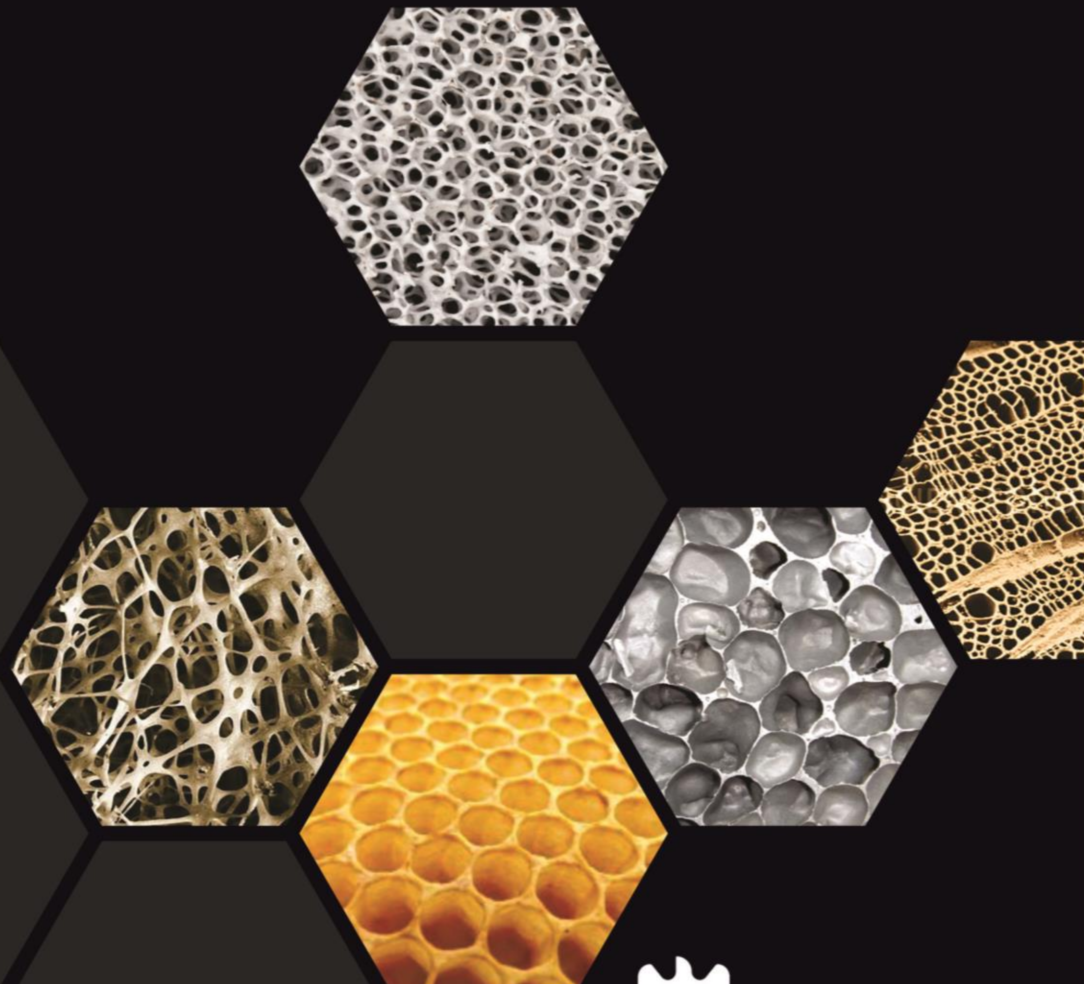
InCell 2019

Book of Abstracts of the International Conference on Multifunctional Cellular Materials

Maribor, Slovenia, September 19-20, 2019

Edited by
Isabel Duarte, Matej Vesenjak, Zoran Ren



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PREFACE

The research of cellular materials has significantly increased over the last two decades, which reflects in the growth of published scientific literature. The industrial sector is also increasingly recognising the importance of cellular materials with appearance of new bioinspired materials that have revolutionised a large number of industrial applications. Workshops, symposiums and conferences have emerged in this field, particularly in Europe. In this context, the first conference in series dedicated to cellular materials (MatCel) was organised at the University of Aveiro, in Portugal, during September 7th – 8th, 2015. The aim of this conference was to identify the number of Portuguese teams that are actively engaged in research in this field. The conference was held at the Department of Mechanical Engineering, with most of the participants coming from Portugal. Then the second conference was organised also at the University of Aveiro during September 25th – 27th, 2017, which was truly international with most of the participants from abroad, and with five plenary lectures given by renowned international experts.

The event has now assumed itself as a biennial conference, aiming to be a regular and privileged forum for the exchange and discussion between scientists, academia and industry, inspiring future collaborations and bringing up new ideas within this field. Furthermore, the National Conference on Cellular Materials "MatCel conference" held in Aveiro (Portugal) has now been converted to an international event. Due to the rising interest in this field and the increasing number of both national and international participants, we have decided to not only rename the conference, but also organize it around the world. The conference is now to be known as the "International Conference on Multifunctional Cellular Materials (InCell, incell.web.ua.pt)" with the purpose of widening the scope of these thematic fields and attracting more participants, covering experimental, numerical and theoretical issues. The InCell 2019 is held in the beautiful city of Maribor, Slovenia, from September 19th – 20th, 2019. This international conference focuses on lightweight stochastic and periodic cellular materials (e.g. foams, hollow-spheres, periodic and optimized truss structures, and honeycombs) with multifunctional attributes that make them appealing for numerous applications, including bot not limited to energy absorption (crash protection), lightweight structural sandwich panels (as the core), vibration damping devices and thermal and acoustic insulation.

The organizing committee would like to gratefully acknowledge support and contribution of the invited speakers Prof. Dr. John Banhart (TU Berlin, and Helmoltz-Centre Berlin, Germany), Dr.-Ing. Peter Quadbeck (Fraunhofer Institute for Manufacturing Technologies and Advanced Materials IFAM, Dresden, Germany) and Dr.-Ing. Thomas Hipke (Fraunhofer Institute for Machine Tools and Forming Technologies, Chemnitz, Germany) as well as all attending participants.

Maribor, 19th September 2019

Isabel Duarte, Matej Vesenjak, Zoran Ren

ORGANISING & SCIENTIFIC COMMITTEES

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Thomas Hipke (Fraunhofer IWU, Chemnitz, Germany)
Zoran Ren (University of Maribor, Slovenia)

Conference Organizer

Dr3n Darja Ren s.p.
Maribor, Slovenia

e-mail: darja@dr3n.si

Webpage: http://incell.web.ua.pt/
e-mail: dem-incell@ua.pt

General Information

Language

The official language of the meeting is English.

INVITED SPEAKERS

John Banhart studied Physics at the University of Munich and obtained a doctoral degree in Physical Chemistry from the same university in 1989. He joined the Fraunhofer Institute in Bremen in 1991 and worked in the field of cellular materials. He became a professor of Materials Science at the TU Berlin and head of a research department at the Hahn-Meitner Institute (now Helmholtz-Centre Berlin) in 2002. His current research focus is on lightweight and cellular materials and imaging with X-rays and neutrons. Throughout his scientific career, he registered 11 patents, published more than 376 articles in SCI journals, 163 conference proceedings and book contributions, 55 miscellaneous publications, and 17 editorships for books and journal issues. He has scientific papers in ISI international journals with over 10280 citations. Moreover, he is the founder and main organizer of the biennial MetFoam conference (International Conference on Porous Metals and Metallic foams), started in 1999 at IFAM, Bremen.

More details:
http://www.helmholtz-berlin.de/media/media/spezial/people/banhart/html/index.html

Peter Quadbeck studied physics at RWTH Aachen and obtained his doctoral degree at in the field of high temperature resistant cellular metallic materials at University of Erlangen-Nuremberg. His research interests cover the development of manufacturing technologies for cellular metallic materials and their application related characterization. With his team, he developed various cellular structure types, covering a wide range of geometries, matrix materials and properties. In particular, he is interested in the transfer of such technologies and materials into industrial applications. In this regard, he has a special focus on the field of medical technology, aerospace, and mechanical engineering. His work furthermore involves research in the field of process analysis of the heat treatment in order to gain deeper understanding of debinding and sintering processes and to achieve optimized process design and process control. Furthermore, his scientific activities include the research of biomedical materials, as for example the development of new biodegradable metals, bone graft materials, and materials for cardiovascular interventions. He is currently a Team Leader at the Fraunhofer Institute for Manufacturing Technologies and Advanced Materials IFAM, Branch Lab Dresden.

More details:
https://www.ifam.fraunhofer.de/en/Profile/Locations/Dresden/Cellular_metallic_materials/offenzellige_metallschaeume/technologie.html

Thomas Hipke received his B.Sc. degree in Mechanical Engineering at the Technical University of Chemnitz in Germany and obtained his Ph.D. in 2001 with the doctoral thesis "Analysis, assessment and suitability of aluminum foams for machine tool construction”. He joined the Fraunhofer-Institute for Machine Tools and Forming Technologies Chemnitz as a scientific engineer in 1996. In 2002, he became the head of the Department of Lightweight Design and the Metal Foam Centre of Chemnitz.

More details:
https://www.iwu.fraunhofer.de/en/research/range-of-services/Competence-from-A-to-Z/lightweight-construction/Materials/Metal-lightweight-materials/Metal-foam.html

SCIENTIFIC PROGRAMME

Programme overview

Day 1 19th September			Day 2 20th September	
08:00–08:45	**Registration**		**08:30–09:00**	**Registration**
08:45–09:00	**Welcome and Opening**			
09:00–09:45	**Plenary lecture** Prof. Dr. John Banhart		**09:00–09:45**	**Plenary lecture** Dr.-Ing. Thomas Hipke
09:45–11:00	**Oral presentations**		**09:45–11:00**	**Oral presentations**
11:00–11:30	**Coffee-break**		**11:00–11:30**	**Coffee-break**
11:30–13:00	**Oral presentations**		**11:30–13:00**	**Oral presentations**
13:00–14:00	**Lunch**		**13:00–14:00**	**Lunch**
14:00–14:45	**Plenary lecture** Dr.-Ing. Peter Quadbeck		**14:00–16:30**	**Oral presentations**
14:45–16:30	**Oral presentations**			
16:45	**Social event 1**		**16:30**	**Closing**
19:30	**Conference dinner**		**17:30**	**Social event 2**

Scientific programme

	Day 1 - 19th September
08:00–08:45	**Registration**
08:45–09:00	**Welcome and Opening**
Chair	**Zoran Ren**
09:00–09:45	**Plenary lecture** **Visualising the evolution of liquid metal foams in 3D and in real time** **John Banhart**, Technische Universität, Helmholtz Centre, Berlin, Germany Francisco García-Moreno Technische Universität, Helmholtz Centre, Berlin, Germany Christian M. Schlepütz, Swiss Light Source, Paul Scherrer Institute, Villigen, Switzerland Paul H. Kamm Applied Materials, Helmholtz Centre, Berlin, Germany Tillmann R. Neu, Materials Science and Technology, Technische Universität, Berlin, Germany
09:45–10:00	**Fabrication of uni-pore materials through explosive compaction using cylindrical geometry** **Kazuyuki Hokamoto**, Institute of Pulsed Power Science, Kumamoto University, Kumamoto,Japan Masatoshi Nishi, National Institute of Technology, Kumamoto College, Yatsushiro, Japan Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Lovre Krstulović-Opara, Fac. of El. Eng., Mech. Eng. and Naval Arch., Split University, Split, Croatia
10:00–10:15	**Incremental forming and friction rolling of closed-cell aluminium foams** **Boštjan Razboršek**, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Janez Gotlih, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Timi Karner, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Mirko Ficko, Faculty of Mechanical Engineering, University of Maribor,Maribor, Slovenia
10:15–10:30	**Metallo-ceramic syntactic foams based on metal-coated cenospheres: synthesis, properties and applications** Andrejs Šiškins, Fac. of Mater. Sci. and Applied Chemistry, Riga Technical University, Riga, Latvia **Jörg Weise**, Fraunhofer Inst. for Manufacturing Technology and Advanced Materials, Bremen, Germany Ervin Blumbergs, Riga Technical University, Faculty of Civil Engineering, Riga, Latvia. Viktor Kozlov, 4Sidrabe Inc., Riga, Latvia Sandis Ziedins, Fac. of Mater. Sci. and Applied Chemistry, Riga Technical University, Riga, Latvia M. Lisnanskis, 5SMW Engineering—Latvia, Riga, Latvia Dirk Lehmhus, Fraunhofer Inst. for Manufacturing Technology and Adv. Materials, Bremen, Germany
10:30–10:45	**Structural investigation of bimodal aluminium matrix syntactic foam** **Alexandra Kemény**, Budapest University of Technology and Economics, Budapest, Hungary Borbála Leveles, Budapest University of Technology and Economics, Budapest, Hungary Bálint Katona, MTA–BME Lendület Composite Metal Foams Research Group, Budapest, Hungary
10:45–11:00	**Compressive properties of light expanded clay particle filled metal matrix syntactic foams** **Irme Orbulov**, Budapest University of Technology and Economics, Budapest, Hungary Attila Szlancsik, Budapest University of Technology and Economics, Budapest, Hungary Szabolcs Kis, Budapest University of Technology and Economics, Budapest, Hungary
11:00–11:30	**Coffee-break**

