required. The in-house developed code presents very good solutions when compared with results obtained by alternative available models. Shells of revolution have a wide range of applications, such as in aeronautics and aerospace structural systems, pressure vessels, cooling towers and atomic equipment. The Formulation and Several shape axisymmetric shell structures will be discussed in the presentation.
ACKNOWLEDGEMENTS This work was supported by FCT, Fundação para a Ciência e Tecnologia, through IDMEC, under LAETA, project UIDB/50022/2020.

On the structural bending response of P-FG nano-beams under hygro-thermo-mechanical loadings.

abst. 2037
Room 2
Wednesday
September 1
14h50

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In recent years, nanostructures made of functionally graded materials (FGMs) have attracted a great deal of attention due to their wide range of applications in several fields of nanoscience as well as in various fields of engineering, such as automotive, chemical industry, energy, biomedical appliance, telecommunications and construction. The latter field of application may be one of the main beneficiaries of this novel type of advanced composite materials, with applications that can improve either the characteristics of building elements surface, such as thermal insulation and fire protection, or the mechanical properties of conventional construction materials, such as the compressive strength and durability. Moreover, due to their excellent energy absorption characteristics, FG materials with internal porosity have also been used in nanostructures under dynamic and impact loading. It is well-known that the size-dependent response of nanostructures may be predicted accurately by adopting scale-dependent continuum mechanics-based formulations, including Eringen's nonlocal theory (ENT) and the nonlocal strain gradient elasticity developed by Lim et al combining the strain gradient model and the Eringen's strain-driven integral formulation. Furthermore, the significant number of applications of FG materials under high temperature and absorbed moisture environments, such as aerospace and marine structures, has attracted particular attention from numerous scientists since the increase in temperature and humidity can lead to a reduction in their thermoelastic properties, thus resulting in a catastrophic failure of the structures. Therefore, some researchers have extended the above-mentioned theories to include the hygro-thermal effects. Although these theories have been used by many researchers to capture size effects in nanostructures, it has been claimed that both Eringen's nonlocal elasticity theory

and Lim's nonlocal strain gradient elasticity, in their differential formulations, are not consistent when applied to finite structures and lead to ill-posed nanostructural problems. The ill-posedness of ENT is related to the fact that the higher-order constitutive boundary conditions are not compatible with the equilibrium requirements. This problem can be overcome by using the stress-driven nonlocal model (SDM) proposed by Romano and Barretta, which has been applied to solve relevant static, dynamic and buckling problems of nanomechanics. Moreover, the application of Lim's approach leads to ill-posed structural problems since the constitutive boundary conditions are in conflict with both non-standard kinematic and static higher-order boundary conditions. The ill-posedness of Lim's nonlocal strain gradient formulation can be advantageously bypassed using the methodology proposed by Barretta et al in which the proper variational formulation of the elasto-static problem of nonlocal strain and stress gradient of inflected beams has been developed. The approach proposed by Barretta also offers a simple and effective strategy to predict the dynamic responses of modern composite nano-structures. This study presents the results of a parametric investigation on the structural bending response of nano-beams made of porous functionally graded (FG) material under hygro-thermo-mechanical loadings, using both the local/nonlocal stress-driven (NStressG) and strain-driven (NStrainG) gradient models of elasticity. The numerical results obtained confirm that such formulations are able to fully capture the structural behavior of porous functionally graded Bernoulli–Euler nano-beams. These results are also important from the point of view of the design and optimization of nanostructures susceptible to hygro-thermal stresses in the case of exposure to severe environmental conditions.

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abst. 2053
Room 2
Wednesday
September 1
15h10

THE STATIC RESPONSES AND STRESSES OF FUNCTIONALLY GRADED EXACT CURVED BEAMS

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In this study, the warping included flexural behaviors of functionally graded circular and exact elliptical beams are investigated under the influence of out of plane loads via the mixed finite element method. The exact curved elliptical beam element is obtained using the curvature derived from the analytical equation of the elliptical geometry. The stress distributions through axial arch lengths and thicknesses of axially functionally graded sandwich and functionally graded exact curved beams are presented. The results of the warping included mixed finite elements are compared to the results of twenty node SOLID186 elements and Timoshenko beam theory. In the present research, the constitutive relations including the variation of Poisson's ratio besides Young modulus are derived from the three dimensional constitutive relations of an orthotropic continuum. The asymmetrical and symmetrical volume fractions of functionally graded material constituents are based on the power law volume fraction. The warping functions are included into the mixed finite elements via a displacement type finite element formulation. The two noded curved mixed finite elements have twenty four degree of freedoms in total. The normal stress distributions are derived over the curvatures of respective cross sections. The shear stress distributions are derived over the axial rotations and warping functions. Quite satisfactory results are obtained with a very less number of unknowns when compared to the twenty node SOLID186 elements which have three degree of freedoms at each node. Besides, the static responses and stresses obtained via the mixed finite elements are compared to the results based on Timoshenko beam theory. Finally, the influence of volume fractions, cross sectional geometries and ellipticity ratios on the static response and stresses of axially functionally graded and functionally graded exact curved beams are investigated.

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abst. 2072
Room 2
Wednesday
September 1
14h30

Schmidt method to study a problem of heat conduction in a functionally graded layered structure with an arbitrary oriented crack

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Das, Subir (), ,

The purpose of this article is to investigate the behavior of a partially insulated crack in a functionally graded layered structure under thermal loading. The crack is arbitrary oriented and its center is located at the interface. Employing the superposition approach and Fourier transformation, a mixed boundary value problem is reduced to a Cauchy-type singular integral equation. The unknown variable of the singular integral equation is the jump of the temperature across the crack surfaces. Representing the unknown variable as a series of Jacobi polynomials, the solution of the singular integral equation is obtained with the help of the Schmidt method. The adopted procedure is quite different from those used in the previous works, in which the unknown variables are the dislocation density functions. With the help of the Schmidt method, the analytical form of heat flux intensity factor at the crack tips are obtained. The salient feature of the article is the pictorial presentations of heat flux intensity factors and temperature fields in the vicinity of the crack tips. A drive has been taken to quantify the effect of partial insulation of the crack surfaces, crack orientation, layers' thickness, and material non-homogeneity parameters graphically.

Investigation of the Structural and Acoustic Response of Functionally Graded Lightweight Panel

abst. 2073
Room 2
Wednesday
September 1
15h30

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The goal of this work is to study numerically the structural and acoustic responses of functionally graded lightweight panel (FGLP) typically made from Al/Al_2 O_3 and analysed at different boundary conditions. The study employs a first-order shear deformation theory as well as finite element method to model the vibroacoustic response of the FGLP. Material characteristics of the FGLP are made to change along its thickness using the Voigt's rule of mixture and a simple power law distribution. Modal characteristics of neat aluminium panel (NAP) of idealized and measured results are utilized for the verification and validation, respectively, the numerical solutions of modal characteristics of NAP configuration. In addition, the results of the numerical NAP configuration are used for the comparison and verification of the results obtained by the FGLP. For the FGLP, the first eight mode shapes are obtained at all boundary conditions. Moreover, the influence of volume fraction index (VFI) on the overall vibroacoustic response is presented. The compared results indicate a significant increase in sound transmission loss of the FGLPs over their conventional NAP configurations. Also, the far-field sound pressure level of both the NAP and FGLP for different VFI are analysed. The study, therefore, shows the promising potential of FGLP and their favourable advantages over their conventional ones. This unique functionally graded material can be especially useful in applications such as noise reducing casings surrounding noisy devices, household appliances or industrial machines, and also, can limit noise transmission to the environment.

Analysis of porosity effect on temporal response of functionally graded plate with simple and efficient finite element model

abst. 2084
Repository

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The objective of the present paper is to study as well as analyzing the effect of porosity parameter on temporal response of functionally graded plate. The formulation is elaborated using a simple and efficient finite element model which is based on the FSDT theory. The pores are functionally graded in the thickness direction of the plate and the effective material properties are estimated using a modified power law distribution taking into account two types of porosity patterns namely even and uneven porosity distributions. The finite element method is used to discretize the equations of motion and the resolution is achieved via the Newmark's time integration scheme. The influence of porosity volume fraction, the types of porosity distributions is examined. Results show that the percentage of porosity into the strucutre and the way of distribution have significant effect on temporal response of FGM plate which must be considered in the control of vibrations and design modeling phases

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abst. 2130
Repository

Multi-scale topology optimisation design of porous femur implant with graded-density anisotropic microstructures using latent variable Gaussian process

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Porous femur implant with lattice microstructure design has attracted increasing attention in the treatment of total hip arthroplasty (THA) for its satisfactory performance in ossature biomimic. Nevertheless, conventional implant porous design adopts isotropic lattice microstructure, which does not accord with femur bone's ascertained structural anisotropy. In this research, a topology optimisation framework is established for design of porous femur implant based on multi-scale anisotropic finite element analysis. The framework enables the adjustment of both relative density and lattice pattern of microstructures to further decrease the total stiffness of the implant, thereby moderating stress shielding phenomenon and preventing post-operative adverse events such as osteoporosis. The implant geometry refers to Ti6Al4V Tri-lock Femoral Stem to guarantee minimum invasion space. The majority of the implant optimisation domain is meshed by anisotropic hexahedral elements. Remaining areas are meshed with isotropic tetrahedral elements. One library containing anisotropic face-diagonal cubic lattice unit cells with different beam weight combinations and another library containing isotropic unit cells with different relative densities are prepared. The stiffness matrices of the unit cells are computed from numerical homogenisation method. The anisotropic unit cells are then positioned in a multi-dimensional latent space via latent variable Gaussian process (LVGP), by which a continuous mutual-mapping relationship between microstructure lattice pattern and anisotropy stiffness properties is established. The variance of the isotropic microstructure stiffness properties against relative density is formulated by single-variable polynomial regression analysis. The framework entity is summarised as a maximum compliance optimisation problem. Constraints include fatigue failure criteria, fracture failure criteria, bone growth requirement and manufacture requirement. The optimisation process adopts modified proportional topology optimisation (PTO) algorithm for isotropic elements and modified moving asymptotes (MA) algorithm for anisotropic elements. Optimisation results are evaluated by comparison of resorbed bone mass fraction and stress shielding intensity between solid implant / uniform-isotropic implant and porous implant designed by the proposed framework. Anisotropic porous implant samples are manufactured via selective laser melting (SLM) method. Digital image correlation results obtained from sawbones compression test are analysed to verify the simulation results.

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abst. 2207
Repository

Theoretical tolerance modelling of axially functionally graded slender beams

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In this note there are considered slender elastic beams, which have a non-periodic microstructure along their axis (the x-axis). However, their macrostructure is functionally graded. The beams of this kind can be called functionally graded beams with microstructure. These beams are made of many small elements, called cells. It can be observed that distant cells can be very different, however adjacent cells are nearly identical. The length of cell l is treated as the microstructure parameter. The height of the beam is assumed to be small in comparing to the length of cell l. Dynamic or/and stability problems of these beams are described by a partial differential equation. Unfortunately, this governing equation has coefficients being highly-oscillating, non-periodic and non-continuous functions of x. Since, this equation is not a good tool to investigate different problems of these beams. Various simplified approaches were proposed to obtain governing equations with smooth slowly-varying coefficients. These methods introduce usually effective properties of the beam. To describe a behaviour of such structures there were often used averaging approaches for macroscopically homogeneous structures. Some of these methods can be found in [8]. Between them it can be distinguished models, which are based on the asymptotic homogenization, cf. [7]. The literature on the problems of dynamics or stability of beams with microstructure is extensive. Strength and buckling of sandwich beams with variable properties of cores were considered using combined analytical approaches and the finite element method, e.g. in [4]. Nonlinear bending and vibrations of axially functionally graded beams were analysed in [3]. However, the effect of the microstructure size was usually omitted in the governing equations of these models. But this effect can play a role in different cases of microheterogeneous structures, cf. [1]. It was considered in some papers related to periodic structures, e.g.: a multireflection method was used to analyse wave propagation in beams with periodically varying stiffness in [2]. Here, in order to propose averaged non-asymptotic model of axially functionally graded beams with microstructure some concepts and assumptions of the tolerance modelling method are applied. Using this approach the differential equations of microstructured periodic (or non-periodic) beams, having highly-oscillating, periodic (or non-periodic), non continuous functional coefficients can be replaced by equations with constant (or slowly-varying) coefficients. Various averaged models based on this method were developed for the analysis of thermomechanical problems of periodic composites and structures in a series of papers, e.g. for free vibrations of medium thickness functionally graded plates [5], for modelling of dynamics and stability for visco-elastic periodic beams on a periodic damping foundation [6]. Keywords: Functionally graded beams; Vibrations; Stability; Microstructure; Tolerance modelling References [1] BRILLOUIN L. (1953) WAVE PROPAGATION IN PERIODIC STRUCTURES, DOVER PUB. INC.: DOVER, UK. [2] CHEN T. (2013) INVESTIGATIONS ON FLEXURAL WAVE PROPAGATION OF A PERIODIC BEAM USING MULTI-REFLECTION METHOD, ARCHIVE OF APPLIED MECHANICS 83, 315-329. [3] GHAYESH M.H., FAROKHI H. (2018) BENDING AND VIBRATION ANALYSES OF COUPLED AXIALLY FUNCTIONALLY GRADED TAPERED BEAMS, NONLINEAR DYNAMICS 91, 17-28. [4] GRYGOROWICZ M., MAGNUCKI K., MALINOWSKI M. (2015) ELASTIC BUCKLING OF A SANDWICH BEAM WITH VARIABLE MECHANICAL PROPERTIES OF THE CORE, THIN-WALLED STRUCTURES 87, 127-132. [5] JĘDRYSIAK J. (2018) TOLERANCE MODELLING OF FREE VIBRATIONS OF MEDIUM THICKNESS FUNCTIONALLY GRADED PLATES, COMPOSITE STRUCTURES 202, 1253-1262. [6] JĘDRYSIAK J. (2021) NON-ASYMPTOTIC MODELLING OF DYNAMICS AND STABILITY FOR VISCO-ELASTIC PERIODIC BEAMS ON A PERIODIC DAMPING FOUNDATION, COMPOSITE STRUCTURES 259, 113442. [7] KOLPAKOV A.G. (1991) CALCULATION OF THE CHARACTERISTICS OF THIN ELASTIC RODS WITH A PERIODIC STRUCTURE, JOURNAL OF APPLIED MATHEMATICS AND MECHANICS 55, 358-365. [8] SURESH S., MORTENSEN A. (1998) FUNDAMENTALS OF FUNCTIONALLY GRADED MATERIALS, CAMBRIDGE: THE UNIVERSITY PRESS.

Topology Optimization of Gradient Lattice Structures Using Surrogate Models

abst. 2291
Room 2
Wednesday
September 1
15h50

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Lattice structure is an attractive material for many design applications such as aerospace and biological engineering due to the excellent properties including light-weight, high specific strength and stiffness, heat dissipation, to name a few. Lattice structures have received considerable attention in the recent years due to the increasingly high flexibility and resolution offered by additive manufacturing techniques. Unrestricted material unit cell designs are often associated with high computational power and connectivity problems, while highly restricted lattice unit cell designs may lack the potential to reach the optimal desired properties despite reducing computational effort. This work explores the possibility to maintain a low computational demand during topology optimization while increasing the flexibility of a restricted unit cell design. A two-scale concurrent optimization of lattice structure and macro structure is addressed in this study, where the topology optimization of the macroscale structure and the underlying material microstructures is performed simultaneously to achieve optimal topologies. The surrogate models are used to define material and geometrical properties to ensure a continuous topology optimization approach. An energy-based homogenization method combined with voxelization is employed to obtain the elasticity tensors for a lattice unit cell library. A multi-variable parameterization of the material unit cell is defined, which allows for the synthesis of functionally graded lattice structures. The performance of the optimized graded lattice structure is compared to a uniform lattice structure.

Wave propagation in thin delaminated composite strips

abst. 2225
Room 3
Wednesday
September 1
12h10

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In this work, a thin pretwisted and delaminated composite strip is modeled using the variational asymptotic method. The original 3D problem is reduced to 2D cross sectional analysis and a 1D problem along the length of the strip. The 1D governing equations of the strip model was solved using the spectral finite element (SFE) method, wherein the structure would be modeled as a wave guide and the dynamic stiffness matrix is derived in frequency domain. The wave response of the delaminated composite structure for different loads and conditions are computed. Further, the model is validated by comparing the result obtained from SFE method with the results obtained from a commercial finite element (FE) package. The usage of SFE is expected to yield a faster result and lesser computation than the FE method for analyzing and monitoring the delaminated strip exposed to high frequency excitations. Additionally, the SFE based modeling scheme are suitable for the inverse problem of damage detection.

Two-directional strain measurement of a composite with a single FBG sensor inscribed in the microstructured highly birefringent side-hole fiber

abst. 2267
Room 3
Wednesday
September 1
12h30

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Fiber Bragg Gratings (FBG) are the most popular optical sensors used in composite strain and temperature sensing. Thanks to their size and shape, they can be successfully integrated into the laminate without significantly reducing its strength. FBG is a periodic change of the refractive index formed in a short length of an optical fiber (2-10 mm). The period of the grating and the refractive index of the fiber determines the wavelength of reflected light (Bragg wavelength). Strain and temperature variation change the grating's period and material's optical parameters, and in consequence, causes Bragg wavelength shift. There are numerous examples of composite structures with integrated FBG sensors in composites for health monitoring purposes. Some of them are blades of wind turbines, high-pressure hydrogen vessels, and airplane constructions. The multiaxial strain measurement in those applications is requested. This sensing is possible by the usage of multiple sensors placed in particular places. FBG sensors inscribed in highly birefringent (HiBi) microstructured fibers are capable to measure the two-axial strain at the same time. Birefringence induced in the fiber's core causes that the spectrum reflected from FBG is in the form of two peaks instead of one. In side-hole fibers, when an axial load is applied to the FBG – both peaks move parallelly - like in a regular FBG sensor. On the other hand, if a transversal load is applied – the distance between peaks changes. Different signals caused by the load allow measuring both load states with a single FBG. The application of FBG sensors in side-hole fibers for two-directional strain measurement is shown in 4-point bending of square samples with integrated

HiBi-FBG sensors. They are embedded inside the composite material, near the surface of a laminate. Samples were manufactured from carbon fiber non-crimp fabric, and epoxy resin by the RTM process. During bending in two directions (along and perpendicular to the fiber), different spectral changes are observed. Based on these results, the possibility of simultaneous measurement of two-directional strain is proposed.

Impact Problems

Low velocity impact (LVI) and compression after impact (CAI) of GFRP laminates

abst. 2007
Room 3
Thursday
September 2
15h10

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Advanced fibrous composites are being used in many advanced structural applications, especially in aerospace. The problem which involving the use of reinforced plastic composite materials is the susceptibility to accidental low energy impact. In particular, such damage may be invisible causing a significantly lowering of the residual strength of composite component. Therefore this critical design aspect, implies application of conservative safety factors to the ultimate load values of composite components. In particular, in order to take into account low velocity impact damages and notch sensitivity effects the ultimate load value is generally reduced by 30%. Typical sources of low velocity impact are tool falling during manufacturing or maintenance operations, hail, debris on the track, bird collision, etc. The object of the analysis are composite plates made of GFRP laminate. The purpose of this work is to analyze the behavior of a composite plates taking into account barely visible impact damage generated by low velocity impact and the damage onset and evolution. The numerical calculations were conducted with the implementation of the progressive failure algorithm, based on the material property degradation method and implementation of the Hashin criterion as the damage initiation criterion. In all analyzed cases high consistency of numerical and experimental results was achieved. The occurrence of delamination, and their evolution was modeled in accordance with a bilinear traction-separation law. The obtained results were compared with the results of the experiment. Numerical calculations showed that delamination modeling enhances the compliance of experimental and numerical results (more than Progressive Failure algorithm application). Additionally, it was found out that the correct estimation of the areas and the nature of damages caused by the impact requires taking into account the In-Situ effect. Based on the results of experimental and numerical studies, it was stated that the highest compliance of determined material degradation was achieved by using the LaRC criterion.

Numerical dynamic response of RC slabs subjected to combined blast and impact loading using plasticity based material model

abst. 2101
Repository

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The development of numerical tools for efficiently modeling the reinforced concrete structures subjected to high velocity blast and impact has been one of the major recent studies in military and research, with the increased terrorist attacks. There are many studies available in the literature to understand the complex response of RC slabs subjected to blast and impact loads separately. In this study, the numerical analysis is carried out using LS DYNA to understand the dynamic response of RC slabs under combined blast and impact load. The concrete is exposed to a rapidly changing stress state and the material shows strain rate sensitivity. Therefore, a plasticity based material model has been proposed to study the response of concrete subjected to dynamic loading. The model is defined by considering pressure volumetric strain relation for the compressive and tensile path of the material, the damage is defined by considering the strain rate effect, strength surface is defined by including the effect of lode angle. A UMAT code is developed for the proposed model and implemented in LS DYNA. The blast and impact loading on the RC slab is validated with the experimental results available in the literature. The dynamic response and damage behavior of slabs subjected to combined blast and impact loading are studied by varying the sequence of applying load. The blast is followed by impact loading and impact followed by blast loading. Then the analysis is carried out by considering the time delay between the initiations of these loads. The slab subjected to impact load followed by subsequent blast load has more spallation because of the flexural and shear failure developed on the slab during impact loading. The slab shows more spallation when the subsequent blast load acts on the slab during the free vibration of the slab subjected to impact load. The numerical analyses are carried out and the dynamic performance and the damage behavior of RC slabs are compared. The

performance based on crack development, crack propagation, maximum displacement, acceleration time and displacement time responses are plotted. The parametric study is carried out by analyzing the mechanical and damage response by varying the slab depth, reinforcement ratio by giving single and double reinforcement, velocity of impact loading, scaled distance of blast loading. It is seen that the slab with increased thickness and reinforcement ratio perform better under combined blast and impact loading. The proposed model is able to measure the performance of concrete slab accurately under dynamic loading.

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abst. 2139
Room 2
Wednesday
September 1
16h50

Numerical investigation on the hybridization effect in glass and aramidic woven composites subjected to ballistic impacts

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Hybrid composites have raised interest in the recent years for improving ballistic properties of composite structure by enhancing protection and reducing costs. This work presents the results of the series of analyses carried out after the experimental campaign involving ballistic impacts on interply hybrid composites. Kevlar® woven composite, glass woven composite and different combinations of the two were used for ballistic impacts simulations. The numerical analyses have been carried out with the LS-DYNA software employing a built-in material model, specifically formulated for impact simulation, accounting for progressive failure in inter and intra-laminar failure modes. The materials mechanical properties were obtained through tensile tests and the parameters accounting for strain rate and softening have been calibrated. The effect of stacking sequence and target thickness on the ballistic curves, the ballistic limit velocity and the energy absorbed by the target, is presented depending on the different configuration of the composite. The results from the analyses are found in agreement with the experimental results, showing the effects of hybridization and confirming the best solution among those studied.

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abst. 2146
Room 2
Wednesday
September 1
17h10

Impact damage modelling in composite structures using strain rate dependent failure models

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The behaviour of composite structures at high strain rates differs considerably from the behaviour in static conditions. This is most evident in the mechanical properties which are determined by the matrix behaviour. Therefore, a numerical methodology for laminated CFRP structures has been developed in this work to include these high strain rate effects into the impact damage simulations. The failure criteria that have been developed for impact damage modelling in laminated composite structures have been implemented into Abaqus/Explicit using the VUMAT subroutine. The methodology follows the approaches in [1,2], where the failure mode-based criteria have been modified to account for the strain rate effects by using scaling functions to model the effects at various impact velocities. Furthermore, the effects of various parameters that affect the damage initiation process have been analysed in this work. The methodology is based on the latest experimental knowledge of the composite materials behaviour at high strain rates while all relevant failure modes have been considered. The methodology has been applied and validated in the simulation of a drop weight impact test at CFRP structures. References: 1) Raimondo, L., Iannucci, L., Robinson, P., Curtis, P. T. (2012). Modelling of strain rate effects on matrix dominated elastic and failure properties of unidirectional fibre-reinforced polymer–matrix composites.

Composites Science and Technology 72(7): 819-827. 2) Daniel, I.M., Werner, B.T., Fenner, J.S. (2011). Strain-rate-dependent failure criteria for composites. Composites Science and Technology 71: 357–364.

THE EFFECT OF LOW ENERGY IMPACT LOADS ON THE PROPERTIES OF A SANDWICH COMPOSITE WITH HEREX CORE

abst. 2205
Repository

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The paper presents findings of selected strength tests of sandwich-type composite materials with herex filling - expanded poly(vinyl chloride), and honeycomb. For the sake of the investigation, three sets of composite sandwich-type samples, of different densities, were prepared. Herex is characterized by high resistance to vibration, impact and tear, at the same time possessing a very low specific weight. The investigations aimed at proving how different density spacer herex fabric affects the strength properties of composite materials, containing it. The investigation covered a static tensile test and an impact strength test performed by means of the Charpy method. The article discusses the composition of composite materials, their manufacture process and the preparation manner of preparing the samples, in compliance with the norm for strength testing. The article describes the course of the measurements. The findings have been depicted in tables, and the research findings are depicted in the illustrations. As a result of the conducted investigations, it was found that the density of the herex-type layer affects the strength of the composite material with a core of this type. The Herex foam core in the sandwich composite absorbs and dissipates the impactor's energy, which at low values of impact loads results in damage only the layer to which the load have been applied and Herex foam. The flexural strength of a composite with a Herex core is dependent on the density of the core material, but higher density does not mean higher strength. The effect is not the same for all the examined parameters.

A NUMERICAL-EXPERIMENTAL STUDY ON THE IMPCAT RESPONSE OF AN ADDITIVE MANUFACTED HYBRID METAL-COMPOSITE STRURCTURE.

abst. 2237
Repository

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The capability to ensure passenger safety is a core requirement of any transportation facility. For this reason, the concept of Crashworthiness, i.e. the capacity offered by a structure to absorb shocks during an accident and preserve occupant safety, over the years, gained a major role in the designing of transportation devices. Indeed, considerable effort has been expended by researchers in the study of shock-absorbing devices able to increase the safety performance. Actually, this paper introduces both a numerical and experimental assessment of the effectiveness of a new hybrid (metal-composite) shock absorber concept, fabricated by means of Additive Manufacturing. Additive technology allows some fundamental benefits such as the possibility to manufacture cores with a complex shape in sandwich panels , able to maximize the energy absorption capabilities. A numerical investigation on the energy

absorption capabilities of different geometrical and material configurations has been carried out, to select the best performing configurations to be manufactured and tested to impact. Impact tests on core, skins and complete sandwich panels have been carried out to assess the capability to absorb impact energy under different boundary conditions.

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abst. 2276
Room 1
Thursday
September 2
16h30

Numerical analysis of thin-walled aluminum profiles with hexagonal triggers using ANN

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Thin-walled profiles with triggers of different geometric sizes were studied numerically using the finite element method. The specimens were loaded axially and the test was carried out until the total velocity of the tup was lost. The variable geometric parameters were height, width, and side edge angle. These parameters were used as input to neural networks at a later stage. MLP type networks were used in this study, which served as a tool to verify the numerically obtained data. In addition, the study presents a sensitivity analysis that shows the importance of each variable. Studies showed that the width of the crush initiator has a major impact on the performance of the energy absorber. Its value increases up to 30% for models with initiator height below 16mm.

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abst. 2277
Room 1
Thursday
September 2
16h50

Crashworthiness analysis of thin-walled circular column filled with aluminum porous structure.

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The subject of this study is the numerical and experimental analysis of bent aluminum tubes. The specimens were filled with aluminum foam with a hole in the center. Due to the arrangement of pores and the behavior of foam materials, they are widely used, particularly in energy absorption. The numerical analysis was performed using the finite element method in Abaqus software. The material model of aluminum foam in the area of plasticity was specified as Crushable Foam, which is dedicated to metallic foams. The experimental test was carried out on a Comatech static testing machine with a head range up to 2.5kN. The test was conducted as a three-point bend test. The results clearly show an increase in CLE up to 27 percentage points models with aluminum foam. This shows a positive effect on the use of porous material fillings to varying degrees depending on the expected results.

Joints

The efficiency analysis of innovative anchorage spiral frictional system for flat CFRP strips

abst. 2093
Room 3
Friday
September 3
12h30

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Current industrial trends revealed that structural use of innovative engineering technologies requires new design concepts related to the development of materials with mechanical properties tailored for construction. Unidirectional carbon fibre-reinforced polymer (CFRP) materials represent a promising alternative to steel because of lightweight, high tensile strength, and excellent corrosion and fatigue resistance. Stress-ribbon structural systems define the potential application object of unidirectional flat CFRP strips, though anchorage difficulties make this idea problematic. Recently, the authors proposed an innovative frictional spiral anchorage system [1] to solve the above problem. The gripping device's contact surface curvature is equal to zero at the strip entering point and gradually increases moving inward the anchorage system. Thus, the applied load and the strip directions at the anchorage support entry coincide. A mechanical clamp fixes the CFRP strip's internal end at the pre-loading stage until the main spiral grips activate the frictional shear stresses. The friction coefficient and curvature of the contact surface determine the distribution of the shear stresses. The resultant tensile stresses in the strip due to the combined effect of the tension and bending loads do not exceed the CFRP tensile strength because of the balance between the curvature increase of the spiral support and the steady decrease of the tension force inside the grips. The corresponding analytical model was developed to design the gripping devices. It shows that the geometry of the contact surface determines the effectiveness of the anchorage system expressed in terms of the traction factor, i.e. the ratio between the incoming and outgoing forces of the gripping device. A high traction factor allows reducing the dimension of the gripping that is essential for structural application. The proposed concept's adequacy was verified experimentally by testing the anchorage system prototype with the polymeric grips manufactured using 3D printing technology. Computer-aided additive production principles fit the Industry 4.0 concept related to revolutionary technology development to the interaction between the manufacturing robots and humans and affect designers' creativeness. A finite element (FE) model, tailored using the test results, described the stresses inside the gripping device. However, the questions about alternative gripping systems' efficiency and the developed anchors' structural applicability were not answered. This study is dedicated to comparing three alternative gripping systems with different shape of the contact surface. A logarithmic curve determines the reference grips system (tested previously). Fermat and Archimedes's spirals define the alternative anchorage layouts with potentially higher traction coefficients than that of the reference one. The verified FE model [1] is adopted to analyse the stress distribution in the anchorage systems. Furthermore, this numerical approach explores the possibilities of developing a self-contracting system with a spiral angle exceeding 2. This problem was beyond the scope of study [1]. The numerical solution is extended to the analysis of full-scale anchorage joints of stress-ribbon bridge structures. [1] Gribniak, V., Arnautov, A. K., Rimkus, A. The Development of Nature-Inspired Gripping System of a Flat CFRP Strip for Stress-Ribbon Structural Layout. Journal of Computational Design and Engineering, DOI: 10.1093/jcde/qwab014.

The issue of use of mechanical fasteners in the assembly of CFRP composite elements

abst. 2157
Room 3
Friday
September 3
12h50

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The problem that is related to the use of CFRP composite materials in mechanical engineering (e.g. aircraft construction) is lower compared to structural metals, resistance to surface pressure, which results in the search for the most efficient ways of assembling components of composites. Composite elements are bonded adhesively (adhesive bonds), mechanically or using the above-mentioned technologies in hybrid (adhesive-mechanical) connections. Mechanical or hybrid connections are the recommended technologies for joining composite elements in aviation structures, due to the much greater diagnostic susceptibility of this type of connection, recognized methods of predicting their durability and the possibility of disassembling mechanical connectors. Based on the literature data, it is known that in the mechanical connections of both metal and composite materials, the friction phenomenon is also taken into account in the transfer of loads between connected elements. In metal elements subjected to cyclic loads, the values of frictional forces in the vicinity of the mounting holes increase, which is caused, among others, by wear of the mating surfaces of the joined elements and the number of wear products present. In composite mechanically joined elements (mechanical fasteners), the increase in frictional forces in the assembly nodes is directly dependent on the clamping forces of the mechanical fasteners. The study assumes that in the case of mechanical joining of composite materials, the frictional forces, which also participate in the load transfer, will have a positive effect on reducing the surface pressure between the connector and the composite, and thus the fatigue life of the joints will be higher. In the own research, a comparative analysis of the fatigue life of joints prepared on the basis of the CFRP composite material and three mechanical fasteners used in aircraft construction, i.e. 3560A aluminum rivets, Hi-lok HL 1012 series and Jo-Bolt fasteners was carried out. Each of these connectors is characterised by different clamping forces, with the mounting pressure being highest in the Jo-Bolt joints. In the endurance tests, the degradation of composite material around the mounting holes was seen using computed tomography technology with the use of a computer tomograph GE v/tome/x m. A positive effect of clamping forces on the fatigue life of composite materials in the vicinity of the mounting holes was found. FEM calculations confirmed the existence of lower surface pressures in the mounting holes as a result of higher mounting loads (higher clamping forces of mechanical connectors).

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abst. 2224
Room 3
Friday
September 3
13h10

Enhanced structural integrity of CFRP T-joints by embedding sacrificial cracks throughout the bondline

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Herein, a novel CFRP adhesive T-joint that mimics the structure of the bondline of two biological systems that have excellent adhesion, gecko and mytilus californianus, was designed. Sacrificial cracks were embedded inside the adhesive layers to activate new dissipative mechanisms and thus increase the effective toughness and strength of the joint. The presence of sacrificial cracks in the bondline leads to crack migration between the skin/adhesive and stiffener/adhesive interfaces, deformation of adhesive ligaments and growth of delamination between stiffener plies. These damage mechanisms lead to large improvement in the strength and toughness of the joint reaching 3 and 6 times compared to conventional T-joint, respectively. Keywords: Adhesive bonding; T-joint, structural integrity; damage mechanisms. Introduction: The preliminary failure of T-joint structures depends on the manufacturing process and design parameters, which define the stress concentration area, where damage initiates. There are four main possible failure mechanisms in T-joint structures with the most predominant being the debonding of the delta-fillet/stiffener interface. The other three mechanisms include the delamination of plies at the stiffener laminates, the debonding of the stiffener flange tips from the skin interface, or finally the vertical debonding at the delta-fillet/stiffener intersection. Furthermore, there are many other factors that can cause the cracks to initiate in T-joints such as manufacturing induced defects, inclusion of foreign objects, resin rich areas, waviness of the plies, voids, and matrix cracking because of thermal shrinkage. Once the delamination/debonding exceeds a certain limit, sudden failure of the T-joint structure will occur, which cause catastrophic failure of the structure [1-3]. Various toughening techniques were developed in CFRP T-joints to provide an improved interface bonding. Such techniques include modifying the geometry of the delta-fillet region or using bio-inspired designs to minimize the stress concentrations [4-6], increasing the resistance by using toughened resins [7], and employing through-the-thickness pinning or stitching [8-11]. Despite their efficiency to improve the global response of the T-joints, the improvement rate is relatively low compared to the complexity of implementing these techniques. Moreover, in some of these techniques, the in-plane stiffness and strength of the skin might be highly influenced, i.e, pinning and stitching. Additionally, the safety of the toughened T-joint using most of this technique is similar to the conventional joint, where catastrophic failure is not inhibited. Bioinspired designs can provide improved damage tolerance at the expense of earlier onset of damage initiation. Recent modern treatments such as CO2 and femtosecond laser have been employed to improve the bonding strength and toughness of T-joints [12,13]. However, the high cost and applicability for large scale composite still limit their applications in large scale structures. In this study, inspired by two excellent adhesion natural systems, gecko and mytilus californianus and based on our previous studies on the mode I and II toughness of bio-inspired adhesives, we present a bio-inspired adhesive bondline in the T-joint structure with improve toughness and structural integrity. We employed PTFE film at certain positions of the bondline to generate sacrificial cracks inside the adhesive layer that activate nonlocal damage mechanisms during loading and hence improves the toughness. Materials: We used unidirectional carbon/epoxy (T700/M21 Hexply, Hexcel) prepregs to manufacture the stiffeners and the skin. The hand lay-up process was used to stack eight plies of 0.25 mm thickness each in a [0/45/-45/90]s stacking sequence in a specially designed mould, resulting in a L-shape of 2 mm thickness. Sixteen plies of the same stacking sequence were moulded over a flat plate and cured resulting in a skin of 4 mm thickness. Compression moulding was used to cure the manufactured samples. Both the stiffeners and the skin were moulded over a peel ply surface to improve their interfacial properties during bonding. During bonding, a PTFE film was placed over the stiffeners after applying half of the adhesive amount (Araldite A/B) with predesigned width of the PTFE film and the gap between two successive films. Then, the second half of the adhesive was distributed over the skin and collected together to be cured at 60°C for 3 h. For comparison, we manufactured a batch of samples without sacrificial cracks (conventional T-joint). Pull-off test was employed to characterize the strength and stiffness of the manufactured samples. A high-resolution camera was used to capture the in-situ evolution of damage during tests. Results and discussion: We demonstrated experimentally that the presence of sacrificial cracks activated nonlocal damage mechanisms such as crack migration to other interface, adhesive ligament formation and propagation of delamination inside the stiffeners. These three damage mechanisms lead to large improvement in the toughness and strength. With the presence of the sacrificial cracks, when the crack initiated at skin/adhesive interface under the delta fillet region, it propagates until reaching the first sacrificial crack, at which stresses are redistributed resulting in delayed crack propagation. At the sacrificial cracks, the stresses increase at the edges of the crack resulting in crack migration to the stiffener/adhesive interface, which form an adhesive ligament between the skin and the stiffener [13]. The deformation of this ligament allow more dissipation of energy and increases the effective fracture toughness of the interface [14]. Once the energy release rate of the interface reaches the interlaminar fracture toughness between skin plies, delamination initiates at the corner of the stiffener. Thus, great improvement is achieved due to the activation of these damage mechanisms, which were not activated in the conventional T-joint. The strength and the toughness of the bio-inspired joint are improved by around 3 and 6 times compared to conventional T-joints. Conclusions: We used PTFE film to generate sacrificial cracks inside the T-joint adhesive layer to mimic the bondline of two excellent adhesion bio systems, gecko and mytilus californianus. We used pull-off test to characterize the manufactured T-joints. The results showed large enhancement in the structural integrity of the T-joints with embedded sacrificial cracks compared to conventional one. The improvement were due to the crack migration between skin/adhesive and stiffener/adhesive interfaces, the deformation of adhesive ligament and growth of delamination between stiffener plies at the corner. References: 1. Gulasik, H. and Coker, D., 2014. Delamination-Debond Behaviour of Composite T- Joints in Wind Turbine Blades. Journal of Physics: Conference Series, 524, p.012043. 2. Trask, R., Hallett, S., Helenon, F. and Wisnom, M., 2012. 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Wagih, A., Lubineau, G., 2021. Enhanced mode II fracture toughness of secondary bonded joints using tailored sacrificial cracks inside the adhesive. Composites Science and Technology 204, 108605 13. Wagih, A., Tao, R., Yudhanto, A. and Lubineau, G., 2020. Improving mode II fracture toughness of secondary bonded joints using laser patterning of adherends. Composites Part A: Applied Science and Manufacturing, 134, p.105892. 14. Wagih, A., Tao, R., and Lubineau, G., 2021. Bio-inspired adhesive joint with improved interlaminar fracture toughness. Under review. Composites Part A.

Keynote Lectures

Emerging numerical approaches for numerical design and optimization of composite structures

abst. 1001
Room 1
Wednesday
September 1
11h30

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The global carbon composites market was worth 23 billion USD in 2018, and studies indicate it might reach 30 billion USD by 2030, assuming increasing demand in aerospace, automotive and wind energy [1]. The UK's share of this market was worth 2.3 billion GBP in 2016, and is expected to be worth up to 12 billion GBP by 2030 if opportunities in various sectors are realized, with the greatest potential for additional value being in aerospace [2]. However, these opportunities may not be realized: the design and optimisation of large modern aircraft composite structures, such as the fuselage or wings of the Airbus A380 or the Boeing 787, are so challenging that they may even lead to equivalent structures in newer aircraft not being made out of composites. It is therefore fundamentally important for the intended growth of the composites sector that new paradigms in design and optimisation of large composite structures emerge. In academia and in industry, significant attention has been placed on the micro-mechanics of failure [3-5], on component design [6], or on multiscale analysis of large but mostly fixed structural configurations [7,8]. Developments in these areas are responsible for models that can potentially predict failure at lower scales while simulating large structures [8]. However, for large and complex structures, these models are expensive to create, require extensive user involvement, and are relatively rigid; they are therefore typically only created at the later stages of the design process for verification, but they do not tend to form part of the early design stages. Material microstructures, structural details, and the positioning of components are therefore typically not optimised for the final composite structure. In the context of an uncertain future for the use of composites in large aircraft structures, this lost opportunity is exceedingly meaningful. In this talk, we will detail emerging numerical methodologies that aim at creating flexible, evolving, multiscale numerical models, coupling mechanical and optimization problems and formulating them within a finite element framework. Firstly, we will show that it is possible to formulate a new type of elements – polymorphic elements [7]– that contain floating degrees of freedom (DOF) and exist as an evolving superposition of multiple states. The floating DOF allow the representation of intricate damage patterns [5], and each of the superposed states of the polymorphic element represents an idealisation of the underlying material with different resolutions using a mesh superposition technique [8] and verifying partition of unity. During the analysis, each element evolves the superposition of different states as required to represent the actual damage that the element experiences at each stage. For instance, with polymorphic elements, as a crack grows, the region near a crack tip can be represented with continuum elements while the regions ahead and in the wake of a crack progressively revert to a structural-element representation. Secondly, we will present a new methodology that enables adaptative positioning of components (lower-level finite element models) in a large structure (higher-level finite element model). By adaptative we mean a single finite element analysis in which the position of a component within the structure evolves on-the-fly during the analysis either as pre-specified by the user or as determined via an embedded optimization algorithm within the finite element code itself. The implication of this methodology is that the optimal positioning of components in large structures can be determined by running a single coupled mechanical-optimisation finite element model, rather than by generating multiple and expensive models and iterating between mechanical and optimization codes. As a result, this methodology does hold the potential to be used from the initial design stages and concomitantly to be used for structural design and optimization of large composite structures. We underpin the above methodology with the development of a new type of finite element – a floating connector element – and we illustrate its capabilities by applying it to optimising the positioning of a stiffener on a structure. By using a floating connector element, there is no need for regenerating the geometry, remeshing or modifying the stiffness matrix of the structural elements as the position of the stiffener (defined by the floating connector element) evolves during the coupled mechanical-optimisation study. The element is implemented as a user-defined element and can readily be integrated into any FE package. Thirdly, we will show how the level-set method can be combined with the use of floating degrees of freedom to perform topology optimization directly within a standard finite element code. [1] Carbon Composites, Industrievereinigung Verstärkte Kunstoffe. Composites Market Report 2018. [2] Composites Leadership Forum, Lightening the Load, The 2016 UK Composites Strategy, 2016. [3] AS Kaddour and MJ Hinton. Maturity of 3D failure criteria for fibre-reinforced composites: Comparison between theories and experiments: Part B of WWFE-II. Journal of Composite Materials 2013 47: 925. 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abst. 1002
Room 1
Thursday
September 2
17h30

Layerwise mixed models for thermo-mechanical analysis and multiobjective design optimization of multilayered plates: composite laminates and functionally graded plates

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The thermo-mechanical modelling and multiobjective design optimization of multilayered plates is addressed, considering composite laminates as well as metal-ceramic functionally graded (FG) plates, with one (or more) embedded functionally graded material (FGM) layer(s), under a series of thermal and/or mechanical loadings. Layerwise mixed models are considered based on least-squares formulation with multi-field independent variables, namely, displacements, temperature, transverse stresses, transverse heat flux, in-plane strains and in-plane components of the thermal gradient. This mixed formulation ensures that interlaminar C0 continuity requirements, where the material properties may actually change, are fully fulfilled a priori, allowing both thermal and mechanical problems to be properly solved simultaneously. As suitable for least-squares formulation, these layerwise mixed models use high-order C0 basis functions, both 2D in-plane and 1D through the layer thickness, chosen independently for distinct layers. An added feature is incorporated to fully describe the FGM layer z-continuous effective properties through-thickness, using any given homogenization method, via high-order z-expansions, similarly to finite element approximations. The multiobjective design optimization of FG plates is explored, in particular. The plate design variables include the thickness of the FGM layer, along with the index of its power-law distribution of metal-ceramic volume fractions, and if present, the thickness of the metal and/or ceramic faces. The multi-objectives focus on the plate mass, deformation and stress field, aiming to minimize all together. The multiobjective optimization problem is solved by Direct MultiSearch (DMS) method, which uses the notion of Pareto dominance to retain a list of feasible non-dominated solutions. Numerical results of thermo-mechanical analysis of composite laminates and FG plates show these layerwise mixed models can predict accurately a quasi-3D thermo-mechanical description of all multi-field variables, in addition to providing optimal designs of FG plates, under thermo-mechanical loadings.