Chair	**Lovre Krstulović-Opara**
11:30–11:45	**The static and dynamic crushing behaviour of EPS foam for packaging application** **Yigit Gurler**, Bosch Thermotechnology, Izmir Institute of Technology, Izmir, Turkey Ayda Ramyar, Bosch Thermotechnology, Izmir Institute of Technology, Izmir, Turkey Alper Tasdemirci, Mechanical Engineering, Izmir Institute of Technology, Izmir, Turkey
11:45–12:00	**Hydrophilic cellular polyacrylates from high internal phase emulsions** **Doris Golub**, Fac. of Chemistry and Chemical Eng., University of Maribor, Maribor, Slovenia Jiři Kotek, Institute of Macromolecular Chemistry, Czech Academy of Sciences, Prague, Czech Republic Peter Krajnc, Fac. of Chemistry and Chemical Eng., University of Maribor, Maribor, Slovenia
12:00–12:15	**Cellular porous beads of polythiolenes from multiple emulsions** **Stanko Kramer**, Fac. of Chemistry and Chemical Eng., University of Maribor, Maribor, Slovenia Peter Krajnc, Fac. of Chemistry and Chemical Eng., University of Maribor, Maribor, Slovenia
12:15–12:30	**Multiple-level cellular porous poly(glycidyl methacrylate) by soft/hard templating** **Peter Krajnc**, Fac. of Chemistry and Chemical Eng., University of Maribor, Maribor, Slovenia Muzafera Paljevac, Fac. of Chemistry and Chemical Eng., University of Maribor, Maribor, Slovenia
12:30–12:45	**Dynamic-mechanical-thermal behaviour of nanocomposite foams based on polysulfone and graphene nanoplatelets** **Marcelo Antunes**, Dept. of Materials Sci. and Metallurgy, Technical University of Catalonia, Spain Hooman Abbasi, Dept. of Materials Science and Metallurgy, Technical University of Catalonia, Spain José I. Velasco, Dept. of Materials Science and Metallurgy, Technical University of Catalonia, Spain
12:45–13:00	**Modeling of thermal properties of polymer foams: recent advances and perspectives** **Christophe Baillis**, EC2-MODELISATION, Villeurbanne, France Dominique Baillis, INSA-Lyon, LaMCoS, Villeurbanne, France Rémi Coquard, EC2-MODELISATION, Villeurbanne, France
13:00–14:00	**Lunch**
Chair	**Matej Vesenjak**
14:00–14:45	**Plenary lecture** **Cellular Metal Materials for bone regeneration** **Peter Quadbeck**, Fraunhofer Inst. for Manufacturing Technology and Advanced Materials, Dresden, Germany Ulrike Jehring, Fraunhofer Institute for Manufacturing Technology and Advanced Materials, Dresden, Germany Cris Kostmann, Fraunhofer Institute for Manufacturing Technology and Advanced Materials, Dresden, Germany Olaf Andersen, Fraunhofer Institute for Manufacturing Technology and Advanced Materials, Dresden, Germany
14:45–15:00	**Metallic scaffolds printed via direct ink writing** **Lisa Biasetto**, Dept. of Management and Engineering, University of Padova, Vicenza, Italy Hamada Elsayed, Dept. of Industrial Engineering, University of Padova, Padova, Italy Nejc Novak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia
15:00–15:15	**Anti-tetra-chiral square grid structure made of orthotropic material** **Tomasz Strek**, Institute of Applied Mechanics, Poznan University of Technology, Poznan, Poland
15:15–15:30	**The experımental and numerıcal ınvestigatıon of the varyıng crushıng strength of a cellular concrete** **Burak Akyol**, Dept. of Mechanical Engineering, Izmir Institute of Technology, İzmir, Turkey Mustafa K. Sarikaya, Dept. of Mechanical Eng., Izmir Institute of Technology, İzmir, Turkey Mustafa Guden, Dept. of Mechanical Eng., Izmir Institute of Technology, İzmir, Turkey

15:30–15:45	**Development of an energy absorber with chiral cellular structure** **Alessandro Airoldi**, Dept. of Aerospace Science and Technology, Politecnico di Milano, Milano, Italy Francesco Sgobba, Dept. of Aerospace Science and Technology, Politecnico di Milano, Milano, Italy Nejc Novak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Matej Borovinšek, Fac. of Mechanical Engineering, University of Maribor, Maribor, Slovenia
15:45–16:00	**Dynamic mechanical analysis of 3D-printed bimaterial beams** Vitor Carneiro, Mech. Eng. and Resource Sustainability, University of Minho, Guimarães, Portugal Pedro Ribeiro, Mech. Eng. and Resource Sustainability, University of Minho, Guimarães, Portugal **Nuno Peixinho**, Mech. Eng. and Resource Sustainability, University of Minho, Guimarães, Portugal José Meireles, Mech. Eng. and Resource Sustainability, University of Minho, Guimarães, Portugal Delfim Soares, Centre for Micro-Electro Mech. Systems, University of Minho, Guimarães, Portugal
16:00–16:15	**Mechanical behaviour of additively-manufactured hybrid lattice structures at different strain rates** **Song Weidong**, Beijing Institute of Technology, Beijing, China Li Shi, Beijing Institute of Technology, Beijing, China
16:15–16:30	**Mechanical properties of novel metallic sheet-based lattices additively manufactured using selective laser melting** **Oraib Al-Ketan**, Khalifa University of Science and Technology, Abu Dhabi, UAE Reza Rowshan, Core Technology Platforms Division, New York University Abu Dhabi, UAE Rashid K. Abu Al-Rub, Khalifa University of Science and Technology, Abu Dhabi, UAE
16:45	**Social event 1 (visit of the old wine cellar, guided tour through Maribor)**
19:30	**Conference dinner**

	Day 2 - 20th September
08:30–09:00	**Registration**
Chair	**Nuno Peixinho**
09:00–09:45	**Plenary lecture** **Metal foams – from research to industrial application** **Thomas Hipke**, Fraunhofer Inst. for Machine Tools and Forming Technology, Chemnitz, Germany Friedrich Schuller, Havel Metal Foam GmbH, Brandenburg an der Havel, Germany
09:45–10:00	**Development of tube filled aluminium foams for lightweight vehicle manufacturing** **Flórián Garai**, Dept. of Materials Technology, John von Neumann, Kecskemét, Hungary Zoltán Weltsch, Dept. of Materials Technology, John von Neumann, Kecskemét, Hungary
10:00–10:15	**Phenomenons during metal matrix composite milling** **János Líska**, Dept. of Vehicle Technology, John Von Neumann University, Kecskemét, Hungary Zsolt Kovács, Dept. of Vehicle Technology, John Von Neumann University, Kecskemét, Hungary
10:15–10:30	**Assessment of the RVE size of virtual foams** **Karol Natonik**, Inst. of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland Marcin Nowak, Inst. of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland Zdzisław Nowak, Inst. of Fund. Technological Research, Polish Academy of Sciences, Warsaw, Poland Ryszard B. Pęcherski, Inst. of Fund. Technological Research, Polish Academy of Sciences, Warsaw, Poland
10:30–10:45	**Characterisation of thin walled sandwich structures comprising steel hollow spheres for the core** **Stylianos Yiatros**, Dept. of Civil Eng. & Geomatics, Cyprus University of Technology, Limassol, Cyprus Orestes Marangos, Dept. of Civil Eng. & Geomatics, Cyprus University of Technology, Limassol, Cyprus Feargal P. Brennan, Dept. of Naval Arch., Ocean and Marine Eng., University of Strathclyde, Glasgow, UK

10:45–11:00	**Infrared evaluation of dynamic loaded tubular structural members with cellular fillers** **Lovre Krstulović-Opara**, Fac. of El. Eng., Mech. Eng. and Naval Arch., University of Split, Split, Croatia Matej Vesenjak, Faculty of Mechanical Eng., University of Maribor, Maribor, Slovenia Isabel Duarte, Department of Mechanical Eng, TEMA, University of Aveiro, Aveiro, Portugal
11:00–11:30	**Coffee-break**
Chair	**Kazuyuki Hokamoto**
11:30–11:45	**Experimental testing of auxetic cellular structures** **Nejc Novak**, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia
11:45–12:00	**Deformation behavior of SLS manufactured auxetic lattices at low and high strain-rates** **Anja Mauko**, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Tomáš Fíla, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Jan Falta, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Petr Koudelka, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Michaela Neuhäuserová, Fac. of Transportation Sci., Czech Technical University, Prague, Czech Republic Petr Zlámal, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Marcel Adorna, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Ondřej Jiroušek, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic
12:00–12:15	**Dynamic properties of optimized auxetic structures** **Bartlomiej Burlaga**, Institute of Applied Mechanics, Poznan University of Technology, Poznań, Poland
12:15–12:30	**The LCF-analyses of auxetic structure using direct cycling algorithm** **Branko Nečemer**, Dept. of Mechanical Eng., University of Maribor, Maribor, Slovenia Janez Kramberger, Dept. of Mechanical Eng., University of Maribor, Maribor, Slovenia Srečko Glodež, Dept. of Mechanical Eng., University of Maribor, Maribor, Slovenia
12:30–12:45	**Designing 2D auxetic structures using multi-objective optimization** **Matej Borovinšek**, Fac. of Mechanical Engineering, University of Maribor, Maribor, Slovenia Nejc Novak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia
12:45–13:00	**Mechanical properties of sandwich beams with auxetic and non-auxetic core** **Hubert Jopek**, Institute of Applied Mechanics, Poznan University of Technology, Poznan, Poland Tomasz Stręk, Institute of Applied Mechanics, Poznan University of Technology, Poznan, Poland Maciej Tabaszewski, Inst. of Applied Mechanics, Poznan University of Technology, Poznan, Poland Institute of Applied Mechanics, Poznan University of Technology, Poznan, Poland
13:00–14:00	**Lunch**
Chair	**Isabel Duarte**
14:00–14:15	**Structural optimization and mechanical characterisation of hybrid auxetic structures** **Stefan Bronder,** LTM, University of Saarland, Saarbrücken, Germany Tomáš Fíla, Dept. of Mechanics and Materials, Czech Technical University, Prague, Czech Republic Marcel Adorna, Dept. of Mechanics and Mater., Czech Technical University, Prague, Czech Republic Ondřej Jiroušek, Dept. of Mechanics and Mater., Czech Technical University, Prague, Czech Republic Anne Jung, LTM, University of Saarland, Saarbrücken, Germany

14:15–14:30	**Multifunctional hybrid foams composed by aluminum open-cell foam filled with polymers** <u>**Susana C. Pinto**</u>, Dept. of Mechanical Eng., TEMA, University of Aveiro, Aveiro, Portugal Paula A.A.P. Marques, Dept. of Mechanical Eng., University of Aveiro, Aveiro, Portugal Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Romeu Vicente, Department of Civil Engineering, University of Aveiro, Aveiro, Portugal Lovre Krstulović-Opara, Fac. of El. Eng., Mech. Eng. and Naval Arch., University of Split, Split, Croatia Isabel Duarte, Dept. of Mechanical Eng., TEMA,University of Aveiro, Aveiro, Portugal
14:30–14:45	**Development of metal-polymer Structures for Impact Energy Absorption** Oscar Carvalho, Mechanical Engineering Department, University of Minho, Guimarães, Portugal C. Areiras, Mechanical Engineering Department, University of Minho, Guimarães, Portugal Paulo Pinto, Mechanical Engineering Department, University of Minho, Guimarães, Portugal F. Silva, Mechanical Engineering Department, University of Minho, Guimarães, Portugal <u>**Nuno Peixinho**</u>, Mechanical Engineering Department, University of Minho, Guimarães, Portugal
14:45–15:00	**Dynamic penetration testing of cellular materials** <u>**Jan Šleichrt**</u>, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Jan Falta, Faculty of Transportation Sciences, Czech Technical University, Prague, Czech Republic Michaela Neuhäuserová, Czech Technical University, Prague, Czech Republic Tomáš Doktor, Czech Technical University, Prague, Czech Republic Tomáš Fíla, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Petr Zlámal, Fac. of Transportation Sciences, Czech Technical University, Prague, Czech Republic Marcel Adorna, Czech Technical University, Prague, Czech Republic Anja Mauko, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Petr Koudelka, Czech Technical University, Prague, Czech Republic Isabel Duarte, Department of Mechanical Engineering, University of Aveiro, Aveiro, Portugal Matej Vesenjak, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Zoran Ren, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Ondřej Jiroušek, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia
15:00–15:15	**Experimental investigation of initial yield surfaces of solid foams and their evolution under subsequent loading** <u>**Anne Jung**</u>, Applied Mechanics, Saarland University, Saarbrücken, Germany Markus Felten, Applied Mechanics, Saarland University, Saarbrücken, Germany Stefan Diebels, Applied Mechanics, Saarland University, Saarbrücken, Germany
15:15–15:30	**Fatigue life analysis of closed-cell aluminum foam using homogenized material model** <u>**Miran Ulbin**</u>, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Srečko Glodež, Faculty of Mechanical Engineering, University of Maribor, Maribor, Slovenia Janez Kramberger, Fac. of Mechanical Engineering, University of Maribor, Maribor, Slovenia
15:30–15:45	**3D geometrical reconstruction of closed-cell aluminum foam using CT images** András Gábora, Dept. of Mechanical Engineering, University of Debrecen, Debrecen, Hungary Tamás A. Varga, Dept. of Mechanical Eng., University of Debrecen, Debrecen, Hungary István Kozma, Dept. of Materials Sci. and Technology, Széchenyi István University, Győr, Hungary Sándor Beke, Aluinvent Zrt., Felsőzsolca, Hungary <u>**Tamás Mankovits**</u>, Dept. of Mechanical Eng. University of Debrecen, Debrecen, Hungary
15:45–16:00	**Experimental and numerical characterisation of open- and closed-cell aluminium alloy foams** João Dias-de-Oliveira, DEM–TEMA, University of Aveiro, Aveiro, Portugal <u>**António Andrade-Campos**</u>, DEM–TEMA, University of Aveiro, Aveiro, Portugal Robertt Valente, DEM–TEMA,University of Aveiro, Aveiro, Portugal Isabel Duarte, DEM–TEMA, University of Aveiro, Aveiro, Portugal

16:00–16:15	**Computational analysis of the uni-directional porous copper mechanical response at high-velocity impact** **<u>Masatoshi Nishi</u>**, National Institute of Technology, Kumamoto College, Kumamoto, Japan Shota Tanaka, Institute of Pulsed Power Science, Kumamoto University, Kumamoto, Japan Shigeru Tanaka, Institute of Pulsed Power Science, Kumamoto University, Kumamoto, Japan Kazuyuki Hokamoto, Inst. of Pulsed Power Science, Kumamoto University, Kumamoto, Japan
15:15–16:30	**Experimental and numerical investigation of the crushing behaviour of an Al corrugated multi-layered cellular structure** **<u>Mustafa Güden</u>**, Dept. of Mechanical Engineering, Izmir Institute of Technology, İzmir, Turkey Mustafa Sarıkaya, Dept. of Mechanical Engineering, Izmir Institute of Technology, İzmir, Turkey İlker Canbaz, Dept. of Mechanical Engineering, Izmir Institute of Technology, İzmir, Turkey Alper Taşdemirci, Dept. of Mechanical Engineering, Izmir Institute of Technology, İzmir, Turkey
16:30	**Closing**
17:30	**Social event 2 (wine tasting at the World's oldest vine tree)**

INVITED ABSTRACTS

VISUALISING THE EVOLUTION OF LIQUID METAL FOAMS IN 3D AND IN REAL TIME

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Keywords: Tomography; Tomoscopy; Aluminium foam

Abstract

Metallic foams have been igniting people's interest for decades due to both their application potential and the fascinating complexity of phenomena associated with liquid and solid foams. In order to elucidate the genesis of liquid metallic foam some new techniques have been developed.

Fast synchrotron X-ray radioscopy has been used to study time-resolved phenomena in liquid metal foams on a sub-second timescale [1]. Over the past years, the temporal resolution of synchrotron imaging has undergone continuous improvement. We present a newly developed in-situ 'tomoscopy' technique, which we define as a method that allows one to monitor time-dependent processes in a continuous way in three spatial dimensions, hence also known as 4D imaging.

We apply the method to evolving metal foams and resolve the entire foaming process in real time: from the solid precursor, over bubble nucleation and growth to the fully expanded liquid foam and eventually to the solidified sample. The whole process is analysed quantitatively at a rate of up to 200 tomographies/s (tps) over several minutes. We calculate the gas bubble nucleation rate and volume distributions for different alloys. Several nucleation stages can be identified and correlated with different gas sources. We follow bubble growth and shape evolution in early stages: It leads from round bubbles to elongated features and sometimes long cracks. This behaviour is explained by the different alloy compositions and precursor compaction methods.

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CELLULAR METAL MATERIALS FOR BONE REGENERATION

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Keywords: Bone replacement; Osteointegration; Biodegradable; Multimaterial system

Abstract

The benefit of using cellular metals as bone replacement material has been discussed for many years. As main argument the natural bone-like structure of network-like metal foams has been referred to, which increases the primary and secondary stability of implants as a result of cellular adhesion on rough surfaces, bony ingrowth and neovascularisation on joint implants (Fig. 1a). Another key aspect is the low stiffness of cellular metal materials, which allows the realization of implants with low elastic mismatch between bones and implant material. Such materials allow for optimal bone remodelling by means of biomechanical stimulation and have been commercially introduced as bone graft materials or for spinal fusion purposes. Anyway, in case of late complications the removal of cellular implants is only possible with extensive damage of the ambient hard tissue (Fig. 1b). These difficulties can be avoided with the use of biodegradable cellular implants. In this concept, progressive osteointegration on the one hand and degradation of the implant on the other hand guarantee an optimal adaptation to the corresponding strength state at any time. Magnesium and iron alloys as biodegradable metals have been investigated during the last decade. As an example, resorbable implants for jaw augmentation have been realized on the basis of cellular magnesium fibre structures with retarded corrosion (Fig 1c-d). Further concepts involve the infiltration by pasty-like resorbable CaP cement, which hardens after contact with water and provides the needed stability of the implant (Fig. 1e). Such concepts have been developed for the therapy of highly loaded defects like corrective osteotomy. The same concept has been used in order to realize patient specific implants for the therapy of cranio-maxillofacial defects with short delivery times. The main idea of this approach is to use pre-assembled open cell titanium foams with high porosity and thin struts, and intraoperatively adapt their shape with the help of a 3D-printed defect pattern. The final implant stability then is provided by the infiltration of the cement-like CaP phase. In the contribution the implant-related properties of the materials will be shown and the pros and cons of the concepts will be discussed.

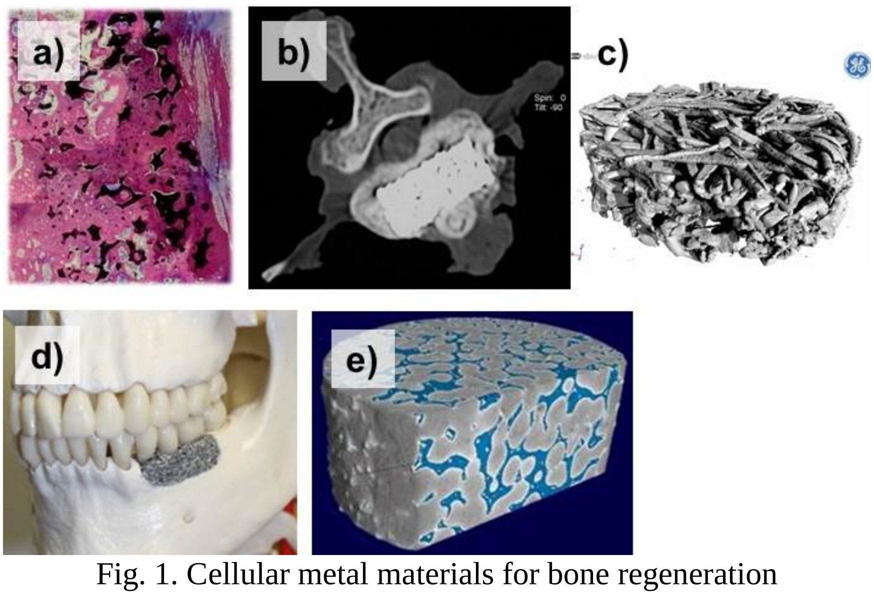

Fig. 1. Cellular metal materials for bone regeneration

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METAL FOAMS – FROM RESEARCH TO INDUSTRIAL APPLICATION

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Keywords: Metal foams; Industrialization, Application

Abstract

The paper presents the development of metal foam history (1996 - 2018) form first research steps up to the founding and industrialisation with the Havel metal foam company.
The overview will cover some highlights in research and development, in manufacturing and the application side.

Compared to the worldwide activities in cellular metals it can be pointed out that Germany still has one of the leading positions. But the industrialisation is not an easy way and many companies have not overcome the last decade.

During the last years the main activities in R&D in cellular metals are focused in energy related applications like heat exchange and storage, thermal insulation and combustion and all kind of lightweight design and crash protection. Additional surface modification (morphological, chemical) became more importance to enhance the functionality of cellular metals. Some progress can be stated in modelling, simulation and their experimental verification.

Havel metal foam is a new manufacturer of aluminium foam. A wide range of products are manufactured like panels, 3d net shape parts and sandwich structures.
In the last years some new real applications coming up in the field of automotive, railway, ship building, machine tools and for design purposes. But the numbers of parts manufactured to date is relatively low. The main reasons are the high processing costs.

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ABSTRACTS

FABRICATION OF UNI-PORE MATERIALS THROUGH EXPLOSIVE COMPACTION USING CYLINDRICAL GEOMETRY

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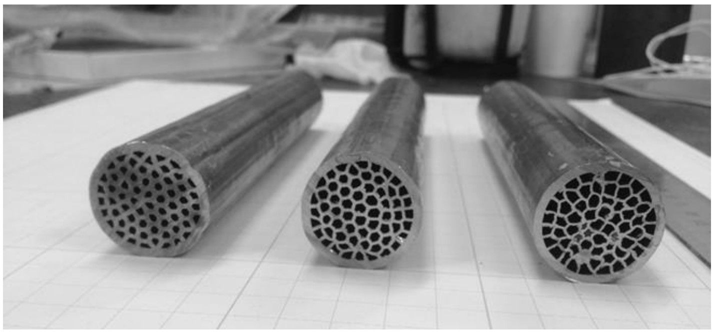
Keywords: Explosive welding; Explosive compaction; Uni-directional porous (UniPore) materials

Abstract

The authors have been investigated the fabrication of uni-directional porous (UniPore) materials through explosive compaction using cylindrical geometry [1-4]. The high-velocity compacting process similar to the explosive welding has been analysed numerically [5] and some advantages of such materials have been demonstrated as heat capacitor [6] and heat exchanger [7]. The authors are going to demonstrate the mechanism of compaction/welding process comparing with the microstructure and the results of compression tests. Some simple 2-dimensional simulated results including the information of collision velocity, in the order of several hundred m/s, are suggested and such velocity enables to achieve metal jet, a kind of fluidized phenomena, which is recognized that the welding mechanism is based on the explosive welding. Also, some potential applications of the UniPore materials are demonstrated at the time of the presentation.



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INCREMENTAL FORMING AND FRICTION ROLLING OF CLOSED-CELL ALUMINIUM FOAMS

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Keywords: Aluminium foam; Incremental forming; Friction rolling; Surface porosity; Integral skin

Abstract

Aluminium foam elements, foamed into moulds, have generally porous core surrounded by a thin layer of non-porous outer surface (integral skin). This layer affects the homogeneity and mechanical properties of the element significantly and has a function of protection against internal corrosion [1]. To produce functional elements, the foams can be machined to a desired end shape. Machining (milling, turning, etc.) deforms such a structure, which results in a reduction of strength properties. In order to maintain the strength properties after machining, it is necessary to perform the deformation processes of the surface to become non-porous again.

This work describes an experimental approach to determine the effects of process parameters on the porosity of the outer surface. Friction Stir Incremental Forming (FSIF) and Friction Stir Rolling (FSR) of four different closed-cell aluminium foams with specified porosity were performed after machining. Both operations were carried out on the same CNC machine, with carbide rod tool, diameter 20 mm, rounding radius 1.5 mm and surface roughness Ra1.6. Samples were processed with precisely defined processing parameters (deformation depth, feed rate and spindle speed). The treated surface was stained for better contrast between the porous and non-porous parts of the surface. High-resolution digital photos of the treated surfaces were taken, and analysed using image segmentation with a multispectral threshold algorithm. The change of surface porosity was calculated for each sample, and the influence of the selected machining parameters was determined using response surface methodology.

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METALLO-CERAMIC SYNTACTIC FOAMS BASED ON METAL-COATED CENOSPHERES: SYNTHESIS, PROPERTIES AND APPLICATIONS

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Keywords: Syntactic foam; Coating

Abstract

Metal matrix syntactic foams (MMSFs) represent an advanced type of metal matrix composites (MMCs), with hollow microspheres as particulate reinforcement, combining properties of conventional MMCs and metal foams [1]. MMSFs typically allow tailoring of properties through choice of matrix, reinforcement and volume fraction of the latter. The present study introduces a further handle for property adjustment - surface modification of the reinforcing cenospheres via vibration-assisted magnetron sputter coating [2]. Coatings based on copper, stainless steel, Ti and double layer Ti-TiN are used. The application perspective associated with the sputter coating approach ranges from low density MMSFs with combined open and closed porosity achieved via direct sintering of metal-coated cenospheres, optimized conventional MMSFs in which the metal coating is foreseen to enhance matrix-particle interface characteristics, and non-metallic SFs in which the thin metal layer on the filler particles provides electromagnetic shielding capabilities at low weight.

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STRUCTURAL INVESTIGATION OF BIMODAL ALUMINIUM MATRIX SYNTACTIC FOAMS

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Keywords: Metal matrix syntactic foam; Bimodal foam; Packing fraction; Compressive strength

Abstract

Nowadays, the mass-reduction of components with the enhancement of specific mechanical properties is a primary goal in industrial applications. This aim can be often achieved by the application of metal matrix syntactic foams (MMSFs), which overall properties are significantly affected by the properties of the used filler materials [1]. MMSFs are cellular materials, where the porosity - which results the cellular structure - is granted by a hollow second phase incorporated into the metallic matrix. Bimodal MMSFs - where two different sized hollow inclusions are used - are a slightly researched area [2].

In our case the filler materials, Ø2.4 mm and Ø7.0 mm nominal diameter Al_2O_3 C795 ceramic hollow spheres (Globocer® from Hollomet® GmbH) were used and the different packing densities were calculated via an analytical expression [3]. The calculated packings have been examined by microscopic images made from different planes of the samples. In this research high performance bimodal aluminium matrix syntactic foams were produced by liquid state infiltration of AlSi12 alloy into different volume ratio of two sized ceramic hollow spheres. The structure of the MMSFs have been examined by metallurgical and scanning electron microscopy and the mechanical properties have been evaluated from compressive measurements. The compressive strength, -strain, plateau strength and fracture energies of the different foams have been evaluated from the compressive tests between two flat and smooth plates. The failure mode of the differently packed foams has been rated along with the deformation method of the samples with different deformation values.