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abst. 1014
Room 1
Thursday
September 2
09h00

A Semi-Discrete Model for Progressive Damage and Failure of Fiber Reinforced Laminates

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High-strength and high-stiffness carbon fiber-reinforced polymer composite laminates (CFRP) are being increasingly used for primary load bearing structures in many industries. The most common material system used is based on thermoset resins (matrix material), which come in the form of convenient prepreg tapes allowing high flexibility and productivity using advanced automated manufacturing technologies. Engineers must provide mechanics based models for the deformation response and failure of these materials and structures. The mechanisms responsible for progressive damage accumulation and failure are (intralaminar) matrix cracks, which can lead to delamination initiation and spreading

resulting in ultimate failure. Interlaminar fracture in CFRP, often called delamination, is defined as an out-of-plane discontinuity between two adjacent plies of a laminate. Delamination behavior has been studied by many researchers and now can be characterized in a standardized manner. Fracture properties of Mode I, Mode II, and mixed-mode (between Mode I and Mode II) delamination can be obtained from ASTM standard tests in conjunction with finite element analysis (FEA). In a CFRP structural component, the intralaminar and interlaminar modes of failure interact and developing a computational model to accurately replicate the failure mechanisms and their interaction has been challenging. In this presentation, a series of experimental results that delineate the different mechanisms of failure will be presented. Based on these results, associated mechanics models will be presented, resulting in a novel semi-discrete progressive damage and failure modeling framework that can be used for assessing the structural integrity and damage tolerance of CFRP aerospace structures.

Variable stiffness composites by means of additive manufacturing technology: multi-scale analysis, design and manufacturing

abst. 1020
Repository

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The recent development of additive manufacturing (AM) technologies for composite structures allows for going beyond the classical design rules, thus leading the designer to find innovative and more efficient solutions than the classical straight-fibre configurations. The use of the AM technology brought to the emergence of a new class of composite materials: the variable stiffness composites (VSCs). An AM machine allows the tow to be placed along a curvilinear path within the constitutive lamina, thus implying a point-wise variation of the material properties (stiffness, strength, etc.). Therefore, the trajectory of the tows can be properly conceived in order to optimise the properties of the resulting structure and can be adapted to the local distribution of stress and strains (within each ply). In previous works [1-4], the authors presented the new version of the multi-scale two-level optimisation strategy (MS2LOS) for the optimum design of VSCs. In the framework of the MS2LOS, the design problem of a VSC is split in two related sub-problems. The first-level problem (FLP) focuses on the macroscopic scale, where the VSC is described as an equivalent single layer (ESL) anisotropic plate, whose mechanical response is described by means of the polar parameters (PPs), which vary point-wise over the structure. The goal is, thus, to find the optimum distribution of the PPs over the structure satisfying the requirements of the problem at hand. Conversely, the second-level problem (SLP) focuses on the VSC mesoscopic scale and the aim is to retrieve the optimum stacking sequence as well as the optimum fibres-path in each layer satisfying the optimised PPs fields resulting from the FLP. The effectiveness of the MS2LOS has been proven through different benchmarks dealing with the maximisation of the first buckling factor [1, 2], the minimisation of the compliance [3] and the maximisation of the VSC strength [4]. Moreover, a suitable formulation of the AM process-related constraints (which intervene mostly at the composite mesoscopic scale, i.e. at the tow-level) has been developed in the PPs space, by taking advantage from the tensor invariant-based representation [2, 4]. The goal of this study is to present the recent developments about the formulation of both FLP and SLP and to discuss some interesting prospects about the formulation of the manufacturing requirements related to the AM process (like minimum steering radius, tows gap/overlap, tow width, etc.) as equivalent constraints at the macroscopic scale in the PPs by exploiting an analogy with topology optimisation problems [5-8] Moreover prospects on the simultaneous optimisation of the topology and the anisotropic fields describing the behaviour of the composite at the macroscopic scale will be also discussed. References [1] M. Montemurro and A. Catapano. Variational analysis and aerospace engineering: mathematical challenges for the aerospace of the future, volume 116 of Springer Optimization and Its Applications. Chapter: A new paradigm for the optimum design of variable angle tow laminates, pages 375-400. Springer International Publishing, 1 edition, 2016. DOI: 10.1007/978-3-319-45680-5. [2] M. Montemurro and A. Catapano. On the effective integration of manufacturability constraints within the multi-scale methodology for designing variable angle-tow laminates. Composite Structures, 161:145-159, 2017. [3] Montemurro, M., Catapano, A.: A general B-Spline surfaces theoretical framework for optimisation of variable angle-tow laminates. Compos. Struct. 2019; 209: 561–578. [4] Catapano, A., Montemurro, M., Balcou, J.A., Panettieri, E. Rapid Prototyping of Variable Angle-Tow Composites. Aerotecnica Missili Spazio, 2019;

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abst. 1026
Room 1
Friday
September 3
09h00

Nano-Scale Mechanical Systems: Recent Trends in Nano-Structural Mechanics

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Nano-scale materials and structures, such as carbon nanotubes, exhibit superior functional performance and are being currently considered as pioneering candidates for applications in modern technology to meet growing design requirements. The use of materials and structures with nanoscale dimensions, for instance, in nanoelectromechanical systems, requires an in-depth understanding of their mechanical response by taking into account size effects. Continuum mechanics-based approaches provide a feasible framework for studying nanostructures without the mathematical complexity usually involved in other methodologies, such as atomistic models. The idea is based on the replacement of the crystal material architecture by a continuous medium with homogenized material properties, which can capture the overall response of the nanomaterials and nanostructures. This requires new constitutive laws for reflecting nano-scale size effects in calculations. The strain-driven nonlocal theory of elasticity, originally proposed in the relevant works of Eringen, belongs to the continuum mechanics approaches and accounts for the size effects by assuming the stress at each point of a body defined as a convolution integral, in terms of stresses, and a smoothing kernel function, in terms of a dimensionless nonlocal parameter. However, for some boundary value problems in bounded domains, which is the case of practical applications in nanotechnology, the Eringen nonlocal theory may cause inconsistent solutions which may be in contrast with the equilibrium requirements. In order to overcome these inconsistencies, a stress-driven nonlocal elasticity theory has been proposed by switching the role of the stress and the strain in the integral or differential forms of the nonlocal constitutive equation of the Eringen theory. In other words, in the constitutive equation of the stress-driven theory, the strain in a point is the output of both the convolution integral and the smoothing kernel. In this work, the stress-driven nonlocal elasticity theory is applied to study statics, dynamics, and instability of nanobeams with consideration of size effects. Despite the Eringen theory of nonlocal elasticity, the new stress-driven model leads to well-posed boundary value problems in nanomechanics, because all boundary conditions are naturally and univocally provided by the theory. For the statics analysis, deflection and torsion of nanobeams are considered for different edge boundary conditions and the effect of the nonlocality on the bending and torsional stiffness is investigated. Unlike the gradient elasticity and Eringen theory, a hardening structural response is exhibited by the stress-driven approach for increasing values of the nonlocal parameter. In order to study the influence of small-scale size effects on the dynamic response of nanobeams, free vibration problem is considered. Spatial and harmonic equations of motion of a Bernoulli-Euler nanobeam are decoupled and solved in closed form and fundamental natural frequencies of cantilever, simply supported, clamped-pinned and doubly-clamped nanobeams are numerically computed. The results are compared with those obtained by the Eringen differential law and by the gradient elasticity theory: the stress-driven nonlocal theory provides, for all considered kinematic boundary conditions, the highest frequencies. Finally, size-dependent stability analysis is performed by considering the buckling problem of a nanobeam placed on a two-parameter (Pasternak) elastic foundation. The analysis shows that the buckling load increases by increasing the nonlocal parameter and stiffness of the foundation. The buckling loads related to the clamped-free and clamped-clamped nanobeams are, respectively, the most and less influenced by the properties of the elastic foundation.

Mixed-mode buckling of shear-deformable composite laminated beams with arbitrary cross-sections and non-orthotropic layups

abst. 2005
Room 1
Wednesday
September 1
17h30

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Mittelstedt, Christian (christian.mittelstedt@klub.tu-darmstadt.de), Technical University Darmstadt, Institute of Lightweight Construction and Design, Dept. Mechanical Engineering, Germany

This paper presents a semi-analytical approach for the local mixed-mode buckling behavior of composite laminated beams. Transverse shear deformations of the individual beam segments (i.e. flanges and webs) are taken into account explicitly by using a higher-order laminate theory, namely Reddy's Third-Order Shear Deformation Theory (TSDT). The analysis method employs separate buckling shape functions for each individual beam segment and combines those into overall buckling shapes considering the interaction of the individual buckling modes (thus explaining the term "mixed-mode buckling"). The local buckling loads are determined from the principle of minimum elastic potential of the beam in the locally buckled state which eventually leads to an eigenvalue problem that is solved numerically. The analysis method is compared to finite element computations and is shown to be much more efficient in terms of computational efficiency while delivering results of comparable accuracy.

Micromechanics

abst. 2086
Room 1
Friday
September 3
16h50

Convergence of Homogenized Moduli of Random Fiber Composites Under Homogeneous Boundary Conditions and Local Stress Field Statistics

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We incorporate homogeneous traction and displacement boundary conditions into a recently proposed hybrid homogenization theory for unidirectional composites with random fiber distributions [1] to investigate the convergence of homogenized moduli as a function of representative volume element size and local stress field statistics. The hybrid approach combines elements of finite-volume and locally-exact elasticity approaches in the solution for the fiber and matrix displacement and stress fields within multi-inclusion representative volume domains that is extremely efficient and accurate [2,5], producing four-fold and greater reductions in execution times relative to the finite-volume micromechanics. Inclusion displacement fields are represented by discrete Fourier transforms that satisfy exactly Navier's equations. In contrast, the matrix displacement field is handled within the finite-volume framework. Novel use of traction and displacement continuity conditions at the inclusion/matrix interfaces seamlessly connect inclusion and matrix phases. Continuity of tractions and displacements within the representative volume domain's interior, and implementation of homogeneous traction and displacement boundary conditions, is enforced in a surface-average sense. Using the extended approach, we investigate the convergence rates of homogenized moduli and the corresponding stress field statistics of representative domains with random fiber distributions under homogeneous boundary conditions relative to periodic boundary conditions as well as relative to the reported convergence rates of representative volume elements with regularly spaced fibers. Keywords: heterogeneous materials, homogenization, elasticity and finite-volume methods [1] Yin, S., He, Z., and Pindera, M-J., A new hybrid homogenization theory for periodic composites with random fiber distributions (submitted). [2] Drago, A. S. and Pindera, M-J., 2008. A locally-exact homogenization theory for periodic microstructures with isotropic phases. J. Appl. Mech., 75(5), 051010-14. [3] Wang, G. and Pindera, M-J., 2016. Locally-exact homogenization theory for transversely isotropic unidirectional composites. Mech. Res. Comm. 78, 2-14. [4] Gattu, M., Khatam, H., Drago, A.S., Pindera, M-J., 2008. Parametric finite-volume micromechanics of uniaxial, continuously-reinforced periodic materials with elastic phases. J. Eng. Mater. Technol., 130(3), 031015-15. [5] Khatam, H., Pindera, M-J., 2009. Parametric finite-volume micromechanics of periodic materials with elastoplastic phases. Int. J. Plasticity, 25(7), 1386-1411.

Modeling in Mechanics and Materials

Data-driven intelligent optimisation of aligned discontinuous composites

abst. 1011
Room 1
Thursday
September 2
10h40

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The mechanical response of aligned discontinuous composites (ADCs) can be tailored through careful microstructural design. For example, ADCs with long fibres that are well-aligned with the loading direction produce a very strong and stiff response, while shorter fibres (or hybrid fibre-types) enable higher ductility. However, this added tailorability leads to increased design complexity; this complexity makes it difficult to optimise the mechanical response of ADCs, as the possible permutations of microstructural parameters becomes prohibitively large. A virtual testing framework (VTF) has been developed, which accurately predicts the mechanical performance of full-size ADC specimens (with over 500,000 fibres); the framework is accurately validated against experiments, and generates results hundreds of times faster than finite element analysis. This efficient VTF is combined with an intelligent Bayesian optimisation routine, which uses machine learning techniques to create a surrogate model of the VTF, and therefore optimise the mechanical performance of ADCs with the minimum the number of VTF evaluations. Single-objective Bayesian optimisation of individual mechanical properties showcases the high tailorability of ADCs, with a maximum initial stiffness of 505 GPa, maximum ultimate strength of 1920 MPa, or a maximum ultimate strain of 4 % all possible with commercially available fibres and matrices. Multi-objective Bayesian optimisation yields Pareto fronts with optimal trade-offs between competing properties (e.g. strength vs. ductility); these Pareto fronts can be used to identify optimal composite microstructures combining high values of those competing properties, e.g. an ultimate strength & failure strain combination of 982 MPa and 3.27%, or a combination of 720 MPa yield strength & 1.91% pseudo-ductile strain. The mechanical performance of ADCs is extremely variable, and therefore the surrogate model from the Bayesian optimisation is used to create an estimated Pareto front, which is found to be a more accurate representation of the expected performance of optimal ADC designs. The surrogate model is also used to perform sensitivity analyses, in order to test the robustness of the optimal designs without further evaluations of the VTF.

An improved mean-field homogenisation scheme based on CZMs to describe particles/fibres debonding

abst. 1019
Repository

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A new semi-analytical homogenisation model based on a Mori-Tanaka homogenisation scheme, containing inclusions with imperfect interfaces, is proposed in this study. To describe the progressive debonding of the reinforcements, the compliance of the inclusion interfaces evolves according to a bilinear traction-separation law, similar to that of a bilinear Cohesive Zone Model taking into account normal and tangential effects. The model is applicable to any type of inclusion geometry as long as its modified Eshelby tensor can be determined. This improved version of the homogenisation model leads to better predictions (with respect to models presented in literature) of the influence of the imperfect interface behaviour on the resulting homogenised composite. Results obtained with this new mean-field homogenisation scheme are compared to FE-based numerical simulations in order to show the effectiveness of the proposed model. The effects of inclusions volume fraction and size are also observed. In particular, the volume fraction of particles stiffens the composite during the elastic loading but a higher load drop is observed as the particles start to debond. On the other hand, an important size effect is visible when debonding occurs for large particles (large particles debond prior to smaller

ones in accordance with the results of the literature). Finally, the proposed model can also be applied to composites materials containing inclusions of multiple sizes by considering the inclusions of different sizes as different phases.

DESIGN AND OPTIMIZATION OF 3D-PRINTED-HONEYCOMB SANDWICH COMPOSITE STRUCTURES FOR IMPACT ENERGY ABSORPTION APPLICATIONS

abst. 2097
Room 2
Friday
September 3
17h10

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Sandwich composite structures with 3D-printed honeycomb cores are currently receiving increasing attention as an efficient and cost-effective alternative to conventional foamed and regular hexagonal honeycomb sandwich structures for impact energy absorption applications. In addition to their load carrying capability, sandwich structures with 3D-printed honeycombs can perform multiple functions simultaneously improving their operational efficiency. Recent studies have shown that thin-walled thermoplastic honeycombs exhibit remarkable energy absorption capabilities to in-plane low velocity impact loading conditions (i.e., in the direction perpendicular to the cell axis). The impact energy absorption mechanism of these structures is initially dominated by linear elastic bending deformation of the cell walls, followed by plastic buckling and ultimate crushing. This is characterized by the cell geometric parameters including cell wall thickness, length, internal angle, and by the core height and skin thickness. The material properties of both the 3D-printed honeycomb and the skin also affect the structural response of sandwich composites to impact loading. By using current 3D-printing technologies, innovative sandwich composite structural designs with optimized geometry can now be produced more efficiently than with conventional manufacturing methods. The present study introduces new sandwich composite designs with optimized geometric configurations for low-velocity impact applications. Explicit nonlinear finite element models are developed to determine the relationship between design variables and energy absorption (i.e., scaling laws). 3D-printed specimens are manufactured with ABS thermoplastic and tested in quasi-static compression to characterize the material behavior. In this study three cell geometries are considered, hexagonal, auxetic, and truss. For each cell geometry, five design variables are selected, cell wall thickness, long versus short wall length ratio, internal angle, core height and skin thickness. Multi-objective optimization algorithms (e.g., genetic evolutionary algorithms and Pareto optimal front) are used to find the optimal design solution that simultaneously maximizes energy absorption and minimizes weight, while satisfying a specific stiffness constraint. Impact energy absorption performance of optimized 3D-printed sandwich composite designs is compared against those with foamed and regular hexagonal honeycombs.

FE implementation of Sublaminate Generalised Unified Formulation models for sandwich plates

abst. 2135
Room 2
Friday
September 3
16h50

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The paper presents the FE implementation of a Unified Formulation approach dedicated to sandwich structures. By referring to a Sublaminate approach, different axiomatic models can be adopted for the thin and stiff skins and for the thick and compliant cores. This allows to reduce the computational cost without loss of accuracy. Classical displacement-based models as well as advanced mixed models formulated in the framework of Reissner's Mixed Variational Theorem (RMVT) are proposed. Four- and eight-nodes quadrilateral plate elements are implemented, in which the transverse shear locking problem affecting isoparametric FEs is eliminated by the use of a modified field-consistent interpolation for the transverse shear strain. As a result, robust and versatile plate elements are available that allow to

optimise the computational cost depending on the desired accuracy for the global and/or local response of sandwich panels. The main features of the proposed implementation are displayed by means of linear static bending analyses carried out on several benchmark problems.

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abst. 2143
Repository

Computer-aided Design for Fiber-Metal-Laminates

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Hybrid materials such as fiber-metal laminates (FML) can lead to significant weight reduction through load-adapted material properties. However, the simultaneous forming of the two solitary materials turns out to be challenging and is usually not considered in the structural design. The HyOpt research project is therefore investigating an optimization-based holistic approach to the design of FMLs. The aim is to develop a CAE method for the design of tailored hybrid materials using numerical optimization algorithms. Starting with the final geometry and given boundary conditions, an optimal material distribution for the FML can first be determined from the structural simulation. However, the formability of this FML is unknown, therefore the formability of the FML is considered in a subsequent routine. By selecting material proportions, thicknesses and orientation angles, optima can be achieved in terms of lightweight, mechanical properties and forming characteristics. All subroutines are merged in an individual software solution - the HyOpt App.