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COMPRESSIVE PROPERTIES OF LIGHT EXPANDED CLAY PARTICLE FILLED METAL MATRIX SYNTACTIC FOAMS

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Keywords: Metal matrix syntactic foams; Composite metal foams; Light expanded clay particle; Mechanical properties; Microstructural characterization

Abstract

Amongst the metallic foams, the so called metal matrix syntactic foams (MMSFs, or composite metal foams (CMFs) are representing high strength – high performance – low density foams as a possible solution for light-weight structural applications. In MMSFs the most common filler material is some kind of hollow spheres: (i) ceramic (Al_2O_3, SiC, mixture of Al_2O_3 and SiO_2) or (ii) metallic (steel, pure iron). The advantage of them is their excellent strength to density ratio and the most important disadvantage is in their costs. MMSFs could have a better chance to be widespread and more commonly applied if their cost is lower. Efforts have been made on this purpose via the application of expanded perlite [1-3], expanded clay [4,5] and pumice [6].

To further investigate the properties of the cheaper version of MMSFs light expanded clay aggregate particles (LECAPs) were applied along with aluminium alloy matrix materials, that are used in the automotive and defensive industry have been produced by liquid state middles gas pressure infiltration. Regarding the LECAPs, the original set of the particles have been sieved into three different diameter ranges to have information on the particle size effect. The aluminium matrix materials were Al99.5, AlSi9MgMn and AlSi9Cu3(Fe), two of them is precipitation hardenable, therefore, the produced MMSFs were investigated in as cast and in T6 treated (peak strength) conditions. Besides the investigations of their structure and microstructural features, the casted blocks were manufactured to cubic samples and were tested in compression mode according to ISO13314:2011 [7] to explore their mechanical properties.

The mechanical properties of the LECAP filled foams can be considered as moderate, exceeding the mechanical properties of the conventional metallic foams, but remaining below the capabilities of the cutting edge hollow ceramic spheres filled MMSFs, respectively. The moderate compressive properties can be advantageous or at least acceptable, if the cost of the MMSFs also considered.

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THE STATIC AND DYNAMIC CRUSHING BEHAVIOUR OF EPS FOAM FOR PACKAGING APPLICATION

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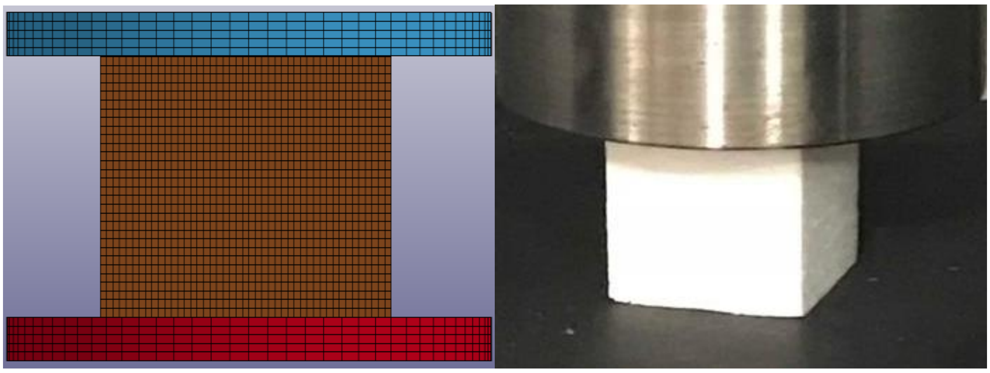
Keywords: Dynamic mechanical characterization; EPS foam; LS-Dyna; Packaging

Abstract

In this study, the energy absorption capability of expanded polystyrene (EPS) foam, utilizing as a packaging material in home appliances, were investigated both experimentally and numerically. During the transport tests of these appliances, the EPS foam may be exposed to impact loading with velocities ranging from 1.5 to 3.5 m/s. Thus, the impact loading on the EPS foam results in strain rate levels of 50 to 150 1/s depending on the material thickness values. There are several mechanical characterization studies of EPS were carried out at quasi-static and high strain rates in literature [1, 2]. However, there are few studies at intermediate strain rates. Quasi-static and dynamic compression tests, ranging from 10^{-3} to 100 1/s, were performed for 30 kg/m^3 EPS foam using a conventional compression test device and a drop tower test machine. The dynamic mechanical characterization of EPS was carried out to determine required material properties. The static and dynamic compressive stress strain curves of EPS foam was determined. The results revealed that significant strain rate dependency was not observed up to 60 % volumetric strain values within the studied strain rate levels. In order to represent the constitutive behaviour, modified crushable foam (MAT_163) material model was selected [3]. This material model does take the strain rate effects into account and enables to define the material stress strain curves as an input. The experimental crushing stages which were obtained from high speed camera and numerical model are well agreement. The validated material model parameters and data will further be used in the numerical simulations of combi boiler assembly drop tests.



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HYDROPHILIC CELLULAR POLYACRYLATES FROM HIGH INTERNAL PHASE EMULSIONS

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Keywords: PolyHIPE; Hydrogel; Porous polymer; Poly(2-hydroxyethyl methacrylate); Poly(dimethylaminoethyl methacrylate)

Abstract

Porous polymers have unique properties, like high permeability, low density, gas and liquid storage capacity, etc. PolyHIPEs (High Internal Phase Emulsions) are prepared by the polymerisation of high internal phase emulsions, wherein the volume of the internal phase exceeds 74 % of the total emulsion volume.[1,2] Hydrophilic polyHIPEs are tipically prepared from oil in water emulsions, where hydrophilic monomers are dissolved in water. Thus prepared hydrogels have the ability to absorb large amounts of water.[3]
Particularly interesting are hydrogels, which properties can change under the influence of external stimulus, like pH and temperature. For preparation of responsive polyHIPE hydrogels, two polyelectrolytes, poly(2-hydroxyethyl methacrylate) and poly(dimethylaminoethyl methacrylate), with different monomer and crosslinker concentration were used. The morphology of hydrogels was observed by SEM, specific surface area measured with gas adsorption and the temperature-sensitive swelling behavior was observed by immersion of the dry hydrogel pieces in buffer solutions at various pH values and various temperature.
SEM characterization showed interconnected, open cellular, porous morphology, where cavity diameters changed with changing the crosslinker concentration. An increase in crosslinker concentration resulted in a decrease in average cavity diameter. Crosslinking concentration also affected the specific surface area of hydrogels – when crosslinking concentration is increased, the specific surface area also increases. Furhermore, water uptake is affected with crosslinking concentration – a lower crosslinking rate results in higher water uptake. In a buffer solution with a certain pH value, the hydrophilic groups in polymer structure gets protonated, the charge repulsion promotes hydrogel swelling and hydrogels were able to increase up to 9 times their weight, with no apparent change in the overall monolith volume. Highest water uptake was observed in solutions with temperature below LCST. When the temperature increased above LCST, the hydrophobic interactions of the side chains of the polymer became stronger and the water uptake was reduced.

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CELLULAR POROUS BEADS OF POLYTHIOLENES FROM MULTIPLE EMULSIONS

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Keywords: PolyHIPE; Multiple emulsions; Thiol-ene polymerization; Polythiolenes; Porous polymer beads

Abstract

Porous polymers can exist in a variety of forms such as beads, monoliths and films. They have a wide range of applications such as reaction supports, separation membranes, tissue engineering scaffolds, controlled release matrices and smart materials [1]. Porous beads with fixed porosity have certain advantages over gel type beads and over other forms of porous polymers and can be fabricated using one of the following methods: oil-in-water-in-oil (O/W/O) and water-in-oil-in-water (W/O/W) sedimentation polymerisation, frozen polymerisation, microfluidic devices, electrospraying, phase inversion or W/O/W suspension polymerisation [2–6]. In recent years, most research based on porous beads has been conducted using microfluidic devices [6]. We are demonstrating a successful synthesis of porous polythiolene beads, using a water-in-oil-in water multiple emulsion. The primary emulsion was a high internal phase emulsion with a water volume fraction of 80% and the organic phase in the primary emulsion was composed of divinyladipate (DVA)/pentaerythritol tetrakis(3-mercaptopropionate) (TT) and trimethylolpropane (TMPTA)/pentaerythritol tetrakis(3-mercaptopropionate) (TT). The beads that were obtained were porous with a bicontinous structure and varying diameters (Fig. 1). The viscosity of the primary emulsion had the greatest influence on the stability of the entire w/o/w emulsion.

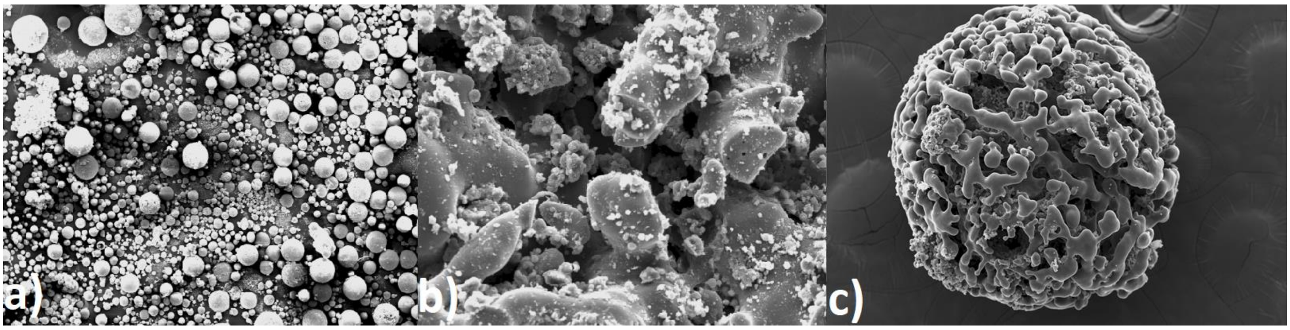

Fig. 1. SEM pictures: a) TMPTA/TT beads, b) structure of the DVA/TT beads, c) surface of the DVA/TT beads

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MULTIPLE-LEVEL CELLULAR POROUS POLY(GLYCIDYL METHACRYLATE) BY SOFT/HARD TEMPLATING

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Keywords: PolyHIPE; Porous polymer; Poly(glycidyl methacrylate); High internal phase emulsion; Hard templating

Abstract

Porous polymers can be prepared by using different methods. One of them is the polymerisation of continuous phase of **h**igh **i**nternal **p**hase **e**mulsion (HIPE). After the polymerisation of the monomer containing continuous phase, an open porous polyHIPE material is formed with macrometer scale primary pores (cavities) and a larger number of secondary interconnecting pores.[1] The diameters of cavities are usually within 1 to 100 μm while the diameters of interconnected pores are typically between 100 nm and 5 μm. Cavities and interconnected pores of polyHIPE material are depicted in Figure 1 (left). An alternative method for the preparation of highly porous monolithic polymers is the use of fused solid beads for templating pores, which can be combined with emulsion templating. Within this method, polymer beads are packed in a vessel and then exposed to an increased temperature that allows controlled fusing, forming a 3D network-like template. A HIPE is applied, protruding into the cavities of the template network and is polymerized, whereas the template is subsequently dissolved. In the resulting macroporous monoliths, pore sizes depend on the diameters of the beads used for the preparation of the template (Figure 1 (right)).[2]

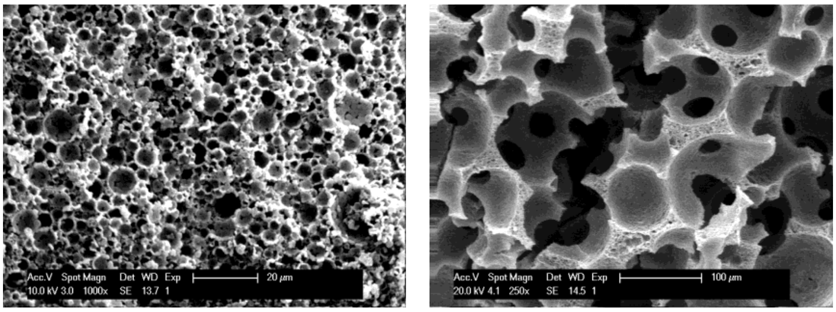

Figure 1: SEM image of typical polyHIPE (left) and SEM image of porous polymer obtained using fused solid beads combined with HIPE (right).

Herein, we report the preparation of porous materials based on glicidyl methacrylate (GMA) and ethylene glycol dimethacrylate (EGDMA). Firstly, typical polyHIPE was prepared using emulsion (soft) templating. The SEM image of such material revealed an open cellular structure, where the cavities diameter sizes of sample were found to be between 4 and 9 μm, while the interconnecting pores were irregularly shaped. On the other hand, polymers prepared by using soft/hard templating resulted in highly porous polymers with largest pores between 60 μm to 120 μm. Those pores are of a similar size distribution as the beads used for constructing the hard template. These pores are connected by channels which are the result of connections between beads that occurred during sintering. Within the polymer network that form the bulk around primary pores, another level of porosity is evident.

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DYNAMIC-MECHANICAL-THERMAL BEHAVIOUR OF NANOCOMPOSITE FOAMS BASED ON POLYSULFONE AND GRAPHENE NANOPLATELETS

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Keywords: Polysulfone foams; Graphene nanoplatelets; Multifunctional foams; $scCO_2$; Dynamic-mechanical-thermal behaviour

Abstract

Due to their high strength, thermal stability, chemical resistance and inherent fire resistance, polysulfones (PSU) have recently been considered for preparing high performance foams, with foaming extending their application range by reducing density and enhancing thermal and acoustic insulation [1]. Also, there has been an increasing interest in further extending the properties of PSU by adding carbon-based nanoparticles, as they act as reinforcements and may add functional characteristics such as EMI shielding enhancement [2-3]. In this work, foams based on PSU and graphene nanoplatelets (GnP) were prepared by water-vapour-induced phase separation (WVIPS) and supercritical CO_2 ($scCO_2$) dissolution. In the case of WVIPS foams, two amounts of PSU (15 and 25 wt%) were dispersed in N-methyl pyrrolidone (NMP) and combined with ultrasonicated GnP-NMP dispersions to create two series of foams containing between 1 and 10 wt% GnP: 15 wt% PSU-GnP foams (relative density: 0.23-0.41) and 25 wt% PSU-GnP foams (relative density: 0.34-0.46). Foams prepared by $scCO_2$ dissolution (relative density: 0.35-0.45) were obtained by dissolving $scCO_2$ into foaming precursors previously prepared by compression-moulding melt-compounded PSU-GnP nanocomposites (0.1-2.0 wt% GnP), and applying a sudden pressure drop.

Comparatively, 15 wt% PSU-GnP foams prepared by WVIPS showed lower relative densities than $scCO_2$ foams, which displayed values comparable to 25 wt% PSU WVIPS foams. Besides, $scCO_2$ dissolution foams presented a homogeneous microcellular structure independently of the amount of GnP, while WVIPS foams' cellular structure resulted less homogeneous and depended strongly on PSU and GnP contents. WVIPS foams with 15 wt% PSU showed bigger cells than those with 25 wt% PSU. In both cases, the addition of 5 and 10 wt% GnP led to foams with a partially-open/fully-open cellular structure.

In terms of the dynamic-mechanical-thermal behaviour, an increasing tendency was observed in the storage modulus of WVIPS and $scCO_2$ foams with increasing relative density. Secondly, there was a reinforcing effect of GnP nanoparticles, as the storage modulus globally increased with augmenting GnP's amount for the two types of foams. Interestingly, $scCO_2$ foams displayed higher specific storage modulus values than WVIPS foams having similar relative densities and the same amount of GnP, which was related to their homogeneous microcellular structure.

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MODELING OF THERMAL PROPERTIES OF POLYMER FOAMS: RECENT ADVANCES AND PERSPECTIVES

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Keywords: Polymer foams; Semi-transparent medium; Equivalent thermal conductivity; Thermal radiation

Abstract

In most of the numerous industrial applications of Polymer Foams, their thermal behavior is a major concern. An accurate knowledge of the heat transfer mechanisms occurring in these materials is thus of primary importance. Now, due to their light-weight and to the transparency of polymer to IR radiation, heat transfer in Polymer foams is a combination of heat conduction (through both solid and fluid phases) and Radiation transport by IR propagation. These two modes of heat transfer are coupled and strongly depend on the density, the morphology of the porous structure, the working temperature and the thermo-optical properties of the constituents. Therefore, an exhaustive modeling of thermal behavior of Polymer Foams requires cutting-edge numerical methods for the computation of the conductive and radiative properties in close relation with their porous structure at the local scale.

Such numerical approaches can be build on:

- X-Ray Tomographic characterizations of real foam samples to reconstruct very faithfully the cellular morphologies of the foam investigated
- Numerical generation methods using the Voronoi approaches to create 3-D finite elements meshes of the porous structure of existing foams. These meshes reproduce actual foam morphology from measured characteristics such as density, cell-size distribution and distribution of polymer in the cells.

Based on our long time expertise in the field [1-5], we will present the latest advances in these numerical approaches. We will notably present the major results of parametric studies conducted on various Polymer Foam types end highlight the structural parameters and thermo-optical properties that influences most largely their thermal performances. This could be of major interest for industrials, manufacturers or users of plastic foams

Note that these latest numerical developments have been incorporated in a freshly developed software, named **modelia** and edited by EC2-Modelisation company.

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METALLIC SCAFFOLDS PRINTED VIA DIRECT INK WRITING

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Keywords: Robocasting; Ti6Al4V; AISI316L; Microstructure; Compressive test; Mechanical properties

Abstract

The use of additive manufacturing technologies, such as Selective Laser Melting and Electron Beam Melting, allows for the production of complex metallic shapes without the use of organic binders and postprocessing machining. However, due to the thermal fatigue cycles the metallic powders are exposed to, a thermal treatment is often necessary in order to homogenize the microstructure and reduce thermal stresses [1, 2]. Due to the use of a laser or electron beam, powders are not homogeneously melted, thus causing discrepancies between as-designed and manufactured parts [2, 3].

In this work, we developed a different approach that consists of the use of a low cost robocasting printer to print metallic inks (Ti6Al4V and AISI316L steel). A proper ink formulation was realized by controlling the rheological properties of the paste with a proper use of a polymer mixture into a water dispersion. After printing and drying, the components were sintered under high vacuum [4]. Since the metallic powders did not undergo thermal fatigue cycles a proper control of microstructure with improved mechanical behaviour was expected.

In order to validate such hypothesis, scaffolds with different geometries were printed and the mismatch between CAD pre-designed and manufactured parts was evaluated by micro-CT analysis. The microstructure was studied by means of SEM-EDS analysis and the compression strength of the scaffolds was measured by quasi-static tests. The experimental results were then further compared with computational results based on the finite element method. A good correspondence between pre-designed and manufacturing geometries was assessed and the absence of martensitic structure was confirmed. In some cases, residual closed porosity, which influences the mechanical properties, was present.

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ANTI-TETRA-CHIRAL SQUARE GRID STRUCTURE MADE OF ORTHOTROPIC MATERIAL

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Keywords: Auxeti; Anti-tetra-chiral; Square grid; FEM

Abstract

Materials with negative Poisson's ratio have been known for over 100 years and are named auxetics [1-2]. Simple mechanical and thermodynamical models, which show negative Poisson's ratio (PR) [3] (auxetic behavior) were found in the 80s of the 20th century. In 1981 Lorna Gibson [2] theoretically and experimentally analyzed the model of cellular material as a simple, two-dimensional array of hexagonal cells in order to identify and analyze the mechanisms by which it deforms.

In this research, the Finite Element Method [4] is used to simulate mechanical properties of two-dimensional square grid structure based on the anti-tetra-chiral shape made of orthotropic material. Figure 1 presents the influence of orthotropic properties of the material on Poisson's ratio of structure.

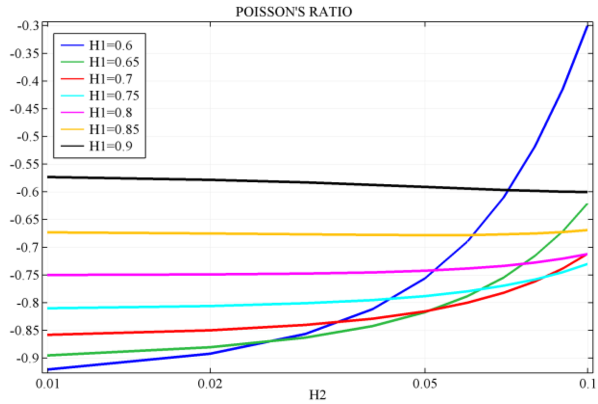

Fig. 1. Influence of geometrical properties (H1 and H2) of structure on PR of structure

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THE EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE VARYING CRUSHING STRENGTH OF A CELLULAR CONCRETE

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Keywords: Autoclaved aerated concrete; Cellular structure; Impact Loading; Modelling; Inertial effects

Abstract

Experimental quasi-static and dynamic tests including compression, indentation, Brazilian, direct impact and confinement were performed on a cellular concrete (600 kg m^{-3}) in order to investigate the strain rate sensitive crushing strength. The compression tests showed two distinct regions of the crushing strength dependence on the strain rate. A lower strain rate dependent crushing stress at quasi-static strain rate-regime ($2x10^{-3}$-$2x10^{-1}$ s^{-1}) was determined than that at the dynamic strain rate-regime (180-10^4 s^{-1}). The dynamic increase factor (DIF=dynamic/static fracture strength) of concrete was previously shown to vary between 1 and 2.5 from static and to dynamic strain rates with a sudden rise after about 100 s^{-1} [1]. The variations between the reported DIF values of concrete were also attributed to the radial and axial inertia [1, 2]. In present study, the indentation tests at quasi-static strain rate-regime however showed moderate DIF values (1-1.13), very similar with those of the quasi-static compression strain-rate regime (1-1.15). The confinement tests between $2x10^{-3}$-380 s^{-1} resulted in a DIF value of 1.35 at 380 s^{-1}, lower than the DIF value of the compression test at the same strain rate, 2.04. These experimental results clearly indicated that the indentation and confinement tests decreased the DIF values significantly and also confirmed the numerically determined DIF value of concrete at 1000 s^{-1} (~1.30) without radial and axial inertia [1]. The compression (1 and 8 m s^{-1}) and direct impact (10, 20, 30, 60 and 108 m s^{-1}) tests in the Split Hopkinson Bar (SHPB) set-up were implemented numerically in LS-DYNA using an anisotropic material model, MAT_096 (MAT BRITTLE DAMAGE), with no strain rate sensitivity [3, 4]. The stress readings at different velocities at the fracture strength were performed at the specimen bar contacts, at the center and near the surface of the sample at sample/bar contact area and from the strain gage locations of the SHPB. The stress readings at the facture indicated that radial and axial inertia were dominant between 1 and 30 m s^{-1}, corresponding to a strain rate between 100-1000 s^{-1}.

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DEVELOPMENT OF AN ENERGY ABSORBER WITH CHIRAL CELLULAR STRUCTURE

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Keywords: Chiral Structures; Auxetic Honeycomb; Energy Absorber; Additive Manufacturing

Abstract

Materials and meta-materials with negative Poisson's ratios may be used to absorb efficiently kinetic energy in case of localized impact on structures. Indeed, the auxetic behaviour related to negative Poisson's ratio involves a contraction in all the directions under the action of compressive impact forces, thus leading to materials harder to be indented and increasing the potential in energy absorption. Both foams and cellular structures with auxetic characteristic have been assessed for the development of energy absorption layers [1,2]. Chiral topologies are one of the most effective solution to develop auxetic cellular structure [3] thanks to the possibility of tuning the response by using several design parameters and the optimal auxetic characteristics, with Poisson's ratio that reaches the physical limit of -1. The activities presented in this work are aimed at developing an innovative energy absorber based on a 3D-printed chiral cellular skeleton filled by polyurethane open-celled foam. The absorber developed by combining foam and chiral cellular structure provides a significant enhancement in energy absorption with respect to using separately the two elements, as proved by initial preliminary tests, performed by using a 3D-printed polymeric auxetic skeleton.
However, tests pointed out the risk of premature failure of the skeleton at high compressive deformation, which should be delayed as most as possible to maximize the auxetic effect. For such a reason, an optimization study was carried out by using parameterized models of a unit chiral cell. Considering a metallic skeleton printed by additive manufacturing, the parameters of the chiral topologies were optimized, taking also into account technological constraints. The optimal parameters to maximize the contraction of the skeleton and the scaling law for applying the concept to different applications were found. Results indicate that properly designed chiral cellular structures filled by foam can amplify the energy absorption performances by maximizing the amount of material involved in the response to localized impacts.

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DYNAMIC MECHANICAL ANALYSIS OF 3D-PRINTED BIMATERIAL BEAMS

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Keywords: Composite; beam; DMA; 3D-printing; Bimaterial

Abstract

Composite beams commonly use different materials to obtain favourable combinations of mechanical properties. Different studies have shown the use of steel-concrete [1,2], timber-concrete [3,4], steel-timber [5,6], carbon fiber [7,8], among others. However, given the advent of additive manufacturing, there is an opportunity for an integrated combination these materials and manufacture composite beams [9]. For instance, the manufacturing of hollow beams and/or produce filled bimaterial beams in one single step. This work shows a characterization of the dynamic mechanical properties of hollow and bimaterial beams that were 3D-printed using fused filament fabrication. Flexible material was used in the filling of hollow beams to enhance their damping properties. The inherent beam stiffness (Storage modulus) and damping (tanδ) were monitored to determine the influence of void and flexible filling in the dynamic properties and optimize the beam performance. It is shown that at room temperature, the introduction of low contents of flexible filling generates an increase in stiffness. This is attributed to the high residual stresses in the filling that result from the manufacturing process. In terms of damping, only high contents of filling seem to be advantageous. When trying to optimize both stiffness and damping, beam with an 80% flexible filling display the most beneficial combination of these properties.

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MECHANICAL BEHAVIOUR OF ADDITIVELY-MANUFACTURED HYBRID LATTICE STRUCTURES AT DIFFERENT STRAIN RATES

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Keywords: Impact dynamics; Energy absorbing characteristics; Strain rate dependence; Lattice structure; Hybrid cells

Abstract

Photosensitive resin hybrid lattice structures with octet-truss cell and re-entrant unit cell were designed and fabricated by digital light processing (DLP). Compression experiments were conducted by electronic universal machine, drop hammer and Split Hopkinson Pressure Bar (SHPB) system to determine the mechanical performance of the material for strain up to 1000/s. All the loading processes were recorded to capture the deformation mechanism of different specimens. A finite element model of the material was established and numerical simulations were performed to explore the phenomena associated with impacts, the failure modes and strain-rate sensitivity of the structures. A significant rate dependency of load-deformation characteristics on the structures is identified and a good agreement between the numerical predictions and the experimental results.