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abst. 2166
Repository

Numerical modelling of damage effect in composite sandwich structures

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Because of their excellent specific properties, composite structures are very important in the design of components that are subjected to different types of loads during its service life. Specifically, in the wind energy sector, composite structures are used to manufacture wind turbines, and one of the challenges ahead is to manufacture larger structures capable of generating more energy. The largest parts of the blades are usually manufactured with sandwich structures or composite laminates, due to their high specific strength and stiffness. As structural components, wind turbine blades are susceptible to be damaged during their service life, and the possibility to present damage increases with their increasing size. Damage at wind turbine blades can occur at any stage of its life cycle, including operation. In this case, damage can be occasioned by external elements such as bird strike, debris carried by the wind, hail rain, etc. These events are represented by high-velocity impacts. However, in any of these events the impact phenomenon is not only produced by a single impact, but by multiple impacts that can be applied simultaneously or sequentially. In high-velocity impacts, the impact energy of the projectile is dissipated through several energy absorption mechanisms, such as: elastic deformation of the laminate, frictional energy absorbed during penetration, inertia of the laminate or back-face deformation, damage generation, etc. Typically, damage mechanisms in composite laminates include delamination, matrix cracking and fibre failure. Additionally, in composite sandwich structures these mechanisms are combined with the debonding between the face-sheet and core. In the case of multi-site impact scenario, stress waves interact with one another or with adjacent damaged areas, causing interference and changes in damage mechanisms resulting in a change in the extent of damage and energy absorption when compared to a single projectile impact. This phenomenon can cause the total failure of the wind turbine blade; consequently, it is necessary to develop reliable methods that allow the detection and prediction of damage. Therefore, the objective of this work is to use a 3D finite-element model, implemented in Abaqus /Explicit commercial code, to investigate the effect of damage on the structural behaviour of composite sandwich structures and in composite laminates (equivalent to both sandwich face-sheets in thickness), and how the overall results can be applied in damage detection applications.

Modelling and simulation of shape memory polymer-based composite structures for morphing application

abst. 2301
Repository

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Shape memory polymer composites have better strength and stiffness compared to pure shape memory polymers without significantly compromising their shape memory properties. Hence, they can be considered as candidate materials for morphing applications in aerospace structures. In this study, a finite element-based numerical framework is developed to analyze the shape memory behavior of shape memory polymer composite (SMPC) structures. This is based on the modified temperature-dependent laminate theory, which is used to predict the thermally induced shape memory response and effective elastic properties of the composite. The model was used to simulate the thermo-mechanical response of various SMPC sandwich structures under different thermal and mechanical loading conditions. The findings reveal that the physical parameters of sandwich structure influence shape storage and shape recovery of the system. The shape recovery is high compared to many pure SMPs due to the presence of elastic elements in the system. Finally, the application of this model is used to simulate and investigate the deformation characteristics of an SMPC morphing wing structure.

abst. 2133
Room 3
Wednesday
September 1
14h30

Modulating the extension-bending-twisting coupling in composite laminate using carbon nanotube grafted laminas

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A computational analysis is performed to explore the use of carbon nanotube (CNT) grafted laminas in tailoring the extension-bending-twisting coupling in structural composites. A 16 ply hygrothermally stable configuration is considered as the base laminate. The effect of CNT grafting is introduced by replacing the elastic constants of base laminas with the CNT grafted laminas. A comparative analysis of coupling behavior in base and modified laminate is carried out using classical laminate plate theory (CLPT) and 3D finite element analysis (FEA) using Abaqus. Five design strategies are adopted to quantify the incorporation of CNT grafted laminas on the coupling coefficients of base laminate. CLPT analysis shows that the coupling coefficients depend on the location, number and the distribution of CNT grafted laminas in the base laminate. To aid the CLPT analysis, 3D FEA simulations are carried out to capture the nonlinear effects. The deformation of a cantilever composite beam made of base and modified laminas is compared under tensile, bending and combined axial-bending loading. FEA simulations reveal that the coupled extension-bending-twisting behavior of base laminate can be extremized through the addition of CNT grafted laminas. It is envisaged that the findings of this study will be a significant step ahead in designing composite rotor and wind turbine blades having desirable tip movement without the addition of any extra weight or complexity due to piezo actuators etc.

Morphing of composites

Flexible joints based on corrugated composite laminates: numerical development and manufacturing

abst. 2026
Room 3
Friday
September 3
09h40

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Composite corrugated laminates have been proposed in the last years for many applications in the field of variable shape and adaptive structures. Indeed, the peculiar orthotropic properties of corrugated profiles make possible the development of structural concepts with large deformation capability in the elastic range in selected directions and significant stiffness and strength in other directions [1-3]. In this work, the properties of corrugated composite laminates are exploited to develop an innovative flexible joint concept based on the integration of corrugated composite tubes into a metallic frame. The composite corrugated elements carry torsional loads and sustain a system of relatively thin metallic stiffeners, which transmit axial loads through the flexible joint. The differentiation of load paths and the interaction between composite and metallic parts leads to high bending compliance, high torsional stiffness and remarkable load carrying capability in the axial direction. A series of preliminary numerical studies is reported to show that the structure proposed can be designed to achieve significant bending deflections in the elastic range, still carrying high compressive and torsional loads. The main design parameters are outlined, including the shape of the corrugated profile, the lay-up of the composite laminates and the design of the frame carrying the axial loads. Moreover, the manufacturing issues related to lamination and assembly processes are outlined. Thereafter, a specific application case is taken into consideration, related to a heavy duty transmission joint that must allow relative rotation between the connected elements while transmitting a torque in operational conditions. Moreover, the joint must not collapse under the action of the severe axial loads that arise in a given crash condition. The linear and non-linear models that led to the identification of a solution fulfilling the conflicting requirements of the application case are presented. Results are discussed pointing out the roles of the different parts and the fundamental role played by adhesive junctions, which were completely represented in the detailed models developed. The structural response in crash conditions are assessed through explicit finite element simulations. Finally, the manufacturing process of the joint is presented. The extensive use of elastomeric tools to accomplish composite lamination on double-curvature surfaces is documented. The tests performed on the element confirm that produced prototype met the requirement related to the bending stiffness, deflection capability in elastic range and compressive strength in operational conditions. References [1] Airoldi, A., Sala, G., Di Landro, L., Bettini, P., Gilardelli, A. (2018). Composite Corrugated Laminates for Morphing Applications. In: (a cura di): A. Concilio et al., Morphing Wing Technologies - Large Commercial Aircraft and Civil Helicopters. p. 247-276, Cambridge, MA:Butterworth-Heinemann, [2] Airoldi, D. Rigamonti, G. Sala, P. Bettini, E. Villa, A. Nespoli (2021). Development of an actuated corrugated laminate for morphing structures. The Aeronautical Journal, vol. 125, p. 180-204 [3] Thill, C, Etches, J.A., Bond, I.P., Potter, K.D., and Weaver, P.M. (2010) Composite corrugated structures for morphing wing skin applications, Smart Mater. Struct., vol., 19

Development of intrinsically heated, interleaved composites with controllable flexural stiffness and shape memory capability

abst. 2039
Room 1
Thursday
September 2
17h10

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Carbon fibre reinforced epoxy polymer (CFRP) composites interleaved with Polystyrene (PS) have been shown to exhibit controllable flexural stiffness properties [1]–[3]. A significant reversible reduction in flexural stiffness is produced when the composite is heated above the glass transition temperature of PS. At this temperature, the composite can be readily deformed and if cooled in this deformed state, it will retain the new shape. These composites also display shape memory behaviour; if the composite is reheated in its new shape, it will return to its original cured shape [4]. In the previous studies investigating the controllable flexural stiffness and shape memory characteristics, the interleaved composite specimens were heated in an oven. In the current work, we have explored the use of an embedded SS304 stainless-steel (SS) mesh (plain weave, wire diameter: 0.028 mm, aperture: 0.082 mm) procured from The Mesh Company (UK) as a heating element within the interleaved composite (Hexcel Fibredux 914/TS/6K/5/34% 0^0 CFRP plies interleaved with 0.07 mm Empera 124N PS sheets). The composites were laid up in $[0^0/PS]7/\ 0^0$ sequence with (1) Layup A having no embedded SS mesh, (2) Layup B having 1 SS mesh and (3) Layup C having 3 SS meshes. For Layup B the SS mesh was embedded in the central PS interleaf (i.e. interleaf layer 4 when counting from the top). For Layup C the SS meshes were incorporated in interleaf layers 2, 4 and 6. For layups with embedded SS meshes, the meshes were attached to a DC power supply to allow Joule heating of the composites. A DC power input of 30 W was chosen as the power input for Joule heating necessary to reach a surface temperature of around 120°C for controllable stiffness and shape memory studies (120°C is the temperature used in previous works [1]–[4]). In layup A (which was heated in an oven) and in layups B and C (subjected to Joule heating), the temporary loss in flexural stiffness (measured by ASTM D7264-07 standard) due to heating was over 98.5%. Furthermore, the shape memory capability of these composites was also investigated. Flat coupons of these composite layups were heated (as described previously), bent to a 90° angle in a 3-point bend test setup and then cooled down in the deformed state. The 90° shape was retained by the composite and when these coupons were again subjected to heating (using an oven for layup A and Joule heating for layups B and C) the original flat shape was fully recovered. For layups B and C, the shape recovery was completed in approximately 1 minute after switching on the Joule heating. The recovery time for Layup A was around five minutes. Optical microscopy was performed to investigate any change in the internal structure of the composites after the shape memory trials. References: [1] H. A. Maples, S. Wakefield, P. Robinson, and A. Bismarck, "High performance carbon fibre reinforced epoxy composites with controllable stiffness," Compos. Sci. Technol., vol. 105, pp. 134–143, 2014. [2] H. Maples, "Composites with Controllable Stiffness," Imperial College London, 2014. [3] H. A. Maples, O. Smith, C. Burgstaller, P. Robinson, and A. Bismarck, "Improving the ply/interleaf interface in carbon fibre reinforced composites with variable stiffness," Compos. Sci. Technol., vol. 128, pp. 185–192, May 2016. [4] P. Robinson, A. Bismarck, B. Zhang, and H. A. Maples, "Deployable, shape memory carbon fibre composites without shape memory constituents," Compos. Sci. Technol., vol. 145, pp. 96–104, Jun. 2017. Acknowledgement: The research leading to these results has been performed within the framework of the HyFiSyn project and has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 765881.

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abst. 2185
Room 3
Friday
September 3
10h00

Experimental and numerical evaluation of a multi-degree of freedom biomimicking fish locomotion with micro fibre composite actuation for a flexible robot

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Biomimicking, aquatic robotic propulsion systems are mostly based on conventional electric machines combined with mechatronical systems, such as gearboxes, rods and articulations. These systems require complex transmission systems and are heavy, compared to other approaches. A robotic swimming performance is commonly expressed by swimming velocity in relation to the body length. Conventional systems reach highest performances but fail in the relation of swimming velocity to weight. This leads to either an extended volume of the devices, or the necessity of additional floaters that allow for a stable positioning in the water. Aim of the concept at hand is to build a surrogate replacement for live fish tests in the assessment of the injury risks for fish passage in hydropower stations. To this purpose a propelled sensor device has to be designed, that will continually measuring pressure and accelerations, the two main sources for injury while passing the turbines. Due to the particular application, size and design characteristics are predefined by the requirements on the similarity to the real fish. Therefore a fish motion mimicking, low weight, flexible, neutrally buoyant and low complex system has to be designed. The device proposed is actuated by micro fibre composites (MFC) build in a bimorph assembly, joining four MFC area actuators with a carbon fibre composite. The actuators are powered in two independent groups as flexor-extensor structures with a tension in range of -500 to 1500 V. The setup allows for a five degrees-of-freedom motion by structural morphing, with independent actuation of two amplitudes, two frequencies and a phase angle shift in between the two groups. Furthermore it features lowest weight-to-performance ratios, the key parameter for this robot. This allows for a small but performant neutrally buoyant device. The 3D printed head of the device is combined with the bimorph actuated skeleton, featuring a clamped beam setup, comprising actuated and rigid passive zones, as well as a deformable tail fin. The fish-alike shape is given by moulded silicone filets with embedded air chambers to obtain a low average density. Finite-Element-Analysis (FEA) and analytical modelling of the morphing characteristics lead to a digital twin of the robot, which allows for the determination of the complex biomimicking morphing by use of sparse information from three pointwise strain gauge measurements. To this purpose, in a first step, the unassembled device without silicone embodiment was measured by displacement sensors and optical measurements for nine points for each of a total of fifty motion laws of the actuated structure. In parallel, the bimorph skeleton with piezoelectric MFC actuators is modelled by the Ansys structural software package, using specialized Piezoelectric an MEMS extension. With the extension, the dielectric matrix and the permittivity matrix for the piezoelectric material of the MFC can be entered in the FE-model. The mechanical deformation i calculated directly from the voltage. For the transient analysis of the movement of the bimorph skeleton, a special script is used to calculate the amplitude, frequency and phase angle of the electrical voltage. The optical measurements provide data for a validation of the results achieved and show high accuracy of the models developed. The deviations of the FEA for the isolated skeleton without embodiment with experimental results was in the bandwidth of the uncertainty of the measurements, with an RMS of 0.07 mm and maximum of 0.12 mm. This will allow for a subsequent optimisation of the propulsion system and investigation of the fluid-structure interactions on the flexible robotic device.

Multi-scale Modeling of Graphene- and Carbon Nanotube-Reinforced Composites

abst. 2002
Repository

Graphene Nanoplatelet (GNPL) Reinforced Cylindrical Shell

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Reinforcements have been produced to create a mixture with novel properties respect to constituent materials. The reinforced structures are used because of their novel properties such as high stiffness and low density. New reinforcement and new methods of composition of these materials leads to excellent properties of structures made of them. The nano reinforcements such as carbon nanotubes (CNTs) and graphene nanoplatelets (GPLs) are new proposed reinforcements applicable in various conditions. The types of composition of these nano reinforcements with matrix leads to various properties and propose different offers for designers. The Introduction section is provided to present a comprehensive literature review on the structures reinforced with GPLs and application of them in various forms. In addition, the general literature review on the graded materials, nano reinforced structures and cylindrical shell is presented. Some experimental works have been reported that shows addition of low amount of nano reinforcements such as carbon nanotubes and graphene nanoplatelets leads to significant improvement of material properties. The results of some important works on the application of nano reinforcements such as carbon nanotubes and graphene nanoplatelets are summarized here before general review of the subject of paper. Rafiee et al. [1] concluded that the Young's modulus of the epoxy matrix was increased 31%, with the addition of 0.1% of graphene platelet reinforcement. Based on another experimental investigation performed by Liang et al. [2], the introduction of 0.7% of weight fraction of graphene platelet reinforcement in the matrix was demonstrated to increase of the tensile strength by 76%, and the Young's modulus by 62%. Graphene is one of the well-known and applied nano-fillers in the field of nano-composites. This material is another form of carbon atom that is produced in single or multi-layered honeycomb structures. The Young's modulus is 1 TPa, fracture strength is 130 GPa, electrical and thermal conductivity similar to copper, and density about one quarter of copper are the primary properties of graphene nano-platelets [3]. There are several micromechanics models for the prediction of the elastic properties of nanocomposite materials, based on the geometry, orientation of the filler, and elastic properties of the filler and matrix, such as the Halpin–Tsai model, Nielsen model, Mori–Tanaka model, and Eshelby model, etc [4-5]. The calculation of the properties of nanocomposites including GNP nanoparticles is usually provided by the Halpin-Tsai model. This model was first used for other particles and short fibers of its type and then developed for nanoplatelets. The accuracy of the Halpin-Tsai model for randomly oriented GNP particles is tested and consistent with the experiments. In another experimental work, it was concluded that addition of 6% of nanoplatelets to epoxy matrix leads to increase 24% of reinforced composite structures [6]. Apart from the random orientations of the particles within the nanocomposite, it is possible to orient the nanoplatelets. Some useful works on the application of graphene nanoplatelets and methods of preparation were performed by various researchers [7, 8, 9]. Analysis of graphene nanoplatelets (GNPs) reinforced cylindrical shell subjected to thermo-mechanical loads are studied in this study based on shear deformation theory. Halpin-Tsai model is used via rule of mixtures with different distributions of reinforcements including uniform symmetric and asymmetric distributions for nanoplatelet material. The shear strains specially at both ends of cylindrical shell are included in our formulation using the two-dimensional first-order shear deformation theory. Minimum total potential energy principle is used to derive the governing equations using Hooke's law and application of Euler equations on the functional of the system. Eigenvalue and eigenvector method is used for solution of the governing equations. The radial and axial displacements and various components of stress are calculated with number of layers, GNP weight fraction, thermal loading, various distributions of reinforecment and coefficient of the elastic foundation. The numerical results indicates that maximum and minimum stresses are obtained for FG-O and FG-X distributions. Also, the biggest and lowest radial displacements are obtained for UD and FG-X distributions, respectively. References [1] Rafiee MA, Rafiee J, Wang Z, Song H, Yu Z-Z, Koratkar N. Enhanced Mechanical Properties of nanocomposites at low graphene content. ACS Nano 2009; 3(12): 3884-3890. [2] Liang J, Wang Y, Huang Y, Ma Y, Liu Z, Cai J. Electromagnetic interference shielding of graphene/epoxy composites.

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Resonance in dangerous mode of a rotating pre-twisted graphene reinforced composite blade with variable thickness

abst. 2147
Repository

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A rotating pre-twisted variable thickness panel reinforced with graphene is developed to investigate the resonance of the rotating blade in dangerous mode. The effects of variable thickness, pre-twisted angle and rotating speed are considered during the modeling process, which will increase the complexity of the system. According to the strain-displacement relationships obtained by Green strain tensor and first-order shear deformation theory, natural frequencies and the corresponding mode shapes are acquired by Rayleigh-Ritz method. Lagrange's equation is utilized to formulate the nonlinear ordinary differential equations. Numerical simulations are carried out to demonstrate the complex nonlinear dynamic behaviors of the rotating blade. Moreover, Campbell diagram is depicted to determine the dangerous rotating speeds and the corresponding dangerous modes. Based on the dangerous mode, the method of multiple scales is used to derive the modulation equations. Numerical simulations are performed to reveal the vibration characteristics of the rotating blade.

REVIEWS ON EXPERIMENTAL AND THEORETICAL APPROACHES TO CHARACTERIZE THE ELASTIC BEHAVIOR OF CARBON NANOTUBE-REINFORCED POLYMERIC NANOCOMPOSITES

abst. 2310
Room 3
Friday
September 3
14h30

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ABSTRACT In recent years, many studies have focused on the incorporation of nanoscale filler materials in the polymer matrix for the development of highly functional and advanced composite materials [1]. In an attempt to improve the mechanical properties of polymeric composites, various types of nanoscale filler materials were reinforced in the polymer matrix [1]. Carbon nanotube (CNT) can be nominated as a potential candidate for fiber-reinforced polymeric nanocomposites, owing to their low

density and outstanding mechanical properties [2]. However, accurate prediction of the elastic behavior of the CNT-reinforced polymeric nanocomposites is difficult because of the effect of the inherent properties of CNT on the nanocomposites (e.g., the interfacial characteristics and the aggregation of CNT). Many of the relevant studies have investigated the effect of CNT reinforcing on the enhanced mechanical properties of the nanocomposites [3], while fewer efforts were given to investigating the elastic behavior of CNT-reinforced polymeric nanocomposites. In this regard, this paper revisits the previous studies of CNT-reinforced polymeric nanocomposites and provides reviews on the experimental and theoretical approaches to characterize the elastic behavior of the nanocomposites. In addition, a preliminary study conducted by the authors to investigate the elastic behavior of CNT-reinforced epoxy nanocomposites is briefly introduced [4]. ACKNOWLEDGEMENT This research was supported by a grant from the National Research Foundation of Korea (NRF) funded by the Korean government (Ministry of Science, ICT Future Planning) (NRF- 2021R1A2C3006382). REFERENCES [1] Cha, J., Jun, G. H., Park, J. K., Kim, J. C., Ryu, H. J., Hong, S. H. Improvement of modulus, strength and fracture toughness of CNT/Epoxy nanocomposites through the functionalization of carbon nanotubes. Compos Part B Eng. 2017;129:169-179. [2] Treacy MMJ, Ebbesen TW, Gibson JM. Exceptionally high Young's modulus observed for individual carbon nanotubes. Nature 1996;381:678–80. [3] Yang, S., Yu, S., Ryu, J., Cho, J. M., Kyoung, W., Han, D. S., Cho, M. Nonlinear multiscale modeling approach to characterize elastoplastic behavior of CNT/polymer nanocomposites considering the interphase and interfacial imperfection. Int J Plast 2013; 41:124-146. [4] Kil, T., Bae, J.H., Yang, B. Lee, H. K. A multiscale modeling approach to characterize elastic-damage behavior of carbon nanotube/carbon fiber-reinforced polymeric composites. 2021;in preparation

Efficient off-line database construction technology for data-driven computational mechanics

abst. 2290
Room 3
Friday
September 3
10h20

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This paper aims to propose an efficient off-line database construction technology for data-driven computational mechanics. In data-driven computational mechanics, the stress-strain database is used to replace the constitutive equation in classical computational mechanics to eliminate the uncertainty and empiricism introduced by the fitting of constitutive model. In this method, the stress-strain database is directly used to drive mechanical calculation, and the closest point to the coordination equation and equilibrium equation in the stress-strain database will be found. Data-driven computational mechanics needs a large database to ensure the accuracy of the results. In experiments, it is very difficult to measure stress and strain in large deformation, which usually requires high-end instruments. Moreover, human operation errors and the accuracy of the instruments will introduce noise. Using numerical simulation to build database is very expensive and the time required will increase dramatically with the size of the database. The proposed technology consists of three steps: (1) sample database acquisition, (2) database expansion based on neural network, and (3) data-driven to solve the mechanical problem. The main idea is to use neural network to expand the database, which can construct the large-scale database efficiently and accurately. Three numerical examples are considered to verify the efficiency and accuracy of the proposed technology. The reference solution is calculated by the multi-scale finite element method. Firstly, a set of strains is applied to the representative volume element, and the stress associated to each applied strain can be calculated by off-line multi-scale finite element calculation. The sample database containing the stress and strain is collected. Then, the sample database is used to train the neural network model, which is used to predict the stress associated to the given strain to expand the database. Finally, the expanded database is used for data-driven to solve the macroscopic mechanical problems. Compared with the off-line multi-scale finite element method, the proposed technology not only ensures the accuracy of data-driven results, but also significantly improves the efficiency of database construction. In addition, noise is added to the sample database to discuss the noise resistance of the technology. This work provides a reliable and efficient technology to construct the large-scale database and improves the efficiency of data-driven computational mechanics.

abst. 1013
Room 1
Thursday
September 2
10h20

Application of fast statistical homogenization procedure for estimation of effective properties of ceramic matrix composites having random microstructure

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The modern polycrystalline composite materials have a complex internal structure due to the fact that they consist of several different phases and interfaces with random distribution. An example of such material is the composite consisting of 2 types of elastic grains, e.g. Al2O3 and ZrO2. This type of composite is widely used for different types of TBCs protection in jet engines. The Al2O3/ZrO2 composite has complex internal structure having grains of different sizes from 0.2 micro-m to 2 micro-m. Using numerical Fast Statistical Homogenization Procedure (FSHP) we estimated: optimal size of the Representative Volume Elements (RVEs), elastic response and effective mechanical properties, like: the Young's modules and the Poisson's ratios. 2-D analysis is based on images of real microstructures of the Al2O3/ZrO2 composite obtained from a scanning electron microscope. The following different types of composition were considered: pure Al2O3, (20%)Al2O3/(80%)ZrO2, (40%)Al2O3/(60%)ZrO2, (60%)Al2O3/(40%)ZrO2, (80%)Al2O3/(20%)ZrO2 and pure ZrO2. According to idea of the FSHP the elastic responses of composites were performed by adoption of virtual element method (VEM) for the inclusions and finite element method (FEM) for matrix. Both types of grains (inclusions and the second - creating continuous matrix) have different mechanical properties. In simplification, grain boundaries were treated as infinitesimal thickness interfaces. The RVEs with optimal characteristic sizes were subjected to uniaxial tension. The results obtained by adopting FSHP, inclusive of a combined VEM-FEM methodology, lead to the conclusion that the proposed approach is more effective in comparison to a standard commercial FEM code and the effective moduli for various volume contents of two-phases in random composites are determined. Acknowledgment: The results presented in this paper were obtained within the framework of research grant No. UMO/2016/21/B/ST8/01027 financed by the National Science Centre, Poland. This work is supported by Italian Ministry of University and Research (P.R.I.N. National Grant 2017 No. 2017HFPKZY (B88D19001130001); Sapienza Research Grants "Progetti Medi" 2017 (B83C17001440005). Dr. Reccia fully acknowledges the research project funded by P.O.R. SARDEGNA F.S.E. 2014-2020 - Axis III Education and Training, Thematic Objective: 10, Specific Objective: 10.5, Action of the Partnership Agreement: 10.5.12, Call for Funding of Research Projects – Year 2017. M. Boniecki, T.Sadowski, P. Gołębiewski, H. Węglarz, A.Piątkowska, M. Romaniec, K. Krzyżak, K. łosiewicz. „mechanical properties of alumina/zirconia composites". CERAMICS INT, 46:1033-1039, 2020. P. Trovalusci, M. Ostoja-Starzewki, M.L. De Bellis, A. Murrali. "Scale-dependent homogenization of random composites as micropolar continua". EUR J MECH A-SOLID, 49:396–407, 2015. M. Pingaro, E. Reccia, P. Trovalusci, R., Masiani. "Fast Statistical Homogenization Procedure (FSHP) for particle random composite using Virtual Element Method". Comput Mech, 64(1):197-210, 2019. M. Pingaro, E. Reccia, P. Trovalusci. "Homogenization of Random Porous Materials With Low-Order Virtual Elements". ASCE ASME J Risk Uncertain Eng Syst B Mech Eng, 5(3), 030905, 2019.

Nonplanar Vibrations of an Imperfect Composite Nanobeam Employing Nonlocal Strain Gradient Theory

abst. 2159
Repository

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In this paper, the nonplanar vibrations in the longitudinal, transverse, and lateral directions of an imperfect nanobeam are investigated. The Kelvin-Voigt model and nonlocal strain gradient theory (NSGT) are employed to describe the viscoelasticity and size-dependent effect. The mechanical model of the Nanobeam is established by applying the Hamilton's principle, while the initial imperfection is described using an initial displacement. The mid-span amplitude of this nanobeam is studied via the differential quadrature method. Findings show that the numerical and published results exhibit a remarkable correspondence. Afterward, the the key factors, like damping coefficient, classical nonlocal parameter, nonlocal strain gradient parameter and lateral motion, are analyzed numerically to highlight the effect of viscoelasticity, size-dependence and nonplanar motion.

Free Vibration of FGM Nanoscale Thick Beams

abst. 2204
Room 1
Thursday
September 2
15h30

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Nanoscale beams can be increasingly found as components of nanoelectromechanical systems, in a wide range of engineering and science applications, such as bioengineering and medical diagnostics and therapeutics, among others. Hence the design of such structures and its adequacy to specific applications will benefit from a more complete understanding of their mechanical behavior. The model developed in the present work intends to capture the small scale effect by considering the non-local elasticity theory of Eringen and takes into account both thickness stretching and shear deformation, while exploring the possibility of different directions' material gradients. A comprehensive set of numerical simulations are performed to conclude on the influence of different parameters that may affect the free vibration performance of such nanoscale beam-type structures.

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abst. 1010
Room 1
Wednesday
September 1
12h10

Infusing Energy Transferability into Coastal Bridge Infrastructures by elucidating a unique IEPM Chemical Bond Feature via IDA Surface Modification

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A surface-modified carbon-fiber reinforced epoxy (CF/E) via exchange-based isophorone diisocyanate amine (IDA) reaction that produces an interfacial matrix (IEPM) elicits excellent mechanical energy transferability in otherwise brittle CF/E. The chemical bonding property of the surface reaction, produced between epoxy and pre-polymerized elastomer moieties, is controlled via a thermodynamic processing parameter (tc), quantified by the reaction time (hours, h) between the epoxy resin and amine-based epoxy hardener constituents. The unique reaction is linked to bulk mechanical energy transferability via Dynamic Mechanical Analysis (DMA) and a Generalized Maxwell Model for small deformations to isolate the thin IEPM from its bordering components. To demonstrate effectiveness of the IDA modification, four AASHTO Type III scaled concrete girders (in typical U.S. coastal bridges) were designed using stress similarity principles and geometries in accordance with the I-10 bay-way bridges across Mobile Bay (Alabama). The test girders were experimentally / dynamically tested using a modified coupled storm surge and slamming wave forcing function (Hurricane Katrina, 2005). Two AASHTO girders – "Pre-Katrina" and "Post-Katrina" – and one CF/E-strengthened girder experienced concrete shear failure at their girder-to-cap-beam connection-detail in less than one load cycle, leading to disengagement of the girder from its cap-beam. The CF/E-strengthened girder experienced fiber and epoxy matrix breakage and delamination, non-sustainable girder-end rotations, and transient hystereses. However, after 12 load cycles, the IDA-modified girder, through its enhanced IDA-modified carbon-fiber connection-detail, successfully transferred the Hurricane Katrina wave energies via a loss modulus property that is directly linked to the molecular vibrational properties of the IEPM layer. As a result, the load-deflection hystereses stabilized after 3 cycles, quickly dissipating the transient response as it approached steady-state, and substantially minimized girder rotations (1% per-cycle), therefore limiting girder damage to local cracking. This was not the case in the CF/E girder as rotations increased between 5% and 15% in sequential load cycles until the girder disengaged from its cap-beam. The loss modulus was quantified following the DMA (RSA-G2 Solids Analyzer) of: six 0-IEPM samples (epoxy + IEPM + elastomer, i.e., no fiber) as a function of tc, one pure epoxy sample, and one pure elastomer sample. For IEPM at tc=0, Atomic Force Microscopy of the left side of the IEPM region depicted a "beach-pebble topography," or small granular transition from pure epoxy, followed by increased jaggedness due to covalent bond formations between epoxy and elastomer moieties. The results were validated by wavenumber mapping of chemical images and non-negative matrix factorization modeling. At tc = 0, the IEPM chemical structure (width: 30 - 50 microns) indicated a strong presence of polyetheramine (–NH2) and epoxide groups (from unreacted epoxy due to the fast diffusion rate of epoxy species upon initial mixing), therefore conducing a large number of reactions with isocyanate groups to produce a high-quality IEPM. However, for IEPM engendered at larger tc, fewer chemical bonds comprise the IEPM region following surface treatment, leading to a decrease in IEPM bond strength and reduced presence of critical molecular properties. A distinct separation exists in the loss modulus of 0-IEPM manufactured using $0 \leq tc \leq 2$ and 0-IEPM manufactured using $3.5 \leq tc \leq 24$ (weaker presence of secondary amine bending modes decreases loss modulus), highlighting the IEPM's large relative contribution to loss modulus, which is two and five times larger than loss modulus of IEPM at tc = 0 and 3.5. As tc increases, IEPM bond enthalpy, density and distribution of covalent bonding, and width of IEPM decrease, therefore decreasing the IEPM's ability to educe sufficient energy transferability.

NUMERICAL MODELING OF DATE-PALM FIBRE-REINFORCED MORTAR

abst. 2100
Room 3
Friday
September 3
10h40

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As is well-known, mortar is characterised by high compressive strength but low tensile strength and fracture toughness. In order to achieve higher values of both tensile strength and fracture toughness, different synthetic fibres are widely used as reinforcement for mortar [1]. However, synthetic fibres are generally related to high production cost and large amount of energy dissipated within the manufacturing process. During last decades, natural fibres have increasingly attracted the interest of the researchers due to their availability, renewability and cost-effectiveness [2]. Previous studies have investigated the influence of different natural fibres on both thermal and mechanical properties of fibre-reinforced mortar. In particular, date-palm fibres have been identified as a good candidate for mortar reinforcement in applications where high strength is not the main design requirement [3]. Therefore, the aim of the present paper is to analyse the fracture behaviour of a date-palm fibre-reinforced mortar. In more detail, three-point bending tests carried out on single edge-notched specimens of both plain mortar and mortar reinforced by date-palm fibres are considered [4]. Fibres are randomly distributed in the cementitious matrix and five different values of fibres content (that is, 2, 4, 6, 8 and 10%) are examined. Subsequently, the modified two-parameter model [5, 6] is employed in order to compute the fracture toughness of date-palm fibre-reinforced mortar. Note that such a method is able to take into account the possible kinked crack occurring during the stable crack propagation, which is typical of quasi-brittle materials. Moreover, the mechanical behaviour of such specimens is analysed by means of a micromechanical numerical model [7]. In particular, according to such a model, the spatial arrangement of the fibres is taken into account by means of a statistical description of their orientation, whereas the mechanical effect of the fibres on the matrix is considered by means of a homogenization approach. Keywords: Date-palm fibre-reinforced mortar, fracture behaviour, homogenization approach, micromechanical model, modified two-parameter model REFERENCES [1] Sharma, S.K., Aditya Anupam Kumar, G.D., Ransinchung, R.N., Kumar, P. (2013) Micro fiber reinforced cement paste and mortar overlays - A review, International Journal of Pavement Research and Technology, 6, 6, 765-772. [2] Ardanuy, M., Claramunt, J., Toledo Filho, R.D. (2015) Cellulosic fiber reinforced cement-based composites: A review of recent research, Construction and Building Materials, Vol. 79, 115-128. [3] Mustapha, B., Lahcen, B., Hassan, H., Brahim, B., Fatima, A. N. (2017) Thermomechanical characterization of a bio-composite building material: Mortar reinforced with date palm fibers mesh, Construction and Building Materials, 135, 241-250. [4] Vantadori, S., Carpinteri, A., Zanichelli, A. (2019) Lightweight construction materials: Mortar reinforced with date-palm mesh fibres, Theoretical and Applied Fracture Mechanics, 100, 39-45. [5] Carpinteri, A., Berto, F., Fortese, G., Ronchei, C., Scorza, D., Vantadori, S. (2017) Modified two-parameter fracture model for bone, Engineering Fracture Mechanics, 174, 44-53. [6] Vantadori, S., Carpinteri, A., Guo, L.-P., Ronchei, C., Zanichelli, A. (2018) Synergy assessment of hybrid reinforcements in concrete, Composites Part B: Engineering, 147, 197-206. [7] Scorza D. (2015) Mechanical Modelling of Short-Fibre-Reinforced Materials under Static or Cyclic Loading, PhD Thesis.

CHARACTERISTICS OF COIR AND FLEECE MICROFIBRIL REINFORCED POLY-LACTIC ACID (PLA) HYBRID GREEN COMPOSITES

abst. 2180
Repository

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As an impact of the industrialization policy and environmental pollution it generates, much of the researchers' attention is devoting to the technology of developing environmentally friendly materials. In particular, the development of composite materials using a poly-lactic acid (PLA) biodegradable matrix reinforced one or more natural fiber has been attracted considerable interest for researchers. In this current study, development and characterization of hybrid green composites (GC) consisting of a varied combination of coir (CMF) and fleece microfibril (FMF) (treated with NaOH solution) and poly-lactic acid (PLA) resin. The hybrid GCs are prepared using a hot-pressed machine. The paper will present the physical properties (density, swelling, internal morphology, FTIR spectrum, and thermal stability) and mechanical properties (tensile, flexural, and impact energy) and the best possible application of these GC materials.

Non-destructive Inspection Techniques for Composite Materials and Structures

Effect of carbon nanotubes on the environmental assisted degradation and damage sensing abilities of glass fiber/epoxy composites

abst. 2155
Room 3
Thursday
September 2
10h00

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An experimental investigation is carried out to examine the effect of carbon nanotubes (CNTs) addition on the environmental assisted degradation and damage sensing capability of glass fiber/epoxy composites (GFRP). To this end, CNT modified epoxy is used to fabricate glass fiber/epoxy hybrid composites. Experimental results show that the addition of 1 wt% of CNTs increases the hardness and interlaminar shear strength (ILSS) by 150% and 36% respectively. Moreover, through the thickness electrical resistance of GFRP decreases by 46% after modifying the epoxy with CNTs. The effect of the environmental condition is simulated by exposing composite samples to 500 hrs of accelerated weathering cycle. The aging cycles lead to an increase in hardness, ILSS, and electrical resistance of GFRP and CNTGFRP. Increase in electrical resistance is attributed to the loss of polymer in composite samples due to exposure to UV rays which creates voids in matrix and hinders the path to flow of current. This results in brittle type sudden failure in aged composite samples. It is shown that the presence of nanotubes in the matrix not only ensures higher load carrying capacity but also assists in better damage detection in unaged as well as aged composites.

Optimization techniques and methods

abst. 2069
Room 3
Thursday
September 2
10h20

Multi-objective optimisation designs for thin-walled deployable composite hinges using surrogate models and Genetic Algorithms

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Thin-walled deployable composite hinges (DCHs) can achieve folding and deployment functions by storing and releasing strain energy, which have great application potential in deployable structures, such as satellite antennas and solar wings. This paper presented multi-objective optimisation designs for DCHs. Firstly, an optimisation problem was established to obtain three conflicting objectives, minimising the peak moment, maximising the strain energy and minimising the mass. Three design variables and one constraint had been considered. Moreover, multiple surrogate models were employed, including machine learning methods and response surface methodology (RSM). Correlation coefficient (R2), mean absolute error (MAE) and root mean square error (RMSE) were used to determine the surrogate model with the highest accuracy. Furthermore, several state-of-the-art Genetic Algorithms were benchmarked to obtain the optimal designs of DCHs. The mimicked inverted generational distance (mIGD) was applied to determine the best optimizer. The research results have significance to practical engineering application of DCHs for space deployable structures.

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abst. 2266
Repository

Influence of electromagnetic field on the orientation of steel fibres in high-performance concrete

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The presented research explores the optimisation of fibre-reinforced high-performance concretes by applying an electromagnetic field to orient the fibres in a preferred direction. Usually, fibres are considered to be randomly distributed and oriented in a fresh mixture. However, this is not true due to various reasons, such as mixing techniques and placement methods. In order to better control the final mechanical parameters of the hardened concrete, it is necessary to be able to also control the fibre reinforcement to better deal with the induced tensile stresses. The principle and design of the apparatus for magnetic orientation is introduced and described in detail. In the experimental

study, high-performance concrete with different percentages of steel fibre volume was investigated. The experimental program included non-destructive methods for confirming the change in orientation of the fibres using the quality factor measurements of a coil with the concrete specimen as its core. This measurement clearly captured the change in fibre volume content as well as the orientation change. The flexural strengths of concrete specimens were significantly higher after orienting the fibres. This means, that either economic savings can be made if a certain strength is required or higher strengths can be achieved with the same volume of steel fibre reinforcement.

Topology and Fiber Path Optimization of Variable Stiffness Composite Structures with Eigenvectors Constraints

abst. 2285
Room 3
Thursday
September 2
10h40

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Over the last thirty years, composite materials have become increasingly present in the aerospace, automobile, and defense sectors. The pursuit of stiffer lightweight structures has led to the development of new concepts such as the Variable Stiffness Composites Laminates (VSCL), which further explore the design potential of these highly tailored materials. Simultaneously, as the number of design variables rise, robust topology optimization formulations are progressively more crucial to achieve optimal solutions. In this work, a design optimization framework is developed by assigning material and fiber orientation on discrete patches of the VSCL structures. The framework is based on the Discrete Material Optimization (DMO) formulation. DMO is a multiphase parametrization that associates a weight to each candidate, and it is compatible with gradient-based optimization methods. The main goal of this study is to design structures to meet dynamic performance objectives. Therefore, the objective function depends on the eigenvalues (natural frequencies) while one set of constraints depends on the eigenvectors (mode shapes). The intended result is the synthesis of modes and their frequencies with the target design. Since repeated eigenvalues might occur during the process, Dailey's Method is used to calculate the derivatives. The Modal Assurance Criterion (MAC) is applied to perform mode tracking between the different design iterations and to evaluate the convergence of the synthetized modes to the pre-defined objective shapes. The synthesis of new modes has several applications such as the design of scaled models with the same dynamic behavior as the full-scale model.

The effect of magnetic field shape and strength on fiber orientation in fresh HPFRC mixture

abst. 2296
Room 1
Friday
September 3
15h10

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This paper deals with the topic of orientation of ferromagnetic steel fibers in a fresh concrete mixture using a magnetic field. Steel fibers are among the most widely used fibers in cement composites. If the fibers are oriented in the direction of the main tensile stresses, they are used in the most efficient way. This orientation can be obtained via effects of a suitable magnetic field. The strength of the magnetic field (magnetic induction) and rheology of the cement matrix play a crucial role in the magnetic orientation of ferromagnetic fibers. A special device generating alternating and direct magnetic fields with different magnetic inductions was built to determine the minimal magnetic induction for the given mixture. Moreover, effects of using alternating magnetic field are explored. The used magnetic inductions are 60 mT, 80 mT, 100 mT, and 120 mT. The effect of the shape of the magnetic field and magnetic induction on the flexural strength of final composite is presented.

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abst. 2316
Room 1
Friday
September 3
15h30

Shunted damping configurations for noise reduction in laminated composite sandwich panels

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This work addresses the issue of vibration and noise reduction in laminated sandwich plates using piezoelectric patches with passive shunted damping. A finite element implementation of a laminated sandwich plate with viscoelastic core and surface bonded piezoelectric patches is used to obtain the frequency response of the panels. The sound transmission characteristics of the panels are evaluated by computing their radiated sound power using the Rayleigh integral method. Resistor and inductor shunted damping circuits are used to add damping to the sandwich panels. The optimal location of the surface-bonded piezoelectric patches is then obtained, along with the resistor and inductor circuits optimal resistance and inductance values, using direct multisearch optimization to minimize added weight, number of patches, and noise radiation, for each one of the vibration modes of the panel or for a certain frequency band of interest. Trade-off Pareto fronts and the respective optimal patch configurations are obtained and compared with those presented previously by the authors. Comparisons are also established between the obtained optimal circuits for each mode and the ones obtained directly by tuning the electrical resonances to the mechanical ones. A mesh dependency study is also presented.