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MECHANICAL PROPERTIES OF NOVEL METALLIC SHEET-BASED LATTICES ADDITIVELY MANUFACTURED USING SELECTIVE LASER MELTING

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Keywords: Architected Materials; Metallic Lattices; Triply Periodic Minimal Surfaces; Mechanical Properties; Powder Bed Fusion

Abstract

The exhibited topology of lattices dictates their mechanical properties to a great extent. Therefore, lattice topologies that promote a stretching-dominated mode of deformation have been proposed and fabricated using additive manufacturing. However, most of these architected metamaterials are strut-based where several struts are joined together at certain nodes. The complexity of the node makes it susceptible to defects upon manufacturing and the sharp geometry of these nodes results in large stress concentrations. In this paper, we show that adopting a different approach in designing lattices can result in reducing the effect of stress concentration. The proposed approach is based on employing mathematically-defined surfaces with smooth transitions to create novel types of sheet-based lattices. For the purpose of demonstration, metallic lattices with geometries based on Triply Periodic Minimal Surface (TPMS) were designed and fabricated using powder bed fusion additive manufacturing. Scanning electron microscopy was utilized to assess the quality of 3D printability. Results showed that adopting a sheet-based approach rather than a strut-based approach can change the deformation mechanism from a bending-dominated deformation behaviour to a stretching-dominated one without sacrificing the toughness. Furthermore, such novel lattices have a wide range of multifunctional properties making them ideal for various engineering applications.

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DEVELOPMENT OF TUBE FILLED ALUMINIUM FOAMS FOR LIGHTWEIGHT VEHICLE MANUFACTURING

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Keywords: Aluminium foam; Ex situ foam-filled tubes; Filling techniques; Strengthening characteristic; Energy absorption

Abstract

The implementation of aluminium alloy foam has made an impact in automobile and aerospace applications where crash energy absorption, vibration, sound damping and weight reduction is obligatory [1,2]. The aluminium alloy foam is an advanced lightweight material providing high strength and stiffness at relatively low density. The technological use of aluminium alloy foam is difficult with the currently available technologies.

The manuscript focuses on manufacturing of aluminium alloy foam-filled tubes with different filling techniques and studying their mechanical behaviour under static bending and compression loading and their mechanical behaviour under shearing loads. We used several filling methods, for example pressing, adhesive bonding and casting aluminium around the foam on high pressure.

The aluminium alloy foam used in the current study is EN 43100 (AlSi10Mg) foam of density range 0.25-0.9 g/cm^3, which is produced using vibration foaming method.

We developed a calculation method to define the cross-section of the foam-filled tubes.
The interfaces of foam-filled tubes, filled with different filling methods, were investigated by metallic microscope and SEM (Scanning Electron Microscope).

Different material tests were carried out on the made specimens. Compression and bending test were the two main test procedures.
In the case of compression test, from the obtained compressive stress-strain curves specific energy absorption, total energy absorption, plateau stress of the empty and filled sections were determined.
The main aim of the bending test was the determination of load/weight chart, depending on wall thickness. From the obtained results, it is able to evaluate the strengthening characteristic of tubes with different wall thickness via reinforcing them with aluminium alloy foam. Shearing test was made as a basis for possible further applications.
The application range of metal foams filled in different geometries offers more and more opportunities with using the experimental results.

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PHENOMENONS DURING METAL MATRIX COMPOSITE MILLING

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Keywords: Metal matrix composite; Tool life; Milling; Experiments

Abstract

Nowadays more and more composite materials are used in the industry, especially in the automotive industry. Some of this can be attributed to eco-friendly solutions, reducing the weight of vehicles to improve emissions and making them safer. This rapid developing requires many cutting investigation because a well-chosen technology and technological parameter greatly can increase the efficiency, the economy and also the lifetime of tools.

In order to examine the goodness of a composite material by cutting, it is worth comparing with another material. In this study, were investigated two type of materials, both of it can be considered as raw material for aluminum foam. One of material is M6061, which is an aluminium alloy with modified silicon and magnesium content. The other aluminium alloy is C355, which contains small portions of ceramic particles (Fig. 1).

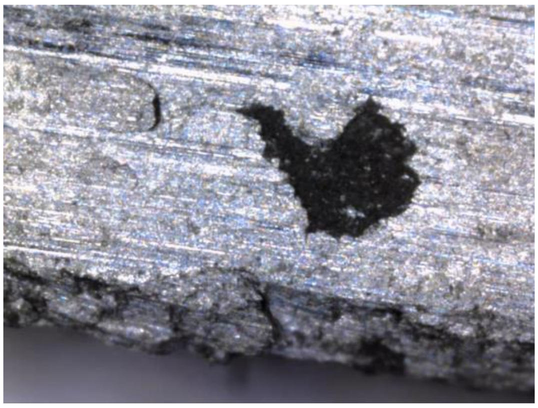

Fig. 1. C355 aluminium composite with ceramic particle

During of this study, several parameters were investigated and number of measured parameters were evaluated. As input parameters two types of cutting tool and the previously mentioned two types of composite aluminium alloy were applied. For machining a milling machine was used and the chip removing was free cutting. After machining the surface roughness, the chip and the tool wear were exanimated and during the milling process the forces were measured too.

The results of this study can help to further research as a cutting guide. For example, in the first part of the experiment it has been shown that there are also 4 phase of force rush. And of course the generated force much higher during the composite machining than the reference material, however, it does not show a remarkably large deviation if using tool which specially designed for steel or cast iron.

Overall, these experiments show that machining of aluminum composite is a complex process and the applied tool's quality greatly influence the output values of the experiment.

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ASSESSMENT OF THE RVE SIZE OF VIRTUAL FOAMS

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Keywords: RVE; Virtual material; Foams

Abstract

The subject of the study is a virtual foam with the geometry of the skeleton defined by the tomograms of a given polyurethane foam. Two kinds of skeleton structure are considered. The open cell convex foams and the reentrant ones. Application of micro computed tomography to the real polyurethane foam with aid of the specialized programs, provides the geometry of the virtual foam skeleton. Assumption of the skeleton material produces the model of particular foam. In particular the copper skeleton is assumed. Finite element computations are used to analyze mechanical properties of a copper foam volume. The aim of the study is to estimate the sufficient size of representative volume element (RVE) that is necessary to assess the validity of the elastic model of the foam under consideration. An array of cubes of virtual foams is used to compute the particular deformation modes providing elastic moduli, Young modulus, shear modulus and bulk modulus as well as the resulting Poisson's ratio.

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CHARACTERISATION OF THIN WALLED SANDWICH STRUCTURES COMPRISING STEEL HOLLOW SPHERES FOR THE CORE

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Keywords: Steel hollow spheres, Sandwich structures, DIC, Experimental testing

Abstract

Steel hollow sphere assemblies are a special type of metal foams that can offer low weight, energy dissipation and ductility [1, 2]. The composite manufactured using thermosetting epoxies can be attractive as core in hollow sections and sandwich configurations, ameliorating shortcomings of precursor powder metallurgy, such as more uniform cell size as well as lower cost and better tensile responses compared to sintered assemblies [3]. The work herein describes the design and mechanical testing of steel foam-epoxy composites to estimate the static and cyclic properties of these composites. This included static properties in compression of sphere assemblies, including the crushing propagation [4]. 4-point bending tests were utilized to capture shear modulus and shear strength in the sphere assembly core, sandwiched by two steel plates. Two types of sphere assembly sandwich cores were tested, the first one being 3 layers of 4.5 mm diameter spheres(referred to as 'SFS4') and the second 4 layers of 2.3 mm spheres and 1 layer of 4.5 spheres in the middle (referred to as 'SFSGRD'), in order to quantify any potential gains in shear strength with limited increase in core density near the face plates. For all static tests, Digital Image Correlation techniques were used to capture surface displacements in the specimens, providing a richer data set for the evolution of the responses.

Fatigue tests in 4-point bending followed, for the two types of sandwich specimens in order to quantify the cycles to failure for the two types as well as the residual stress in the specimens, after the failure had occurred. The fatigue tests also included the testing of aged specimens, which were dipped in north sea saline conditions for 15 days, in order to quantify the effect corrosion on exposed sandwich specimens.

All in all, more than 100 specimens were used in this study and the data has provided insights in the response of these cellular assemblies as core in sandwich configurations in static and cyclic conditions, which is useful in defining potential multifunctional applications for such structures.

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INFRARED EVALUATION OF DYNAMIC LOADED TUBULAR STRUCTURAL MEMBERS WITH CELLULAR FILLERS

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Keywords: Tubular structures; Cellular material; Dynamic loading, Infrared thermography; Plastification

Abstract

Increasing the carrying capacity of structures without increasing the weight is a constant focus of research and contemporary technology developments. Tubular structural members under tension loading are sensitive to bending and bucking. Inserting lightweight cellular filler in tubular structural member significantly increases loading and energy absorption capacity. Presented work is an overview of the collaboration between the University of Maribor (Slovenia), University of Aveiro (Portugal) and University of Split (Croatia), where numerical and experimental research has been performed. Evaluation of structural response under dynamic mechanical loading conditions has been performed by means of infrared thermography used as a passive method for tracing plastification occurrences in material. Such an approach based on infrared thermography enables better understanding of collapse mechanism and benefits of using cellular fillers. It additionally provides information to standard load-displacement curves.

Aluminium tubes, with and without cellular filler, have been subjected to compression and three-point bending dynamic tests. As filler material, Advanced Pore Morphology (APM) spheres [1] and closed cell aluminium foams have been used. Aluminium foam was formed in moulds and inserted in tubes (*ex-situ*) [2], or foamed directly in tubes (*in-situ*) [3]. *In-situ* approach causes better stress redistribution due to bonding between the tube and filler, while exposure to heat results in structural changes of heat treated aluminium tubes. It has been shown that three-point bending test is an appropriate method for evaluation of such structures and comparable with results of numerical simulations [4], what is often not the case for simple compression or tension tests.

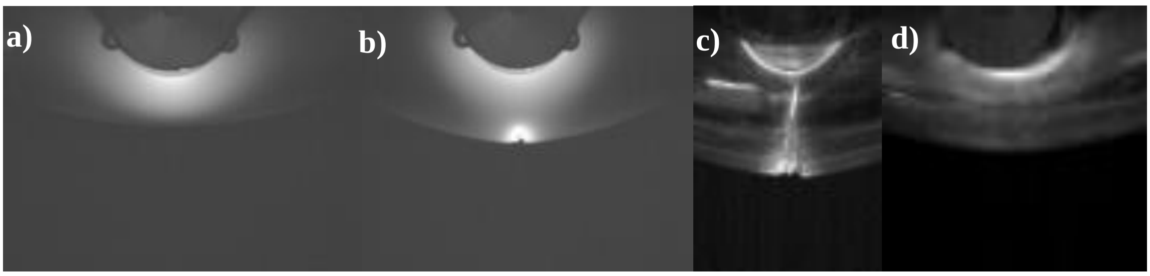

Fig. 1. Three point bending test of the: a) empty tube, b) tube filled with APM spheres, c) ex-situ filled foam, d) in-situ filled foam

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EXPERIMENTAL TESTING OF AUXETIC CELLULAR STRUCTURES

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Keywords: Cellular structures; Auxetic; Geometrical characterization; Experimental testing; Mechanical properties

Abstract

Auxetic cellular structures are modern metamaterials, which possess negative Poisson's ratio [1]. Negative Poisson's ratio is a consequence of kinematic movements of cellular structure's struts, which are precisely predefined in order to assure auxetic behaviour [2]. The unique deformation behaviour of auxetic cellular structures can enhance the mechanical behaviour at various fields in engineering, medicine, fashion, etc. From that reason, there is a necessity to evaluate the mechanical response of these structures with experimental testing under different loading conditions.

In this work, the mechanical behaviour of two different types of auxetic cellular structures will be analysed – auxetic cellular structures build from inverted tetrapods and chiral auxetic cellular structures. All specimens were produced with additive manufacturing technologies from Ti6Al4V and copper powder. Geometrical characterisation is based on the MicroCT scanning, microscopy and metallography in order to evaluate the fabricated geometry of the specimens. After evaluation of the fabricated geometry, quasi-static and dynamic (up to high-strain rates) compressive experiments were performed [3]. The quasi-static and low velocity dynamic tests were done on universal testing machine, where the experimental testing was also supported also with infrared thermography. High strain rate testing was done using Split Hopkinson Pressure Bar (SHPB) and powder gun device [4].

The quasi static and dynamic responses of auxetic cellular structures have shown an orthotropic behaviour for all analysed specimens. The high strain rate loading has shown a strain rate hardening effect, which is a consequence of the change in deformation mode to shock mode (due to the inertia effect, the material deforms at the impact front).