Porous and cellular materials

Large deflection of composite beams by finite elements with node-dependent kinematics

abst. 1030
Room 2
Thursday
September 2
17h10

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In the last decades, new challenges demanded by aerospace, automotive and other en- gineering fields require the adoption of sophisticated and eventually light-weight structures. For this reason, composite materials, thanks to their outstanding structural performances, in terms of strength and stiffness properties compared to metal alloys, have encountered great success [1]. However, the correct design of composite components generally requires enhanced calculation techniques to account for anisotropy coupling effects, interface phenomena, and 3D stress states. The need for a high level of accuracy and reliability from the structural sim- ulation pushed engineers to use high-performing three-dimensional models, with a high effort in terms of computational cost. In order to cut down this drawback, scientists and researchers have been encouraged to develop lighter one-dimensional (1D) and two-dimensional models, with the goal of maintaining the same level of accuracy when compared to the heavier 3D tools. In addition, particular attention must be given to local phenomena when structures are subjected to large deformation, e.g., large displacements and large rotations. In fact, for an accurate design of structures undergoing extreme loading conditions, a geometrical nonlinear analysis must be carried out. In many real applications, local phenomena and large cross-sectional deformations occur in particular areas of the structure, for example, in the nearby of external loads or constraint conditions. In such cases, it would be needed to build a model with variable kinematics, namely, capable of refining only the portions of the structure which undergo high deforma- tion or rotation. In this way, the accuracy is still guaranteed, with a drastic decrease in the number of degrees of freedom and, subsequently, of the computational cost. Compatibility conditions have to be guaranteed in the interface zones between different domains, for instance with Lagrange multipliers, see the work by Prager [2]. In the present work, the use of the node-dependent kinematics concept for the geometrical nonlinear analysis of composite one-dimensional structures is proposed. With the present approach, the kinematics can be independent in each element node. Therefore the structural theory changes continuously over the computational domain, describing remarkable cross- section deformation with higher-order kinematics and giving a lower-order kinematic to those portion of the structure which does not require a refinement. In this way, the reliability of the simulation is ensured, keeping a reasonable computational cost. This is possible by Carrera unified formulation [3, 4], which allows writing finite element nonlinear equilibrium and incremental equations in compact and recursive form. Compact and thin-walled com- posite structures are analyzed, with symmetric and unsymmetric loading conditions, to test the present approach when dealing with warping and torsion phenomena. Results show how finite element models with node-dependent behave as well as ones with uniform highly refined kinematic. In particular, zones which undergo remarkable deformations demand high-order theories of structures, whereas a lower-order theory can be employed if no local phenomena occur: this is easily accomplished by node-dependend kinematics analysis. References: [1] X. Zhang, Y. Chen, and J. Hu. Recent advances in the development of aerospace materials. Progress in Aerospace Sciences, 97:22–34, 2018. [2] W Prager. Recent progress in applied mechanics. Almquist and Wiksell, Stockholm, 1967. [3] E. Carrera, G. Giunta, and M. Petrolo. Beam Structures: Classical and Advanced Theories. John Wiley Sons, 2011. [4] E. Carrera, M. Cinefra, M. Petrolo, and E. Zappino. Finite Element Analysis of Structures through Unified Formulation. John Wiley Sons, Chichester, West Sussex, UK., 2014.

Modelling of effective thermal conductivity of a packed bed of steel bars with the use of chosen literature models

abst. 2193
Repository

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Transport phenomena of heat in different porous media have been the subject of many industrial and academic investigations. The majority of the studies reported in the literature deal with low porosity granular media. A specific example of such a kind of medium are steel bars heated during the heat treatment in the form of cylindrically shaped bundles. Depending on the equipment available to the manufacturer, these processes are carried out in box-type, bell-type or soaking furnaces. The intensity of the bundle heating is determined by the processes of heat transfer which occur in the radial direction of the bundle. In this direction the considered charge is characterized by the lack of continuity of the solid phase. For this reason the ability of the bundles to transfer heat in this direction is expressed by means of effective thermal conductivity kef. Knowledge about this coefficient of the bar bundles is necessary to optimize their heat treatment processes. A geometrical model of a bar bundle which is used to analyse the phenomena of heat transfer is a packed bed of bars. The article presents the results of calculations of the coefficient kef for packed bundles of steel bars obtained for a few selected analytical models. The paper analyses both simple models, in which only primary parameters occur, and complex models, in which apart from primary parameters there are also secondary parameters. Primary parameters include: porosity j and thermal conductivities of the solid phase ks and gas phase kg. Secondary parameters are: contact resistance, heat transfer through radiation and values which describe the geometrical configuration of a medium – it is usually the mean diameter of grains or voids. The quality of the results was verified on the basis of experimental measurements. These tests consisted of measuring the effective thermal conductivity of packed bar beds in a guarded hot plate apparatus.

Finite element reliability analysis of edge delamination onset due to the interlaminar stresses in general composite laminates

abst. 2080
Repository

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Fiber-reinforced composite materials have many applications in engineering fields such as aerospace structures because of their unique properties, such as high strength and density ratio compared to other materials. However, composite laminates are prone to the formation of various damage modes, including fiber-matrix debonding, matrix cracking, fiber breaking, and delamination. Delamination is one of the catastrophic damage modes of a structure; hence its formation significantly reduces the stiffness and strength of composite laminates. Various studies have been conducted using different methods to predict delamination formation. Interlaminar stresses caused by the free edge effect are the main reasons for delamination. The reliability analysis of composite laminate is exceptionally efficient for the design optimization of structures. By reviewing the literature, comprehensive comparisons between different studies in terms of failure criterion, reliability analysis methods, random variables, and the probabilistic analysis aim are performed. This comparison pointed out that reliability analyses have mainly been performed for the probabilistic prediction of global failure in composite laminates. However, it seems to be necessary to investigate other failure modes such as delamination than global failure. While it is the most significant and catastrophic failure mode and given the scarcity of studies is essential to propose a generic approach to predict the reliability of the composite laminates under the delamination mode. In this paper, a new stress-based reliability analysis algorithm is proposed for the probabilistic prediction of edge delamination onset. Although the actual values of interlaminar stresses can be found by numerical analysis using the finite element method (FEM), however, due to the singularity of the stress (exactly on the free edge), the obtained interlaminar stresses from the FEM analysis cannot be used directly in a failure criterion without further consideration. In this study, a quadratic stress-based failure criterion is employed based on the mean stresses at a characteristic length, i.e., material properties. If the interlaminar stresses z, yz and xz exceed the interlaminar strengths Sz, Syz and Sxz, respectively, the edge delamination will be created. It should be noted that in the cross-ply laminates [0/90]s the interlaminar stresses z and yz, in off-axis balanced laminates [+/−]s the interlaminar shear stress xz and in an arbitrary layup [±/±]s all three interlaminar stresses can occur simultaneously at interfaces. In this paper, the algorithm of stress-based finite element reliability analysis (FERA) of edge delamination onset is developed. To this purpose, a coupling process between MATLAB and ANSYS is employed to calculate the onset probability of delamination by using the first and second-order reliability methods (FORM and SORM). The proposed generic FERA algorithm is examined for AS4/3501-6 carbon/epoxy composite laminate with stacking sequences of cross-ply [0n/90m]s, off-axis balanced [+n/−m]s, and any arbitrary layup [±n/±m]s laminates. It should be mentioned, using the developed algorithm, the effects of the angle of plies, interface location, different longitudinal stress, the thickness of plies are investigated on the onset probability of edge delamination. The obtained results by the FORM and SORM are verified using Monte Carlo simulation (MCS). Moreover, the convergence of the MCS versus the results of FORM and SORM is performed. Eventually, the effect of data scattering of the random variables is investigated through the coefficient of variation of the random variables.
Keywords: Reliability analysis, Probability of failure, Delamination, Interlaminar stress

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Adaptive dimensional reduction of probability spaces in the RBRDO of composite laminates structures

abst. 2241
Room 1
Friday
September 3
14h50

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The need to quantify the uncertainty associated with the main design features of composite laminates has been recognized by the scientific and industrial communities. The concept of Reliability-based Robust Design Optimization (RBRDO) aims to find the best design performance, while acknowledging the existence of random variation in the structural responses and the probabilistic failure of structural systems. The imposition of probabilistic reliability constraints in the design of composite laminates has proven to be necessary, due to the uncertainty inherent to the failure modes of this kind of structures, often associated with the material and geometric properties. However, reliability assessment is known to aggravate the efficiency of structural design optimization. In the case of composite laminates, the probability space defined around each design solution easily becomes hyper-dimensional, due to the elevated number of variables associated with structural strength. Yet not all variables are important. In structural reliability assessment, a proper characterization of the probability spaces is vital for the good behavior of numerical methods. In constructing a probability space, it is understood that if it is too large the computing costs will be high, and both efficiency and accuracy compromised. The aim of this work is to implement an efficient dimensional reduction method that systematically determines which random variables must be considered in reliability assessment. Most dimensional reduction methods in the literature are numerical and computationally expensive, despite their accuracy. In structural design optimization, such costs become excessive in the overall optimization process. We propose the application of Sobol' indices to reduce the dimensionality of probability spaces, in reliability assessment. Sobol' indices are variance-based importance measures defined from the ANOVA decomposition of multivariate functions. Hence, their direct calculation is usually achieved by expensive sampling methods. Instead, we apply an approximate analytical solution of Sobol' indices, knowing that any multilinear kth-order Taylor polynomial (of a multivariate function) is coincident with its own ANOVA decomposition. Thus, obtaining an approximate ANOVA decomposition of the limit-state functions in polynomial form, allowing to calculate Sobol' indices analytically. A first [U+2010] order approximation is proven sufficient. The derivatives are calculated by an Adjoint Method, only requiring an adjoint system of equilibrium equations to be solved. Thus, a random variable is said to be important if the respective Sobol' index is greater than or equal to a nonnegative threshold parameter. This criterion is evaluated recursively for all design solutions and will determine how many random variables must be considered in reliability assessment. As a numerical application, the criterion is applied to the RBRDO of a composite laminate shell structure, solved exclusively by evolutionary algorithms (EAs). The goal is to study how the dimensional reduction in reliability assessment affects the RBRDO of composite laminate structures. Therefore, conclusions are drawn by comparison with the results obtained without any dimensional reduction. The results show that, from a total of 16 random mechanical properties in reliability assessment, only 5 to 8 are important. In fact, among the optimal solutions, the important random variables alone explain at least 99.7% of the uncertainty. In practice, it is achieved a drastic reduction in the number of finite elements simulations resulting in computing times between 2 to 12 times faster, in reliability assessment. Consequently, the proposed dimensional reduction allowed the whole RBRDO problem to be solved around 2 times faster. At the same time, the optimal design solutions were identical to those obtained without any dimensional reduction, demonstrating the goodness of the proposed method.

Smart Composites

A spectral Tchebychev solution for electrostatic analysis of functionally graded composite plates with integrated piezo-patches

abst. 1012
Room 1
Friday
September 3
16h10

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In this study, we present a modeling approach to determine/analyze the electro-elastic dynamic behavior of electromechanical functionally graded material (FGM) plates with multiple surface-integrated piezo-patches. The first order shear deformation plate theory (FSDT) assumptions are used together with Hamilton's approach to derive the governing electro-elastic dynamic equations of the coupled structure. The extension of shear deformation terms in the model accurately estimates the electro-elastic behavior for thin and moderately thick plates. Two-dimensional spectral Tchebychev (ST) technique is used to solve the governing equations and Gauss-Lobatto sampling approach is used to discretize the geometry. In order to assess the accuracy of the developed solution approach, a modal analysis with a system-level finite-element simulation is performed using a commercial finite element (FE) software; and the predicted natural frequencies, structural/electromechanical frequency response functions (FRFs), and voltage FRFs are compared. It is shown that in all of the case studies, maximum difference between the predicted natural frequencies using ST and FE analysis are below 1%. The electromechanical FRFs is obtained by including the vibration response and electrical output of the system under a transverse point force excitation using the ST approach and the results are shown to match perfectly with the finite element (FE) simulations. Furthermore, the investigated case studies demonstrated that the computational cost of the developed method is significantly lower than that of FE simulations.

Microstrip Patch Antenna with Sandwich Type Radar Absorbing Structure

abst. 2149
Repository

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Stealth technology is an essential technology for survivability of weapons, and for this reason, studies on stealth technologies have been conducted. Stealth technology aims at controlling the target's signal for reducing the probability of detection. Especially in the case of radar, which uses electromagnetic waves, information such as the position of the target and the type of velocity can be known, so much research on electromagnetic stealth technology has been conducted. The most important parameter for electromagnetic stealth is the radar cross section (RCS) of the target. There are various methods to reduce RCS such as shaping, radar absorbing structures (RAS), radar absorbing materials (RAM) and cancellation. It is suitable to use RAS for an aircraft because the materials have electromagnetic wave absorbing and load bearing capabilities simultaneously enabling light weight aircrafts. There are various concepts of RAS such as matrix control method, fiber coating method, circuit-analog (CA) absorber and sandwich type absorber and most of these RAS are designed by using impedance matching technique for absorbing electromagnetic wave and contain metal materials for reflection. Antennas are transceivers that change electromagnetic energy to electric energy or electric energy to electromagnetic

energy. There are 10 to 20 antennas on an aircraft for communication, navigation, identification friends or foe (IFF), etc. The antenna for aircraft is needed light weight and low profile for reducing fuel consumption, aerodynamic drag and RCS. The patch antenna is studied in this paper for aircraft, because it is a low profile antenna which can be mounted on surface easily. These antennas generally contain metal materials to outer parts for transmitting and receiving electromagnetic waves, and these metal parts are important contributors in increasing RCS of an aircraft. Therefore, the purpose of this study is to design an antenna with RAS for reducing RCS of aircraft, and confirm the antenna performance and stealth performance of this antenna through simulation. For this study, sandwich type RAS was designed by using nickel coated glass /epoxy and foam core, and the patch antenna was designed by using glass/epoxy and then this antenna was inserted into the lower skin part of sandwich RAS. For measuring the antenna gain and radar absorbing performance, this antenna will be made by autoclave curing process. The radar absorbing performance will be measured by free space measurement equipment and antenna performance will be measured by antenna in anechoic chamber. The impedance of the antenna with sandwich structure is similar with antenna without sandwich structure, however antenna gain decreased due to presence of foam and upper skin. The antenna with sandwich RAS showed 90% radar absorbing performance at target frequency band. For stealth aircraft, the stealth performance is the most important, so reducing RCS of antenna is necessary. The antenna performance of antenna with RAS was decreased, however the RCS of antenna also decreased by -10 dB than conventional antenna.

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abst. 2152
Room 1
Friday
September 3
15h50

Finite Element Analysis of Intrinsically Self-healing UD Composite Material

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This work presents a micromechanical constitutive model of intrinsically self-healing unidirectional Carbon Fibre Reinforced Polymer (CFRP) composite material. Intrinsic self-healing is a feature of the matrix constituent and it is modelled using the previously developed elastic-plastic damage-healing constitutive model for the pure matrix material [1]. On the other hand, the reinforcing fibres are modelled as transversely isotropic linear elastic material. Thus, there is neither damage nor healing in the reinforcing fibres. Moreover, the homogenised composite material is modelled using a three-dimensional micromechanical model, based on the Rule of Mixtures (ROM), i.e. relations defined in [2]. Using the principles of the ROM, components of the homogenised composite orthotropic elasticity tensor are defined. Using the ROM Voigt (iso-strain) and Reuss (iso-stress) approximations, fibre and matrix strain tensors are defined. Furthermore, Voigt and Reuss approximations are used with the principle of additive decomposition of strain to define the homogenised composite elastic and plastic strain tensors. Finally, the developed constitutive model is validated using experimental results of three-point bending tests taken from [3]. References: [1] Smojver et al. A constitutive model for a self-healing composite matrix polymer material: [Manuscript submitted for publication]; 2020. [2] Goldberg RK. Strain Rate Dependent Deformation and Strength Modeling of a Polymer Matrix Composite Utilizing a Micromechanics Approach [PhD thesis]. Cleveland, Ohio: NASA Glenn Research Center Cleveland; 1999. [3] Park JS, Darlington T, Starr AF, Takahashi K, Riendeau J, Thomas Hahn H. Multiple healing effect of thermally activated self-healing composites based on Diels–Alder reaction. Composites Science and Technology. 2010;70:2154–9. doi:10.1016/j.compscitech.2010.08.017.

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abst. 2179
Repository

Effect of Rain and Sea Water Immersion of Magnetorheological Elastomers

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Silicon matrix MRE material applications in outdoor environments exposed to rainwater and sea water needs to be analyzed and evaluated. MRE specimens (silicon RTV mixtures of CIP 70% weight fraction) were fabricated under isotropic and vacuum conditions. The immersion test for 6 weeks shows a decrease in the percentage of absorption and the dissolution of the material indicated by a change in the color of the immersion water. The sea water immersion specimens have a solubility of 0.05%, while the freshwater immersed specimens are 0.03%. The hardness was measured using Durometer Shore A. The results decrease to 43.6A (seawater immersion) and 47.6A (freshwater immersion). FTIR test shows the findings of new peaks (formation of N-CH3 and methylene) in seawater immersion specimens. SEM results show the surface damage of seawater specimens indicated by changes in the surface grooves of the specimens. Moreover, rust on its surface was also found in the macro photos. The experimental works could be further considered for the design consideration of silicon based MRE for outdoor application.

Rate dependences in the magneto-mechanical response of magnetorheological elastomers: an experimental study

abst. 2262
Room 1
Friday
September 3
16h30

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This work comprises a big experimental study on rate dependences in magneto-rheologicalelastomers (MREs). We present experimental characterisation of an extremely soft MRE combining more than 100 experimental conditions. The experiments include uniaxial compression, magneto-mechanical DMA tests, relaxation tests, oscillatory shear tests at different deformation rates and magnetic conditions, magneto-mechanical shear frequency sweep tests, and novel magneto-mechanical experiments. The experiments provided herein show intrinsic links between microstructural features and the macroscopic response of magnetic multifunctional composites. Overall, we show a wider span when designing applications for MREs working in axial compression or shear modes. Starting from1-4 kPa, the mechanical properties of the material can be tuned within a wide range. This adaptability makes it ideal to be used in bioengineering and soft robotics applications. In addition, the work presented opens the door for modelling approaches addressing these questions and offers a new starting point for constitutive theories bringing together a wide set of characterisation data.

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abst. 2022
Room 1
Thursday
September 2
15h10

Approximate postbuckling analysis of omega-stringer-stiffened composite panels

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A new approximate computational model for the postbuckling analysis is introduced to contribute to the preliminary design of thin-walled composite structures. The investigated structure is an omega stringer stiffened composite panel which is a type of stiffened panel used in current aircraft designs but is also relevant generally for application in aerospace structures and marine vessels. The model is derived by energy methods and aims to approximate the postbuckling behavior near the bifurcation point, i.e. with low load proportionality factors. The loadcase of uniaxial compression is considered and the quality of the new method is assessed in comparison to numerical methods. The overall aim is to reduce computational effort without unfeasible compromises in the quality of the results.

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abst. 2038
Room 1
Thursday
September 2
14h30

FG beam thermal buckling analysis

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This paper presents the thermal buckling analysis of functionally graded (FG) beams. As the temperature changes, the longitudinal fibers tend to extend in the axial direction. If the extension is disabled, axial stresses occur in the longitudinal fibers, which can cause the buckling. For this reason, the loss of stability is defined by the critical buckling temperature. The critical buckling temperature can be defined as temperature at which column collapses or deflections tends toward the infinity. In order to determine critical buckling temperatures, several numerical examples are run for various material parameter. The effects of material distribution on beam stable state is considered. Thermal buckling responses are ilustrated via temperature vs deflection curves.

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abst. 2041
Room 1
Thursday
September 2
14h50

A locking-free shear deformable beam model for stability analysis of beam-type structures with composite thin-walled cross-sections

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In the last few decades, load-carrying structures composed of beam-type structures with thin-walled composite cross-sections are extensively used in engineering practice, both in stand-alone forms and as stiffeners for plate-like or shell-like structures. Unfortunately, such weight-optimised structural components, especially those with open profiles, are commonly weak in torsion and susceptive to instability or buckling failure. Stability analysis of such structures can be performed using two different approaches, both of which furnish different kinds of valid and important information. In the first case, the stability analysis, also known as the linear one, is performed in an eigenvalue manner, which allows us to determine the instability load of the structure in a direct manner without calculating the exact magnitude of deformations. In the second case, the stability problems are investigated using the load-deflection approach, by which the structural behaviour throughout entire range of loading of interest, including the pre-buckling and post-buckling phases, is evaluated by plotting the loading of the structure as a function of deformations. In this work, a shear-deformable beam model for stability analysis of beam-type

structures made of composite materials is being developed. The incremental equilibrium equations for a straight beam element are derived within the framework of updated Lagrangian formulation and the displacement field of cross-sections, which accounts for the restrained warping and the large rotations effects. Timoshenko's theory for non-uniform bending and modified Vlasov's theory for non-uniform torsion are applied to include the shear deformation effects. An improved shear-deformable beam model is developed by taking into account the bending-bending and bending-warping torsion coupling shear deformations effects occurring for the asymmetric cross-section where the principal bending and principal shear axes do not coincide. To account for the semi-rigid connection behaviour, the hybrid finite element is introduced. The obtained results indicate that the proposed numerical model can be classified as shear locking-free one.

Structural Health Monitoring

abst. 2048
Repository

Self-sensing of CFRP Impact Damage using Electrical Route Models

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Fiber reinforced plastics (FRPs), especially carbon fiber reinforced plastics (CFRPs) are applied to various applications recently such as aerospace, automotive and civil infrastructures. Hence, their structural health monitoring (SHM) is getting important to ensure the structural safety as well as to manage maintenance cost. In this research, self-sensing of CFRP impact damage was performed by monitoring carbon fiber's electrical resistance. When structural damage occurs, the internal electrical network via carbon fibers undergoes simultaneous changes. In this study, the CFRPs made of uni-directional carbon fiber laminates in a single direction and in a cross-ply were addressed to investigate electrical network changes. CFRPs with diverse orientation were investigated considering the mechanical fracture and electromechanical behavior with impact tests. For the uni-directional CFRPs, 2D equivalent electrical circuits were introduced. The location and the size of the puncture can be identified by using the equivalent circuit models. Applying the fact that electrons prefer the electrically easiest way, 3D electrical route models were proposed for cross-ply CFRPs. The calculated detour length is able to identify the severity as well as the size of the impact damage.

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abst. 2050
Repository

Impact Self-sensing Algorithm Embedded Smart CFRP for Structural Health Monitoring and Non-destructive Evaluation using Artificial Neural Network

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Structural health monitoring (SHM) and non-destructive evaluation (NDE) of carbon fiber reinforced plastics (CFRPs) have been steadily spotlighted due to safety and maintenance cost. For the sake of real-time monitoring, studies for the deformation self-sensing of CFRPs is an uprising research topic. The fundamental mechanism of the self-sensing lies in the changes of electrical network of a CFRP from its mechanical deformation. Electrically conductive carbon fiber itself represents electrical resistance change when deformation is applied, and this is called piezoresistive behavior. Furthermore, electrical network between adjacent carbon fiber tows can be changed when mechanical deformation changes their contacts. While numerous researchers studied self-sensing mechanisms of CFRPs, not a few self-sensing principles were still unrevealed because there are enormous electromechanical parameters in CFRPs. Therefore, this study utilized artificial neural network (ANN) which is a tool of machine learning (ML) to acquire self-sensing results. In other words, the ANN tool for SHM and NDE was developed which identify impact damage without considering electromechanical factors such as piezoresistive behavior, inter-tow interaction, and inter-ply interaction. ANN was trained by several sets of inputs and targets. In this step, ANN determines coefficient of an equation, usually linear function, in a hidden layer. When the ANN receives a new input set, an output is calculated through the trained algorithm, and hence, any theoretical equation of composites is not considered. That is, no individual equation is required to obtain the results in need on the contrary to the conventional methods. Therefore, the proposed smart CFRP using ANN can detect not only the location of impact damage but also internal damages without any mechanical theories.

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abst. 2054
Repository

Structural Health Monitoring of Various Carbon Fiber Reinforced Plastic Tubes using Electrical Resistance (based Self-sensing)

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As lightweight materials are getting its popularity, carbon fiber reinforced plastic (CFRP) is one of the widely used material due to its superior mechanical properties such as strength-to-weight ratio and corrosion resistance. As CFRPs are applied to various fields, structural health monitoring (SHM) and non-destructive evaluation of CFRP are becoming important. In particular, self-sensing using electromechanical behavior of CFRP has gaining spotlighted because applied stress or strain can be detected by monitoring electrical resistance changes. In this electromechanical behavior, contact between adjacent carbon fiber tows or plies lead to electrical resistance changes. While there are uncountable studies as to self-sensing 2D CFRP plate, the studies for the self-sensing of 3D CFRP are limited. Therefore, in this research, CFRP tubes with different fiber stacking configurations are analyzed under flexural bending test to examine electromechanical self-sensing capability with respect to their structural deformations. The self-sensing performance and reliability were not only verified but also compared with strain gauge, finite element analysis and visual inspection. Multiple channels of electrical resistance were analyzed for the real-time SHM of the structures. The resistance based self-sensing successfully realized real-time SHM in terms of not only localized deformation but also fiber-wise failure.

Life-cycle structural health monitoring of composite laminate using encapsulated phase-shifted fiber Bragg grating with cantilever structure

abst. 2131
Repository

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Life-cycle monitoring of the composite structure is of high importance because the distortion in forming process and failure in service would weaken the reliability of the product. Fiber Bragg grating (FBG), especially the phase-shifted fiber Bragg grating (PSFBG) sensors taking advantage of small size, lightweight, and other excellent properties, are comprehensively researched in life-cycle monitoring of composites. However, the forming process monitoring using the embedded FBG is scarcely correlated to in-service monitoring because the spectrum distortion may occur under the high pressure in the forming process, causing difficulty in subsequent in-service monitoring. The encapsulated PSFBG can overcome the issue, but the encapsulated structure would severely affect the sensitivity of the sensor for ultrasonic signals. Hence, an encapsulated PSFBG sensor with a cantilever structure will be applied to break through these limitations. The newly designed PSFBG prevents the spectrum distorting and can precisely measure actual temperature during the forming. Then, the study focused on the in-service monitoring performance of the sensor. Unlike the conventional encapsulated PSFBG which lacks the high sensitivity to the wave measurements, the proposed sensor with a cantilever structure possesses resonance characteristics that can detect resonance frequencies of relatively high signal-to-noise ratio without amplifier or long average time. In addition, the sensor is designable as it can be sensitive to specific frequencies by adjusting the length of the cantilever beam. The acousto-ultrasonic detection was conducted after forming to measure the porosity of composite specimens and evaluate the impact damages based on the encapsulated PSFBG cantilever sensor. The specific frequency signals were excited on composite specimens with different porosity and recorded by the proposed sensor. The attenuation coefficients of the ultrasonic wave were associated with the porosity. Then, further detection for the impact damages was also implemented to assess the relationship between the damage and ultrasonic signals, validating the ability of the sensor for real-time in-service monitoring. In this study, a novel embedded PSFBG sensor with encapsulated and cantilever structure is proposed to correlate the forming monitoring with in-service monitoring, providing a feasible and efficient way for life-cycle structural health monitoring of composites.

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abst. 2177
Repository

Design, analysis and manufacturing of a smart composite skateboard with self-sensing capability

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Composite materials and structures have witnessed substantial developments over the last few decades. Mechanochromic polymers are a new class of smart composites with the ability to self-report their health condition on-line. The design mechanism in these materials is such that initiation of any force or mechanical stimuli leads to a color change in the composite surface, so that the damage can be monitored and repaired at early stages, resulting in longer fatigue lifetime of the structures. This paper aims to design a novel mechanochromic composite sensor to be used as an overload/damage indication tool on the surface of skateboards. The smart composite skateboard with damage monitoring sensor is then manufactured and tested under different loading conditions. The results clarify that the proposed skateboard could well detect and visualize the damage on the surface/back faces while it is light-weight, high-performance and environmentally friendly. It is also highlighted that the mechanochromic sensors can well act as a structural health monitoring (SHM) system in other composite structures such as wind turbine blades, automotive panels etc.

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abst. 2243
Repository

Application of Electrical Resistance Change Method for Impact Damage Monitoring in Quasi-isotropic Hybrid Composites

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This study investigates the possibility of barely visible impact damage detection in carbon fibre-reinforced polymer composites using a novel coating hybrid composite made of glass/carbon prepregs. A set of quasi-isotropic [45/0/90/-45]4S laminates made from unidirectional T800 carbon/MTM49-3 epoxy prepregs, as substrate, with a thin-ply hybrid composite sensing layer made of single plies of unidirectional ultra-high modulus carbon (YS-90)/epoxy and S-glass/epoxy material were damaged by barely visible impact at various energies. The hybrid composite sensors change their appearance and electrical resistance at different energy levels of impact due to induced subcritical damage mechanisms such as carbon fracture and incremental crack growth at the carbon/glass interface in the sensing hybrid composite. These changes are correlated with the barely visible impact damage induced in the quasi-isotropic substrate carbon composite. It has been shown that monitoring electrical resistance change and appearance change at the same time is a suitable tool for detection of impact energy level and therefore extent of the induced damage.

Thermal problems on Composite structures

New analytical thermal buckling solutions of orthotropic rectangular thin plates with two opposite edges free and the other rotationally restrained

abst. 2034
Repository

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Orthotropic rectangular thin plates received various applications in modern engineering since the investigations of the mechanical behavior of such structures attract both scientists and engineer's attention. External environment factors such as temperature and moisture, significantly affect the performance of plates. It is challenging for plates to work in such extreme environments. Consequently, researchers have a special interest in thermal buckling analysis of orthotropic thin plates. Previous studies focused on plates with classical boundaries, which lead to rare analytical benchmark thermal buckling results for plates with non-classical boundaries. The non-classical boundaries such as the rotationally restrained edges are commonly encountered in practical engineering, but increase the mathematical difficulty in plate's problems. Therefore, exploring straightforward and effective analytical approaches for complicated plate problems becomes an essential task. The classical finite Fourier integral transform approach is employed to obtain the analytical benchmark thermal buckling solutions of orthotropic rectangular thin plates with two opposite edges free and other edges rotationally restrained. Compared with the plate with classical boundaries, the plate with non-classical boundaries such as free and rotationally restrained edges is more challenging. Performing the adopted transformations on the governing thermal buckling equation and the investigated boundaries yields the Fourier coefficient for the deflection expressed by some unknown constants. Incorporating the inversion formula to satisfy the remaining boundaries leads to set of homogenous linear algebraic equations, which can determine the critical temperature and the corresponding mode shapes. In addition, the plates with classical boundaries can be attained by setting the rotational fixity factors. Therefore, an accurate benchmark thermal buckling results for isotropic/orthotropic thin plates with non-Levy type boundaries are obtained. The precision and efficiency of the adopted approach are well validated by comparing the obtained results with the finite element method using ABAQUS software. Appropriate extension of the present approach enables one to explore more benchmark solutions for moderately thick plates and thick plates with more complicated boundaries.

Determination of operating times and temperatures of carbon fibre-reinforced polymers at different heat fluxes

abst. 2063
Room 2
Friday
September 3
16h30

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In this work, real threats such as fires are simulated with long-lasting low heat fluxes and heat flashes with short-lasting high heat fluxes to characterize the thermal damage of carbon fibre-reinforced polymers (CFRP). For this purpose, the commercially available CFRP HexPly® 8552/IM7 is thermally irradiated from one side by an electrical heater of a cone calorimeter and a xenon short-arc lamp of laboratory heat flash simulator with heat fluxes between 5 and 175 W/cm2 at varying time intervals. During thermal loading, the sample temperature is recorded at different laminate depths. The specimens are tested with non-destructive methods such as infrared spectroscopy (ATR-FTIR) and microfocused computed X-Ray tomography (µCT). Moreover, destructive tests are performed to determine the interlaminar shear, compressive and tensile strength. Basically, the loading scenarios vary in heat flux and exposure time. Therefore, different temperature distributions, decomposition processes and damage

gradients occur along the sample cross-section. However, by applying the 2 % method according to DIN 65583, operating times and temperatures of carbon fibre-reinforced polymers can be determined for different thermal loading scenarios. Furthermore, with these findings, a deeper insight into the damage behavior of CFRP can be obtained and threshold times for the beginning of strength loss can be defined.

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abst. 2206
Repository

Numerical modelling of composite panels with microvascular channels

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Bio-inspired vascular networks are widely used in engineering fields such as battery cooling, nanosatellite panels, self-healing and self-cooling materials. This paper demonstrates the methodology of numerical modelling of microvascular channels in a composite material. Computational fluid dynamics (CFD) simulations are performed to analyze panel cooling effectiveness using several designs of two-dimensional channel networks at different coolant flow rates and channel diameters. Simulation results show the channel diameter has a negligible effect on cooling performance. CFD simulations confirm that microvascular composite panels can cool typical battery cells.

Improving the buckling capacity of composite panels with cutouts using continuous curvilinear fibres and stiffeners based on streamlines

abst. 2117
Room 2
Thursday
September 2
16h10

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Advanced manufacturing techniques such as automated fibre placement and additive manufacturing are able to fabricate variable[U+2010]stiffness composite panels with curvilinear fibres and stiffeners. In this paper a novel concept is proposed for improving the buckling capacity of grid-stiffened composite panels with cutouts. The key idea is to adopt the streamlines of a fluid flow around a body with an arbitrary shape that represents the cutout to define both the fibre and stiffener trajectories. As opposed to the traditional straight paths of fibres and stiffeners which break at the cutout, the trajectories that emulate the streamlines curve around the cutout in a continuous fashion leading to improve the structural performance of the panels. The buckling performance of a typical aircraft panel with a cutout subjected to a combination of in-plane uniaxial compressive and shear loads is addressed. Circular cutouts with different sizes as well as elliptical ones with different sizes and alignments are considered. A Python[U+2010]Abaqus script is developed to perform the buckling analysis of the panels. The skin is modelled using shell elements and the stiffeners are idealized by beam elements. Different tailoring scenarios for grid[U+2010]stiffened and unstiffened quasi-isotropic and variable[U+2010]stiffness skins are presented to demonstrate the impact of steering the fibres and stiffeners that imitate the streamlines around the cutouts on the buckling performance. It is shown that up to 25% improvement in the buckling load of the unstiffened panels can be achieved by using continuous curved fibres around the cutout compared to their straight fibres baseline. For the grid-stiffened panels the improvement may reach 190% for the large cutouts and 38% for the small ones. Finally, it is demonstrated that the stiffeners constructed using streamlines can create beneficial doublers around the circular and elliptical cutouts leading to promising designs in composite aircraft structures.

Experimental and numerical analysis of the effect of processing parameters on the deformation behaviour of continuous fiber reinforced plastics made by Tailored Fiber Placement under tensile loading

abst. 2134
Repository

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In this work, the influence of several Tailored Fiber Placement (TFP) processing parameters on the local deformation behaviour under tensile loading and the influence on the tensile modulus in TFP based unidirectional carbon fiber reinforced plastics (CFRP) is investigated experimentally and numerically. The TFP technology is a textile manufacturing technique particularly for variable stiffness composite laminates, where a fiber roving is placed along almost any arbitrary curves in a 2-D plane. The roving is fixated by the stitching yarn on a textile base material using a double locked stitch in a zig-zag stich pattern. The characteristic TFP process parameters are stitch distance (distance between two stitches parallel to the placing direction), stitch width (distance between two stitches orthogonal to the placing direction) and roving distance (distance between the center-line of two adjacent rovings). Due to the displacement volume of the stitching yarn and the used stitch type the placed roving is undulated with

in the placement plane and out of the plane and the morphology is inhomogeneous, which leads to a variation of the local fiber volume content within the placed rovings. In this study unidirectional TFP based CFRP laminates with 7 different TFP parameter sets, which display the capabilities of typical TFP devices, were produced using resin transfer molding (RTM) in a cavity with a constant thickness of 1 mm. The laminates vary regarding their stitch width and stitch distance, while roving type, matrix system, base material, laminate thickness and average fiber volume content are identical. Six specimens of each configuration were tested in a tensile test rig according to the DIN ISO EN 527 standard. Strain measurement was performed using a 3D Digital Image Correlation system. The optical strain data are compared with numerical derived strain data of a 3D representative volume element (RVE) finite element model presented in previous research. The RVE considers the geometrical impact of the stitching yarn on the local fiber orientation and the local fiber volume content in a single unidirectional layer of CFRP into account. With the RVE approach the optical derived inhomogeneous strain distribution data could be confirmed in the numerical simulations. This allows a significantly better prediction of the resulting material properties as a function of the applied TFP process parameters in TFP based parts.

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abst. 2288
Room 2
Thursday
September 2
16h30

Dynamic Response Optimization of Variable-Angle Tow Laminates

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Nowadays, composite manufacturing processes allow the production of variable angle tow laminates, where the fibers follow a curvilinear trajectory. This has led to an increase in the design possibilities for fiber orientations inside the same ply which consequently influences the composite properties. In this context, this paper presents a numerical investigation and optimization of the modal response of composites fibers with curvilinear trajectories. Variable angle tow laminates are often manufactured using the automated fiber placement process. This process is limited in terms of radius of curvature and can sometimes introduce defects in the final product. In light of this, this investigation considers different case studies by including different boundary conditions, manufacturing constraints and design variables. The main objective is to optimize a tow-steered composite plate to either have the maximum fundamental frequency or the maximum specific damping capacity. The equations of the composite plate are modelled using finite elements complemented by the strain energy method to model damping, and the optimization is based on genetic algorithms. Results show that curvilinear fiber orientations can lead to composites with improved dynamic characteristics.

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abst. 2293
Room 2
Thursday
September 2
16h50

Buckling Optimization of Grid-Stiffened Curvilinear Fiber Composite Panels

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Automated Fiber Machines (AFP) can manufacture variable[U+2010]stiffness composite panels with curvilinear stiffeners. In this work, the buckling performance of curvilinear composite panels with different grid-stiffened layouts is optimized. The panels are subjected to in-plane compressive loads under various boundary conditions. In this study, an optimization framework is developed using genetic algorithms. To this end, the objective is to maximize the buckling loads. The design variables are defined for the fiber orientation of the skin and the layout of the stiffeners. The fiber reference path for the skin varies linearly in its orientation along one spatial direction. This definition implies two design variables, i.e., fiber orientation at the center and side of the panel, for each layer of laminates, as the panel dimensions are assumed to be fixed. The stiffeners layout is parametrized using other two design variables, which are the stiffener location and its curvature. Tailoring both laminated fiber orientation and stiffeners shape can lead to an improvement in buckling behavior compared to their straight-design analogues. Using the finite element method, the skin is modelled using shell elements and the stiffeners are idealized by beam elements. Manufacturing constraints in terms of maximum curvature allowable by the AFP machine are imposed for both skin fibers and stiffeners fibers. The optimal designs are obtained considering the effects of gaps or overlaps of each ply as a defect of composites manufactured by AFP machines. KEYWORDS: Variable Stiffness Composite Structures, Curvilinearly Grid-stiffened panel, Manufacturing Constraints, Buckling, Finite element analysis, Optimization.

Author Index

Ömer Civalek, 167
Özaslan Emre, 43
İplikçi, Hande, 54
İriş, Erdem Mehmet, 54
Abbaszadeh, Shokoofeh, 140
Abd-Elhady, Amr, 35
Abderrahim El-Mahi, 33
Abed, Farid, 46
Acanfora, Valerio, 7, 121
Adrian Chajec, 75
Afrasyab Khan, 7–11
Agnihotri, Prabhat, 138
Agnihotri, Prabhat K, 151
Airoldi, Alessandro, 67, 139
AKBAROV, Surkay, 82
Akbolat, Mehmet Çağatay, 67
Akhatov, Iskander, 29
Aktaş, Engin, 54
Alfredo Rocha de Faria, 36
Alhaj Ahmad, Ahmad, 169
Alhazmi, Waleed, 35
Alhoubi, Yazan, 46
Ali Yetgin, 43
Alkhedher, Mohammad, 74
Altenbach, Holm, 36
Althahban, Sultan, 35
Amaro, Ana Martins, 73
Amico, Sandro Campo, 120
Amirouche Goumghar, 33
Amirtham Rajagopal, 100
Amirtham, Rajagopal, 64, 65, 119
Anders, Boström, 78
ANDRES CECCHINI, 135
Andrzej Komorek, 121
Andrzej, Leski, 102
Angel Arias, 161
Ansari, Mohammad, 33
Anton Shipsha, 45
Anuszkiewicz, Alicja, 117
Araújo , Aurélio L., 111
Araújo, Aurélio L., 12
Arameh Eyvazian, 7–11
Araujo, Aurelio, 154
Archer, Edward, 28
Arefi, Mohammed, 142
Arias, Angel, 86
Aribas, Umit Necmettin, 112
Arnautov Aleksandr K., 123
Arranz, Sofia, 170
Arruda, Mario Rui, 48
Ashkan Farazin, 74
Asrofi, Mochamad, 150
Atalay, Mert, 112
Attard, Thomas, 148
Augello, Riccardo, 24, 26, 29, 155
Avey, Mahmure, 80
Bülent Acar, 43
Baak, Nikolas, 88
Badurowicz, Przemyslaw, 71
Bagdasaryan, Vazgen, 155
Bai Jiangbo, 152
Bai, Xiaowei, 12
Ballarin, Pietro, 139
Balokhonov, Ruslan, 99
Banat Dominik, 66
Banić, Damjan, 162
Barışık, Murat, 54
Baranowski, Pawel, 5
Barbosa, J.I., 147
Bareille, Olivier, 14
basdogan, ipek, 159
Bedi, Harpreet, 138
Bedi, Harpreet Singh, 151
bediz, bekir, 159
Belingardi Giovanni, 30
Bender, Marcel, 117
Beomjoo Yang, 143
Bhola, Lalit, 137
Bibinger Johannes, 167
Bienias Jaroslaw, 58
Bismarck, Alexander, 140
Bittrich, Lars, 169
Bochenski, Marcin, 20
Boiocchi, Matteo, 139
Bonthu, Dileep, 42
Borowiec, Marek, 20
Bortoli, Fabio da Silva, 54
Bottasso, Luigi, 139
Boursier Niutta Carlo, 30
BOZTOPRAK, YALÇIN, 81