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DEFORMATION BEHAVIOR OF SLS MANUFACTURED AUXETIC LATTICES AT LOW AND HIGH STRAIN-RATES

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Keywords: Auxetic Structures; Split Hopkinson pressure bar; Digital image correlation; Numerical simulations

Abstract

Auxetic cellular materials exhibit a negative Poisson's ratio and are thus of significant interest for the energy absorption applications and protection against penetration. In-depth characterization of their deformation behavior at high strain-rates is of a crucial importance for successful application of auxetic materials in this field. This presentation reports on experimental and computational study of three different auxetic structures subjected to conventional quasi-static compression from low strain-rate to high strain-rate impact using Split Hopkinson Pressure Bar (SHPB). The three investigated structures were: a) 2D hexa-chiral, b) 2D tetra-chiral and c) 3D tetra-chiral with dimensions of approx. 14 × 14 × 14 mm. The specimens were manufactured from the powdered SS316L austenitic steel using selective laser sintering (SLS) technique. The specimens were first tested quasi-statically in compression using a servo-hydraulic loading device. The samples deformation during the compression was observed using a high-resolution CCD camera with bi-telecentric lenses and the digital image correlation (DIC) technique was applied to analyse deformation behaviour of the specimens from recorded images. The SHPB apparatus was used next for the impact compression of samples at two different strain-rates. The SHPB bars were equipped with foil strain-gauges that were calibrated using quasi-static force calibration and dynamic void tests for a high-precision of the measured data. The impact tests were observed using two synchronized high speed cameras with approx. 250 kfps and 80 kfps, respectively. The captured images from both quasi-static and dynamic experiments were processed using custom DIC algorithm to evaluate displacement and strain fields in the specimens as well as the Poisson's ratio. DIC results were compared with the results of other methods. A digital twin computational model of the impact experiment was developed and successfully computed with the LS-DYNA software system with good correlation to the experimental data.

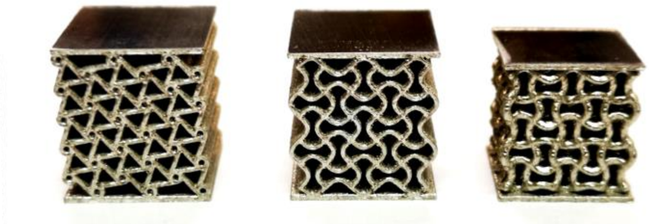

Figure 1: From the left to right are presented: a) 2D hexa-chiral b) 2D tetra-chiral and c) 3D tetra-chiral structure.

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DYNAMIC PROPERTIES OF OPTIMIZED AUXETIC STRUCTURES

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Keywords: Auxetics; Poisson's ratio; Dynamic simulation; FEM

Abstract

Metamaterials, such as auxetic structures, have unique properties which distinguish them from common materials. Due to great ability to absorb and dissipate energy, auxetics have found use as dampers and different protectors. [1, 2]
Author present analytical and computational approach to dynamic properties of auxetic structures after topology optimization. In the first part, the description of four optimized structures can be found (such as re-entrant, tetrachiral, lozenge grid and 4-STAR grid). All four types of structures were prepared in similar way. Aim of topology optimization was to maintain stiffness of the structure with mass reduced by 25%, 50% and 75%. Example model of re-entrant structure is shown on Fig. 1.

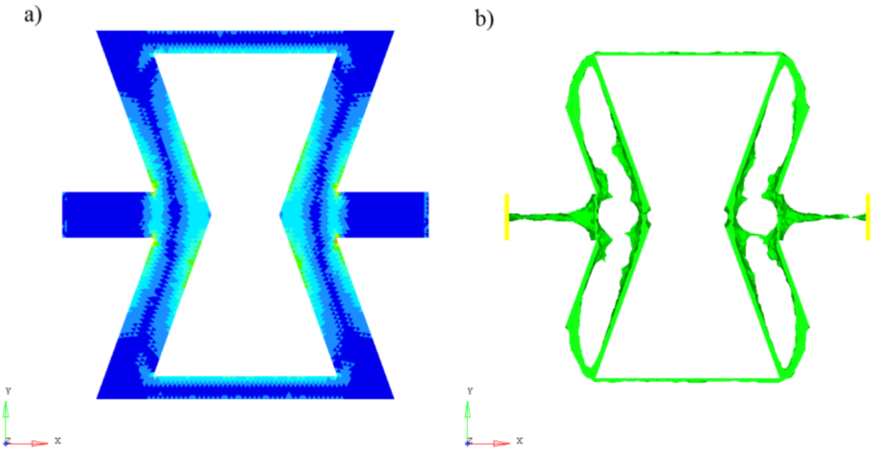

Fig. 1. Example model before (a) and after topology optimization (b) with 25 % of mass. View on XY-plane

In second part, the author describe process of developing three dimensional CAD model from optimized shape. CAD models were prepared to be produced with additive manufacturing.
Material properties, boundary conditions and dynamic simulation settings are presented in third part of this paper. All simulations are made in similar way and models have similar dimensions and masses. Material with low stiffness and elastic behaviour was used in simulation. Material properties was compared to actual, physical material – thermoplastic polyurethane (TPU).
Topology optimization was done with HyperWorks software. For dynamic simulation, LS-Dyna software was used, due to its ability to accurately simulate high displacements and dynamic responses.
In final section, results were presented and discussed. The dynamic response and damping of optimized structures were compared to hollow non-optimized structures with the same mass. Based on results, author determined effectiveness in absorbing and dissipating energy in this structures.

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THE LCF-ANALYSES OF AUXETIC STRUCTURE USING DIRECT CYCLING ALGORITHM

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Keywords: Auxetic porous structures; Low cycle fatigue; Computational analysis

Abstract

Auxetic porous structures are modern metamaterials which exhibit some typical features (e.g. negative Poisson's ratio, counter-intuitive deformation behaviour, etc.), which are useful in various engineering applications, such as aerospace engineering, automobile industry, constructions, etc. [1]. The negative Poisson's ratio is a consequence of rotating cells in the geometry of the auxetic structure when an external load is applied [2]. In general, auxetic porous materials can be divided into the three main groups [3]: auxetic honeycombs, auxetic microporous polymers and auxetic composites. In the last few decades, a numerous studies in the field of quasi-static [4]–[6] and ballistic [7] performance of auxetic cellular structures were done. However, a few researches were focused on the fatigue and fracture behaviour of the auxetic cellular structures.
This study presents the computational analysis for determination the fatigue life of conventional 2D auxetic porous structures. The low-cycle fatigue analysis using a damage initiation and evolution law is performed where the damage state is calculated and updated based on the inelastic hysteresis energy for stabilised cycle. The direct cyclic analysis capability in Abaqus/Standard is used for low-cycle fatigue analysis to obtain the stabilised response of a model subjected to the periodic loading. In this study we used two-dimensional auxetic porous structure as a basis for the finite element simulations, exposed to the sinusoidal cyclic loading. In order to examine the crack propagation paths finite elements with severe damage were deleted and removed from the mesh during simulation. With the cyclic loading conditions fatigue cracks were formed in the corners of porous structures and cracks further propagated in the direction where stress highly concentrates.

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DESIGNING 2D AUXETIC STRUCTURES USING MULTI-OBJECTIVE OPTIMIZATION

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Keywords: Auxetic structures; Compliant mechanism; Topology optimization

Abstract

Auxetic structures exhibit a negative Poisson's ratio when loaded [1]. They have high energy absorption and fracture resistance, which makes them suitable for novel applications in defence and civil sectors as body armour, shock absorbing material and packaging material. Some well-known auxetic structures were already well investigated. However, there is a need for new shapes of auxetic structures to achieve different possible design goals for their use (dynamic behaviour, fatigue resistance, manufacturability).

The behaviour of the auxetic structure under external load can be seen as the behaviour of the compliant (flexible) mechanism, of which design is governed by two opposing objective functions, namely the flexibility and stiffness. In this study the multi-objective topological optimization based on genetic algorithms and finite element method was used to find the optimal shape of such two-dimensional compliant mechanism. The optimization was performed on one quarter of a double symmetric representative unit cell, which is a building block of the auxetic structure. Static linear computational simulations were performed to determine the mechanical response of the structure with use of a very coarse mesh of rectangular finite elements to improve the optimization speed. Thus, obtained optimal geometries are sharp edged which causes high stress concentrations under loading, which were neglected. The obtained optimal geometries were first smoothed (Figure 1) and then loaded with compressive displacement that equals 20% of engineering strain. The deformation behaviour of the sharp edged and smoothed geometries shows a good agreement in terms of displacements and auxetic behaviour.

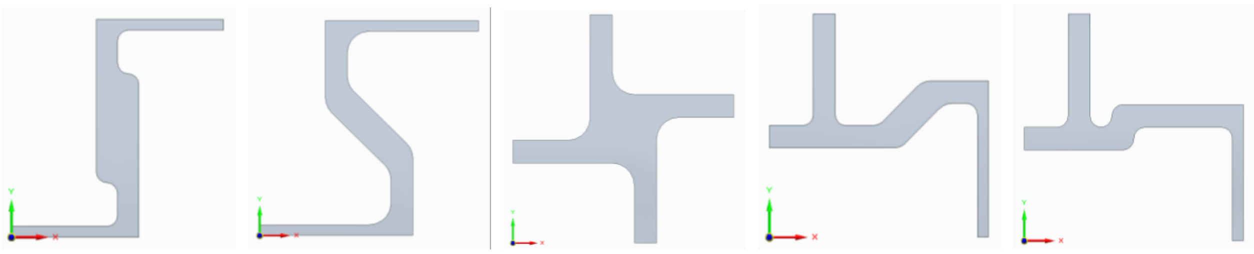

Fig. 1. Displacements field of the optimized representative unit cell (deformation scale factor 1x)

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MECHANICAL PROPERTIES OF SANDWICH BEAMS WITH AUXETIC AND NON-AUXETIC CORE

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Keywords: Sandwich beam; Auxetic

Abstract

Auxetic materials have recently become a popular research object in the last few years due to their remarkable mechanical properties i.e. negative value of the Poisson's ratio. In addition, the ability to produce almost any structure thanks to the 3D printing method has also significantly contributed to the development of research on the microstructure of materials.
The influence of auxetic core has already been analysed in the case of compressed sandwich panel [1, 2].
In this paper, the mechanical properties of the sandwich beam are analyzed, where the internal structure of the sandwich core could be either auxetic or non-auxetic. Parametrical analysis has been performed with the use of FEM in order to assess the influence of the auxeticity of the core on the behavior of the beam.

Fig. 1. The geometry of the sandwich beam with auxetic structure core

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STRUCTURAL OPTIMIZATION AND MECHANICAL CHARACTERISATION OF HYBRID AUXETIC STRUCTURES

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Keywords: Auxetic; Hybrid material; Optimisation; Dynamic experiments; Energy absorption

Abstract

Auxetic materials dispaly a negative Poisson's ratio, meaning they expand laterally when pullend in the perpendicular direction [1]. This behaviour leads to enhancements in the mechanical behaviour such as higher impact resistance [2] and energy absorption capacity [3]. These two properties make auxetic materials of special interest for crash-absorbers in i.e. cars or trains.

The present work focuses on the optimisation of auxetic unit cells via finite elemte analysis (FEA) for the purpose of a lightweight crash absorber. Therefore, four different existing auxetic unit cells were modeled using the commercial FEA software ABAQUS® and optimised in terms of the mass distribution along the struts using a self-developed optimisation routine. Two different geometry parameters were introduced to each unit cell and a model of 3x3x3 unit cells was simulated to compute the mass specific energy absorption capacity. The two models with the highest energy absorption capacity were selected for experimental analysis. The 3D-printed polymer specimens were electrochemically coated with nickel to create a Ni/polymer hybrid structure. All specimens were studied using quasi-static compression experiments and Open Hopkinson Pressure Bar (OHPB) experiments. The experimental results before the first crack matched the simulation very well. All specimens displayed brittle failure, so the polymer was melted out. The dynamic OHPB experiments were performed using strain-rates 400 s-1 and 800 s-1, respectively. Only a small increase of the stiffness under dynamic loading for the polymer specimens was detected. As for the hollow-strut structures, an increase in the plateau stress and the plastic collapse stress occured for the high strain-rate (800 s-1). The specimens with the highest energy absorption capacity according to the simulation, were much weaker due to the hollow struts. Instead of bending, the struts folded themselvs, which rendered them much weaker.

In conclusion it is possible to improve existing crash-absorber elements with tailored auxetic hybrid structures. They absorb higher amounts of energy while saving mass compared to conventional Ni/Al-hybrid foams. Due to additive manufacturing the production of those complex structures is easily possible. In a crash the hybrid structures absorb higher amounts of energy without changing their stiffness.

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MULTIFUNCTIONAL HYBRID FOAMS COMPOSED BY ALUMINIUM OPEN-CELL FOAM FILLED WITH POLYMERS

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Keywords: Open-cell aluminium foam; Polydimethylsiloxane; Hybrid foam; Graphene-based materials; Compressive behaviour

Abstract

Multifunctional materials represent one of the most current and promising class of materials for engineering applications. This type of materials shows enhanced performance resulting from the combination of the individual constituents' properties [1]. Hybrid foams are a particular class of these materials usually prepared by filling the voids of the foam with a secondary material. Aluminum open-cell foams are one of the most interesting multifunctional materials with applicable properties, such as high thermal and electrical conductivities and high internal surface area, recyclability and non-flammability. However, they are mechanically weak compared to other materials. This drawback can be overcome with the combination of a stronger filling material (polymer) [2,3]. In this study, an aluminum open-cell (OC) foam was filled with polydimethylsiloxane (PDMS), resulting in polydimethylsiloxane-aluminum (PDMS-OC) hybrid foam. Quasi-static and dynamic uniaxial compressive tests and infrared thermography were performed to compare the PDMS-OC hybrid foams with the individual components (OC foam and PDMS). The effect of the incorporation at a low content of graphene-based materials (GBMs) dispersed into the PDMS matrix was also evaluated. Results show an improvement of the compressive strength and energy absorption capacity of hybrid foams compared to the individual components (OC foams and PDMS). The use of the PDMS as a void filler also changed the typical layer-wise collapse mechanism of the aluminum open-cell foam. Simultaneously, the elastomeric behavior of PDMS allowed that the material can undergo higher loads without cracking. The PDMS enforced a symmetric deformation by folding in the middle of the hybrid foams. The high energy absorption values of aluminum OC foams embedded with PDMS compensated for the mass increase due to the PDMS filler. The incorporation of GBMs introduces voids into the PDMS matrix and avoids higher degree of crosslinking/polymerization in PDMS. The thermal conductivity of the OC/PDMS hybrid foams was slightly higher comparatively to the PDMS specimens. This effect is more pronounced with the addition of GBMs in the PDMS matrix.