Branco, Ricardo, 73
Brezetić, Dominik, 160
Brogliato Alessandro, 83
Broughton James, 133
Bu Guangyu, 152
Burgstaller, Christoph, 140
Campos, Claudia Maria de Oliveira Campos, 71
Cao, Dongfeng, 2
Cardoso, Daniel, 52
Carlone, Pierpaolo, 29
Carpinteri, Andrea, 149
Carrera Kristýna, 152
Carrera, Erasmo, 24, 26, 29, 155
Carrera, Kristýna, 153
Carvalho, João, 170
Catapano Anita, 133
Chalimoniuk, Marek, 123
Chauhan, Ankit, 151
Chen Changhao, 165
Chen Yuan, 36
Chen, Changhao, 35
Chen, Heze, 47
Cho, Jin-Rae, 26
Choe, Hyeonseok, 17
Choe, Jaeheon, 14
Choi, Won-Ho, 39
Choi, Won-Woo, 39
Chowaniec, Agnieszka, 49
Chunwei Zhang, 7–11
Ciampaglia Alberto, 30
Ciardiello Raffaele, 30
Cieplak Kamil, 83
Cinefra, Maria, 22
Civalek Ömer, 4
Civalek, Omer, 142
Cojocaru Sergiu, 77
Colatosti, Marco, 81
Conceição António, Carlos, 157
Coppede, Daniel, 54
Correia, Victor F., 111
Costa,Mauro, 115
Cotrim, Bruno, 154
CRACIUN Eduard-Marius, 64
Craciun, E-M, 36
Crespo-Miguel, Javier, 86
Czél, Gergely, 62, 65
Czarnecki, Sławomir, 50
D'Ottavio, Michele, 135
Dae sung Lee, 85
Dae-sung Lee, 38
Dammak Fakhreddine, 113
Daneshkhah, Ehsan, 24
Daniel Garcia-Gonzalez, 161
Darnal, Aryabhat, 56
das Neves Carneiro, Gonçalo, 157
Das, Subir, 36, 112
Das, Sukanta, 69
DAVID SERRANO, 135
De Bellis Laura Maria, 146
De Corte, Wouter, 53
De Rosa, Sergio, 14
Debski, Hubert, 28, 29
Dehneliler, Serkan, 54
Delbariani-Nejad, Ali, 157
Delp, Alexander, 90
Demirbas, Munise Didem, 26, 29
Deng, Linlin, 92
Deng, Xiaowei, 114
Deshpande, Himani, 56
Dhaladhuli Pranavi, 100
Di Cara, Girolamo, 135
Dian Wang, 6
Dimitri, Rossana, 60
Dmitrii Volkov- Bogorodskii, 57
Doddamani, Mrityunjay, 42
Donati, Lorenzo, 92
Dong, Kun, 105
Dooher, Thomas, 28
Dragan, Krzysztof, 102
Droździel, Magda, 57
Droz Christophe, 79
Drozdziel Magda, 58
Du,Changmei, 97
Duarte, Roberto Nunes, 54
Dubovikov, Evgeny, 96
Eerme, Martin, 1
Eibl Sebastian, 167
EKİCİOĞLU KÜZECİ, Zeynep, 82
El Oualid MOKHNACHE, 16
ElRefai, Ahmed, 46
Elvas, André, 153
Ermanni, Paolo, 43
Ersoy Hakan, 4
Esenoğlu, Gözde, 54
Esteves, Mafalda, 18
eyvazian, Arameh, 74
Fabbrocino, Francesco, 25
Fagan, Edward, 41
Falaschetti, Maria Pia, 92
Falkowicz Katarzyna, 31
Fantuzzi Nicholas, 152
Fantuzzi, Nicholas, 25, 37, 80, 81
Farrokhabadi, Amin, 157
FASCETTI, Alessandro, 46
Feng, Xin, 23
FEO, Luciano, 46, 73, 111
Ferdynus Miroslaw, 31
Filippi, Matteo, 26
Finley, James, 133
Fiumarella Dario, 30
Folkow, Peter D., 78

Fomin, Aleksandr, 1
Fomina, Marina, 1
Fornůsek Jindřich, 152
Fornůsek, Jindřich, 154
Fotouhi, Mohamad, 166
Fotouhi, Mohammad, 157, 166
Fotouhi, Sakineh, 166
Frajuca, Carlos, 54
Franco, Francesco, 14
FREDERICK JUST AGOSTO, 135
GÜÇLÜ, HARUN, 18
Gąsior, Paweł, 117
Gaitanelis, Dimitrios, 89
Gajewski, Jakub, 122
Gandhi, Yogesh, 41
Gao, Wan-Yang, 105, 107
García-González, Daniel, 86
Garcia-Castillo, Shirley K., 136
Gawryluk, Jarosław, 88
Gawryluk, Jaroslaw, 20, 102
Geng Ling, 16
Gentieu Timothée, 133
Gerdes, Lars, 91
Gevorkyan, E.S., 85
Ghiasvand, Sara, 67
GHITA Marius Glibert Daniel, 64
Giannaros, Efthymios, 120
Giglio, M., 98
Giglio, Marco, 120
Gilles Lubineau, 59
Gliszczynski Adrian, 119
Goggins, Jamie, 41
Gomez, Jose, 47
Gonzalez-Jimenez, Alvaro, 98
Gowid,Samer, 84
Gribniak Viktor, 123
Groh, Rainer M.J., 22
Gudladt Hans-Joachim, 167
Guisong Wang, 16
Gulevsky, Igor, 96
Guruprasad, P.J., 137
Guruprasad, PJ, 44, 117
H. Sam Huang, 100
H.K. Lee, 143
Haddad Khodaparast, Hamed, 157
Hak jin Lee, 86
Hao Peng, 37
Hao, Huali, 2
Hao, Ziqing, 92
Harrison, Philip, 166
Hartmann, Stefan, 5
Hashem, Mjed, 124
Hassan Lakiss, 79
Heggemann, Thomas, 35
Heidari, Hadi, 166
Hilal Reda, 79
Ho jin Jeong, 86
Hoerner, Stefan, 140
Hoffman, Joe, 14
Homberg, Werner, 35
Honório, Gabriel de Carvalho, 71
Hong, So-Mang, 39
Horta Muñoz, Sergio, 89
Hu Heng, 145
Hu, Haixiao, 2
Hu, Heng, 12, 25
Hu, Ke-Xu, 105
Huelsbusch, Daniel, 88
Hui, Yanchuan, 25
Hye ree Lee, 86
Hyeon seok Choe, 85
Hyeon seung Jo, 85
Hyun-Seok Ko, 40
Iarriccio, Giovanni, 93
Ichchou Mohamed, 79
Ichchou, Mohamed, 14
Isaac, Chukwuemeke William, 113
Ivañez, Ines, 136
Ivančević, Darko, 120, 160
Jędrysiak, Jarosław, 114
Jacek Janiszewski, 83
Jae-hyeong Jeong, 38
Jafarzadeh, Ata, 78
Jakubczak Patryk, 58
Jakubczak, Patryk, 57
Jan Godzimirski, 121
Jang, Min-Soo, 159
Jang, Woo-Hyeok, 159
Jasztal, Michał, 123
Jazaa, Yosef, 35
Jean-Francois Ganghoffer, 79
Jia,Jiale, 97
Jia-le Che, 70
Jiang, Jingqiao, 2
Jianglin Li, 104
Jianhe Xie, 104
Jiao-Wang, Liu, 5
Jie-Kai Zhou, 32
Jin, Do-Hyun, 159
Jin-Ho Bae, 143
Jin-Hwe Kweon, 40, 72
Jin-hwe Kweon, 38
Jinaga, Ujwal Kishore, 67
Jinghui Zhang, 167
Jonak, Jozef, 29
Joon-Hyung Shin, 40
Jorge Gonzalez-Rico, 161
Jumel Julien, 133
Jun sung Lee, 85
Jun-Jie Zeng, 32, 105, 108
Jung, Jaehyung, 17
K, Akshaya Gomathi, 119

K, Surya Shekar Reddy, 65
Künzel Karel, 152
Künzel, Karel, 153
Kłonica, Mariusz, 95
Kaleta, Jerzy, 117
Kang, Jung Min, 48
Kaore , Ameya, 99
Kappel, Andreas, 21
Kara, Yahya, 41
Karjust, Kristo, 1
Katnam, Kali Babu, 67
Kaur, Amanpreet, 15
Kazemi Vanhari, Afrooz, 41
Kazilas, Mihalis, 89
Kendall, Ken, 93
Khalid, Hasan M., 6
Khan, Muhammad, 93
Kheml Přemysl, 152
Kheml, Přemysl, 153
Kim, Chun-Gon, 159
Kim, Dong-Hyeop, 31
Kim, Jeeeun, 56
Kim, Min-Jun, 39
Kim, Sang-Woo, 31, 32
Kim, Sol, 159
Klein, Jens, 3
Kloda, Lukasz, 20
Konrád Petr, 152
Konrád, Petr, 153
Koshuro, Vladimir, 1
Krimo Azouaoui, 33
Krismawati, Novita, 160
Kuželová Košťáková, Eva, 62
Kucewicz Michał, 83
Kucewicz, Michal, 5
Kucharczyk, W., 85
Kulpa, Maciej, 49
Kumar, Rajnish, 101
Kumar, Vipin, 69
Kumosa, Maciej, 14
Kuncius Tomas, 61
Kuprin, A.S., 85
Kuruoglu, Nuri, 80
Kvaternik Simonetti, Sandra, 162
Kweon, Jin-Hwe, 39
Kweon, Jinhwe, 17
Kwon, Hyunseok, 159
lahe motlagh, Peyman, 159
Lanc, Domagoj, 162
Latko-Duralek, Paulina, 34
163.com, 152
LE, Thi H.C., 135
Lee, Daesung, 17
Lee, Jeongun, 48
Lee, Keung-In, 39
Lee,Dahun, 164
Leistner, Chris, 5
Lessing, Vincent, 3
Levin,Vadim, 96
Li Liang, 145
Li, Aonan, 95
Li, Guochang, 50, 51
Li, Shuxin, 2
Li, Xiao, 50, 51
Li, Yong, 37
Li, Zhangxiang, 107
Li,Hanhua, 96, 97
Lilholt, Hans, 101
Lim, Jaehyeong, 32
Lim, Jun Woo, 14, 15
Lim, Yun Mook, 48
Liu Bo, 21
Liu Tianwei, 152
Liu, Liu, 92
Liu, Pengfei, 80
Liu, Runze, 50, 51
Liu, Sixin, 166
Liu, Wang-Wei, 107
Logakannan, Krishna Prasath, 17
Loja, M.A.R., 147
Lou, Tiejiong, 107
LOVISI, Giuseppe, 111
Lubineau, Gilles, 124
Luciano, Raimondo, 130
Lukasz Sadowski, 75
Luo, Yunhua, 4
Mára Michal, 152
Mára, Michal, 153
Mészáros, László, 42
Małachowski Jerzy, 83
uaeu.ac.ae, 46
Madeira, Jose, 154
Madsen, Bo, 101
Mahdi, Elsadig, 84
Majak, Jüri, 1
Makinde, Olumide Mayowa, 36
Malachowski, Jerzy, 5
Manes, A., 98
Manes, Andrea, 120
Mania, Radosław, 66
Mania, Radoslaw, 44
Marano, Giuseppe Carlo, 109
MARCO MENEGOZZO, 135
Marek Rośkowicz, 121
Maria Luisa Lopez-Donaire, 161
Marino, Salvatore Giacomo, 62, 65
Marques, António, 18
Martin, Seçkin, 54
MARTINELLI, Enzo, 73
Martinez-Tarifa, Juan Manuel, 86
Masahito, Ueda, 61
Maurício Vicente Donadon, 36

Mazurkiewicz, Lukasz, 5
Mazzeo, Giulia, 14
McCann, Finian, 48
McIlhagger, Alistair, 28
Mejias-Fernandez, Javier, 86
Mercan Kadir, 4
Mercan, Kadir, 142
Miedzinska, Danuta, 34
Miguel Angel Moreno, 161
Mikkelsen, Lars, 101
Min-Jun Kim, 40
Minak, Giangiacomo, 41
Mirauskaitė Akvilė, 61
Mitra, Mira, 117
Mittelstedt, Christian, 3, 21, 131, 162, 169
Mittelstedt, Siham, 131
Moita, José S., 111
Moleiro, Filipa, 128
Molnár, Kolos, 41
Monaco, Alessia, 108, 109
Montemurro, Marco, 129
Morokov, Egor, 96
Moses, William, 28
Mota Soares, Cristóvão M., 111
Mousa, saeed, 35
Mujumdar, P.M., 137
Mujumdar, PM, 44
Muliana, Anastasia, 56
Murali, Gokul Ganesh, 139
Mustapha Assarar, 33
Musyarofah, Lailatul, 149
Nóvoa, Paulo, 18
Nagham Mawassy, 79
Nam, Young-Woo, 39
Nam, youngwoo, 17
Nardi, Davide, 57
Nasedkin, Andrey, 64, 65
Nasedkina, Anna, 64, 65
Neto, Maria A., 73
Nguyen, Minh Hoang, 100
Nicolescu, Adrian Eracle, 24
Niedermeier, Michael, 88
Niu, Yan, 80, 143, 147
Oh, So Young, 164
Ojo, Saheed O., 6, 22
Okada, Takao, 69
Olmedo, Álvaro, 5
Omurtag, Mehmet Hakkı, 112
Ostash, O.P., 85
Ostrowski, Krzysztof Adam, 106
Osuch, Tomasz, 117
Ouyang, Li-Jun, 107
Pacek, Dawid, 71
Padhee, Srikant, 138
Pagani, Alfonso, 48, 155
Pang, Miao, 107
Papež Václav, 152
Papež, Václav, 153
Paredes-Gordillo, Marco A., 136
Park, Ji Woon, 48
Park, Young-Bin, 164
Pasnik, Jakub, 59
Paul Olugbeji Jemitola, 36
Paweł Baranowski, 83
Paweł Przybyłek, 121
Pawelczyk Marek, 113
Peinado, Jairo, 5
Pellicano, Francesco, 93
PENNA, Rosa, 46, 73, 111
PEPE, Marco, 73
Per Wennhage, 45
Petr Belov, 57
Petrone, Giuseppe, 14
Petronyuk, Yulia, 96
Piątek, Bartosz, 49
Pimenta, Soraia, 133
Pindera, Marek-Jerzy, 47, 132
Ping Hu, 59
Pingaro Marco, 146
Pinho, Silvestre, 127
Platek Pawel, 83
Platek, Pawel, 5
Podhurska, V.Ya., 85
Podolak Piotr, 58
Podolak, Piotr, 57
Pohlak, Meelis, 1
Polit, Olivier, 135
Poplawski Arkadiusz, 34
Potluri, Prasad, 67
Predecki, Paul, 14
Prikhna, T.A., 85
Prusty Aurojyoti, 64
Punith, P, 117
Qian, Connie, 93
Qiduo Jin, 78
Qiu, Zengmei, 50, 51
QUAN, 63
R, Jayaganthan, 17
R, Velmurugan, 17
Rafiei Anamagh, Mir Meysam, 159
Rajagopal Amirtham, 64
Rajchel, Mateusz, 49
Ran Tao, 59
Ratas, Mart, 1
Reccia Emanuele, 146
Reddy, K Surya Shekar, 64
Rede, Francisco, 18
Reis, Paulo N.B., 73
Rezak Ayad, 33
Rezasefat, M., 98
Rho Shin Myong, 86
Riccio, Aniello, 7, 121

Rickard Persson, 45
Rimašauskas Marius, 61
Rimašauskienė Rūta, 61
Rimkus Arvydas, 123
Rinaldi, Martina, 60
Risso, Giada, 43
Riva, Marco, 139
Rośkowicz, Marek, 123
Robert Szczepaniak, 121
Robinson, Paul, 139
Robles, Guillermo, 86
Rocco Libero Giossi, 45
Rofi'i, Imam, 150
Rogala, Michał, 122
Roh, Hyung Doh, 164
Romanova, Varvara, 99
Ronchei, Camilla, 149
Rondina, Francesco, 92
Rong, Chong, 53
Rozylo Patryk, 31
Rozylo, Patryk, 28, 95
Ruan, Dong, 17
Rubio, Patricia, 136
Rucki, M., 85
Rusinek, Alexis, 86
Russo, Angela, 7, 121
Ryo,Higuchi, 61
Ryoma,Aoki, 61
Ryota,Sako, 61
Ryzhova, Tatyana, 96
Rzeczkowski, Jakub, 59
Sałaciński, Michał, 102
Sadowski Tomasz, 146
Sadowski, Łukasz, 50
Safonov, Alexander, 29
Saitta, Serena, 25
Sakovsky, Maria, 43
Salamat Ullah, 167
Salid, Mohd. Sapuan, 150
Sallam, Hossam Al-Din, 35
Samborski, Sylwester, 59, 95
Sang min Lee, 86
Sapli, Hüseyin, 35
Saputo, Salvatore, 7, 121
Sarzynski Marcin, 83
Saurav, AK, 44
Scazzosi, Riccardo, 120
Schürmann, Helmut, 3
Schilling, Jakob C., 162
Schledjewski, Ralf, 117
Schneider, Jens, 131
Scorza, Daniela, 149
Sebastian Stichel, 45
Sellitto, Andrea, 7, 121
Serbenyuk, T.B., 85
Sergey Lurie, 57
Serna Moreno, Maria del Carmen, 89
Seung-Hwan Chang, 70
Shaffer, Milo S P, 133
Shahid, Zaryab, 56
Shao Qian, 145
Shen, Jiahui, 48
Shi, Farui, 37
Shu-Hua Xiao, 105
Shuangyan Ju, 6
Singh, Ritika, 36, 112
Siwowski, Tomasz, 49
Skoczylas, Jakub, 95
Slaitas Justas, 104
Smarzewski, Piotr, 46
Smojver, Ivica, 160
So-Mang Hong, 40, 71
Sofiyev, Abdullah, 80
Sohouli Abdolrasoul, 83
Sohouli, Abdolrasoul, 115, 153, 170
Solazzi, Luigi, 55
Somoskői, Balázs, 41
Song, Jiang, 107
Song, Peihao, 2
Souza, Marco Antonio, 54
Souza, Renato Chaves, 54
Sovják Radoslav, 152
Sovják, Radoslav, 153
Spickenheuer, Axel, 169
Spychala, Maciej, 34
Srenivasa, Karthik, 64, 65
Stommel, Markus, 169
Striemann, Patrick, 88
Sujito, 149
Suleman Afzal, 83
Suleman, Afzal, 115, 153, 170
Supriyanto, Edy, 150
Sutisna, Sutisna, 150
Synaszko, Piotr, 102
Türkdoğan, Ceren, 54
Tabatabaeian, Ali, 166
Taegeon Kil, 143
Talebi Cihan, 43
Tam, Lik-ho, 2
Tamer A. Sebaey, 7–11
Tanoğlu, Metin, 54
Tanwar, Anshika, 36
Tatár, Balázs, 42
Teter, Andrzej, 20, 88, 102
Thomason, James, 75
Tomaszewski, Michal, 5
Tomczyk, Barbara, 155
Tome, Marta, 154
Tomohiro,Yokozeki, 61
Tondolo, Francesco, 109
Tornabene, Francesco, 60
Tröster, Thomas, 136

Trabelsi Sourour, 113
Triebus, Marcel, 136
Trinh, Luan, 33
Trinh, Luan C., 22
Trovalusci Patrizia, 146
Trovalusci, Patrizia, 37, 81
Trullo, Marco, 60
Tucci, Fausto, 29
Turconi, Tommaso, 139
Turkalj, Goran, 162
TURKOGLU, İBRAHİM KÜRŞAD, 18
U, Ubaidillah, 160
Uhlig, Kai, 169
Upnere Sabine, 168
Uyttersprot, Jordi, 53
Valivonis Juozas, 104
Van Paepegem, Wim, 53
Vankar , Sachin Rajaram, 99
Vantadori, Sabrina, 149
Vedernikov, Alexander, 29
Vescovini, Alessandro, 120
Vescovini, Riccardo, 25
Vieira, Francisco S., 12
Waas, Anthony M., 100
Waas, Antony, 128
Wachtarczyk, Karol, 117
Wagih, Ahmed, 124
Wajdi Zouari, 33
Walther, Frank, 88, 90, 91
Wang Yu, 37
Wang, Shuai, 95
Weaver, Paul, 33
Weaver, Paul M., 6, 22
Weber, Christian-Toralf, 140
Wei, gaojian, 92
Wen-Kai Lin, 32
Wiśniewski, Adam, 123
Wibowo, w, 160
Williams, Babajide, 14
Won-Ho,Choi, 71
Won-Woo Choi, 40
Worrall, Chris, 89
Wrona, Stanislaw, 113
Wu Qi, 165
Wu, Chao, 2
Wu, Qi, 34
Wu, Qiliang, 80, 147
Wyczółkowski, Rafał, 156
Wysmulski Pawel, 31
Xian Yang, Xu, 29
Xiong Ke, 165
Xiong, Ke, 35
Xue, Jianghong, 77
Xypolias,Georgios, 75
Yan Yang, 21
Yan,Shi, 96, 97
yang bo, 79
Yang Jie, 145
Yang, Dongmin, 95
Yang, Jian, 105
Yang, Jie, 12, 25
Yang, Liu, 75
Yang, Yichen, 25
Yang, Zhijian, 50
Yao Sishi, 77
Yao, Minghui, 80, 143, 147
YAZICI, MURAT, 18, 81
Ye Lin, 36
Yerramalli , Chandra Sekher, 99
Yin, Shizhen, 132
Yiru Ren, 78
Yokozeki, Tomohiro, 69
Yong-Chang Guo, 105
Yongchao Li, 104
Yoshikawa, Nobuhiro, 35
Young-Hoon Ko, 70
Young-Woo Nam, 40, 72
Young-woo Nam, 38
Yu, Zechuan, 2
Yu-Yi Ye, 105, 108
Yuan, Hao, 93
Yunfei Qu, 6
Yuta, Urushiyama, 61
Zaczynska, Monika, 44
Zanichelli, Andrea, 149
Zasada, Dariusz, 34
Zeng, Junjie, 53
Zghal Souhir, 113
Zhai, Hongzhou, 34
Zhang Hanqi, 165
Zhang, Haoqi, 95
Zhang,Liangliang, 23
Zhang,Qiuhua, 97
Zhao Qingxin, 167
Zhao, Hongchao, 53
Zhao, Jiuzhou, 114
Zhao,Yun, 96
Zhong, Yucheng, 74
Zhongyu Lu, 104
Zhou, Ao, 2
Zhou, Yu, 69
ZHU, Yingbo, 46
Zine Abdelmalek, 79
Zippo, Antonio, 93
Zucco, Giovanni, 33
Zuo, Siming, 166
Zurowski, W., 85