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DEVELOPMENT OF METAL-POLYMER STRUCTURES FOR IMPACT ENERGY ABSORPTION

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Keywords: Hybrid cellular structures; Lost wax casting; Compressive properties; Energy absorption

Abstract

This study presents the evaluation of the compression behaviour of two types of hybrid foams (one-size and dual-size cell structure) composed by aluminium alloy and filled with two different polymers. The chosen polymers were Polypropylene (PP) and Acrylonitrile butadiene styrene (ABS) polymers.
The manufacturing process of the structures consisted in the production of metallic foams for subsequent impregnation of polymers. The production of metallic foams was made by lost wax casting. The polymer impregnation was assisted through a process of temperature assisted impregnation in a specially developed tool. Compressive testes were realized and the deformation was analysed, concluding that the hybrid foams induced a significant improvement in energy absorption compared with metallic foams without the polymer.

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DYNAMIC PENETRATION TESTING OF CELLULAR MATERIALS

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Keywords: Cellular materials; Penetration testing; Hopkinson bar; Digital image correlation

Abstract

Cellular metallic materials like metal foams, hybrid foams or auxetic lattices are types of lightweight materials with enhanced energy absorption properties. They are suitable for protection against high speed penetration or blasts. The deformation behaviour of cellular metals at different strain rates needs to be experimentally evaluated since these materials often have complex internal structure, which strongly influences their behaviour. Deformation behaviour of three types of cellular metals was evaluated in this study: a) aluminium advanced pore morphology (APM) spheres embedded in polyurethane, b) aluminium APM spheres embedded in epoxy resin, and c) closed-cell aluminium foam. Classic quasi-static compression testing was performed first to determine the base material properties of tested materials in compression. Then a modified Open Hopkinson Pressure Bar (OHPB) apparatus was used for the dynamic penetration testing of specimens. The cylindrical specimens with diameter of 60 mm and thickness of 30 mm were mounted on a horizontal tripod stand with the internal aperture of 36 mm. The tripod was instrumented by foil strain-gauges for the measurement of the individual reaction forces. Back side of the specimens was supported by the high-strength aluminium transmission bar instrumented with piezo-electric load-cell for the measurement of the back-side penetration force. The specimens were penetrated by direct impact of the high-strength aluminium incident bar accelerated by the gas-gun system. The incident bar was instrumented using the foil strain-gauge. Impact velocities in range from 5 m/s to 25 m/s were used in the experiments. The experimental setup was observed by a pair of synchronized high-speed cameras at approx. 100 kfps. Reaction forces on tripod, back side penetration force and impact side penetration force were measured during the experiments. Digital image correlation (DIC) was used for the analysis of the penetration depth of the incident bar and movements of the transmission bar. The measured forces were compared with the DIC data. Complex analysis of the material behaviour during mid-speed penetration was carried out. Penetration stopping capabilities of the individual materials were evaluated and compared.

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EXPERIMENTAL INVESTIGATION OF INITIAL YIELD SURFACES OF SOLID FOAMS AND THEIR EVOLUTION UNDER SUBSEQUENT LOADING

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Keywords: Multiaxial experiments; Yield surface; Metal foam; Hybrid foam

Abstract

Metal foams are bio-inspired cellular materials mimicking the construction elements of bones [1]. Ni/PU hybrid foams are special foams consisting of open-cell polymeric foams acting as structural template for a coating by electrodeposition of nickel [2]. Foams can be used for lightweight construction, as energy absorbers or for functional applications such as heat exchangers, for sound absorption or electromagnetic shielding [3]. The advantage of Ni/PU hybrid foams is that they are a multifunctional material, where the individual properties can be tailored by the pore size, the coating material and the coating thickness.

In nearly all kind of application, foams are exposed to multiaxial stress states, which make multiaxial characterisation and the analysis of yield surfaces of foams important for the design of reliable components made of foams [4]. However, due to the challenging task of multiaxial testing of cellular materials, common experimental characterisations on foams mostly deal with compression or tensile tests. The present study deals with the experimental investigation of initial yield surfaces of open-cell aluminium foams and Ni/PU hybrid foams using uniaxial compression and uniaxial tensile tests, torsion as well as combined tension-torsion and compression-torsion tests with superimposed uniaxial loads. The yield surfaces were described by the model according to Bier et al. [5], since it is able to account for symmetric and asymmetric shapes. The effect of pore size, coating thickness and density on the shape and size of the yield surface was studied and enriched by structural information from computer tomography scans and metallographic cross sections. Furthermore, the evolution of the post-yield surfaces under subsequent loading was analysed. Digital image correlation was used to elucidate the local deformation behaviour.

The waist width of the struts changes the shape of the yield surface for struts with a more homogeneous mass distribution along the strut from a symmetric yield surface to an asymmetric one for struts with more mass concentrated in the nodes. The yield surface increases with increasing density and coating thickness. Post-yield surfaces mainly shrink in the tensile part of the surface, whereas there are only little changes in the compression part with further loading.

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FATIGUE LIFE ANALYSIS OF CLOSED-CELL ALUMINUM FOAM USING HOMOGENIZED MATERIAL MODEL

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Keywords: Closed-cell structure; Aluminum foam; Fatigue; Homogenized material model

Abstract

Fatigue life analysis of porous materials as metal foams [1] are very difficult to process because the comprehensive computational analysis using numerical models with a huge number of finite elements is required for that purpose. Instead of modelling the exact internal structure of treated porous material, an appropriate homogenized material model can be performed in the subsequent numerical analysis.

In the presented study, the fatigue analyses of a tensile specimen made of closed-cell aluminium foam using homogenized “Crushable Foam” material model is performed. The used material model is based on the previous experimental and numerical simulations on the aluminium foams. The obtained results were derived from different specimen porosities and then statistically evaluated. In addition, the used material model was homogenized and verified and is now implemented into the Abaqus software [2]. The computational results (nonlinear stress-strain relation) of treated aluminium foam were then used for the subsequent fatigue analyses [3] to determine the fatigue life of the treated porous structure. Required fatigue material parameters are determined using an inverse procedure, based on experimental fatigue test and by means of optimization. The optimization is performed by comparing the numerical results obtained for fatigue analysis and experimental results.

The determined computational results for the fatigue life of treated closed-cell aluminium foam are compared to the available experimental results and to the computational results of the previous numerical analyses, which have been performed using the complex numerical model as presented in [4].

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3D GEOMETRICAL RECONSTRUCTION OF CLOSED-CELL ALUMINUM FOAM USING CT IMAGES

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Keywords: Closed-cell aluminum foam; Geometrical reconstruction; CT

Abstract

Closed-cell aluminum foam is a popular advanced material with a cellular structure and extraordinary mechanical and physical properties at a very low density. It is considered to be suitable material for structures that need to be light weight and at the same time stiff, energy absorber, sound and vibration insulator.

The development of an efficient procedure for three-dimensional modeling of metal foams remains one of the greatest challenges for engineers [1-3]. The numerical determination of mechanical properties of foam structure is a demanding engineering task and is indispensable for design purposes. In this research closed-cell aluminum foams with different cell sizes produced by Aluinvent Zrt. are analyzed in non-destructive way. The purpose of the research is to map the inner structure of the material using X-ray computed tomography and to establish the most accurate 3D geometrical model of the actual structure which is suitable for finite element investigations. Accurate numerical calculations depend not only on the resolution of the X-ray but on the exactness of the reconstruction.

An essential part of the procedure is a manual reconstruction method for objects of complex geometry. The first step is the preparation of plane sections (CT images) with parallel planes of given density. The second is the performance of a series of transformations providing a geometrically accurate three-dimensional object that is suitable for finite element analysis. The investigation of specimens proves that the accuracy of the proposed reconstruction method meets the requirements and the procedure can be reproduced, validated and suitable for quality control purposes [4].

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EXPERIMENTAL AND NUMERICAL CHARACTERISATION OF OPEN- AND CLOSED-CELL ALUMINIUM ALLOY FOAMS

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Keywords: Aluminium alloy foams; Micro-CT; Tomography; Modelling; Deformation mechanisms; Compressive behaviour

Abstract

Several experimental and numerical studies have been performed to correlate mechanical properties with the characteristics of the internal cellular structure of foams. Most experimental studies were performed using conventional mechanical tests (e.g., compression tests) supported by microscopy and optical techniques [1]. On the other hand, most numerical studies are modelled to represent both open- and closed-cell representative unit-cells [2]. This paper reports the findings of an experimental and numerical study to investigate the quasi-static axial compression behavior and the deformation modes of a periodic aluminum alloy open-cell foam and a stochastic closed-cell foam, which were prepared by, respectively, the investment casting method and powder metallurgy method. Herein, X-ray micro-computed tomography (micro-CT), together with *in situ* stepwise uniaxial compression tests (using Bruker´s Material Testing Stage), were performed to characterize the real 3D internal cellular structures and their changes. The samples were subjected to a controlled load that was interrupted after reaching predefined levels of compression for micro-CT scanning. The curves for load *vs.* displacement of the different foams were measured in real time. Nanoindentation tests were also used to evaluate both Young modulus and hardness of the foam's base material. Finite Element Method (FEM) models based on CT scan images were employed to predict the elastic-plastic deformation behavior of the foams under compressive loads, relating the geometrical properties of internal cellular structures (e.g., cell size, cell distribution, cell anisotropy and strut geometry) with the macroscopic compressive behavior. Numerical results were compared with experimental results.

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COMPUTATIONAL ANALYSIS OF THE UNI-DIRECTIONAL POROUS COPPER MECHANICAL RESPONSE AT HIGH-VELOCITY IMPACT

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Keywords: Porous material; Uni-directional porous metal; High-velocity impact; Computational analysis

Abstract

The advantages of cellular materials are low density, efficient damping, high grade of deformation, high energy absorption capability, durability at dynamic loadings high thermal and acoustic isolation. The uni-directional pore is one type of porous structure. Hokamoto et al. [1] have proposed a new method for fabrication of porous metal with longer and uniform unidirectional pores, named "UniPore", using explosive compaction of cylindrical metal pipe assembly. This proposed method has improved the length of unidirectional pores as the order of several meters.

This UniPore consisted of a bigger outer pipe completely filled with smaller inner pipes and those pipes were welded. Vesenjak et al. [2] have conducted the extensive research on microstructural and mechanical properties of those porous copper structures and it has been confirmed that the fabricated UniPore specimens have good compressive properties with high-energy absorption capability.

This paper studies the mechanical response of UniPore copper sample under a high-speed impact testing accelerated by a powder gun and computational simulation techniques using ANSYS AUTODYN 3D to analyze deformation process. Here, two types of the cubic copper specimen, UniPore copper and solid copper of the same mass as first specimen was impacted.

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EXPERIMENTAL AND NUMERICAL INVESTIGATION OF THE CRUSHING BEHAVIOUR OF AN AL CORRUGATED MULTI-LAYERED CELLULAR STRUCTURE

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Keywords: Corrugated; Aluminum; Impact; Velocity; Modelling

Abstract

Quasi-static and dynamic modified Split Hopkinson Pressure Bar tests were used to measure both the plateau and shock stress of a multi-layered (15 layers) Al corrugated structure as function of impact velocity. The corresponding models of each type of tests were then implemented in Ls-Dyna. The quasi-static compression tests were performed at 0.0048 m s^{-1}, while the impact tests between 9-200 m s^{-1}. Several sceneries of imperfect layer inclusions in between multi-layers were also investigated numerically using three different material models (perfectly plastic, plastic strain hardening and plastic strain and strain rate hardening) to determine the effect imperfection on the crushing behaviour at different velocity regimes. In accord with literature [1] the results have shown three deformation modes of the tested cellular structure: a quasi-static homogenous mode till intermediate velocities e.g. 20 m s^{-1}, a transition mode at the intermediate velocities, between 60 and 90 m s^{-1}, and a shock mode after 90 m s^{-1}. The perfect and imperfect models resulted in nearly the same initial crushing stresses in the shock mode, showing a vanishing effect of imperfection on the crushing stress at increasing velocities. The layer strain histories revealed a velocity-dependent layer densification strain. The densification strain increased with increasing velocity in the shock deformation regime. The increase of velocity from quasi-static to intermediate velocities both increased the test and numerical shock stress, while the plateau stress almost stayed constant between 20 and 250 m s^{-1}. The increased plateau stress of strain rate insensitive models confirmed the effect of micro-inertia and Type-II behaviour of the tested structure [2]. Furthermore, the contribution of strain rate to the plateau stress of cellular structures made of low strain rate sensitive Al alloys was shown to be relatively lower as compared with that of the strain hardening and micro-inertia, but it might be substantial for the structures constructed using relatively high strain rate sensitive alloys. The critical velocity for the shock deformation was also well accord with the experimentally and numerically determined critical velocities. Both model types, the imperfect and perfect, well approximated the stress-time histories and layer deformations of the shock mode. The stress-time and velocity-time histories of the rigid-perfectly-plastic-locking model of the shock mode [3] and the critical velocity for the shock formation were well predicted when the dynamic plateau stress determined from the distal end stress in the shock mode was used.

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NOTES

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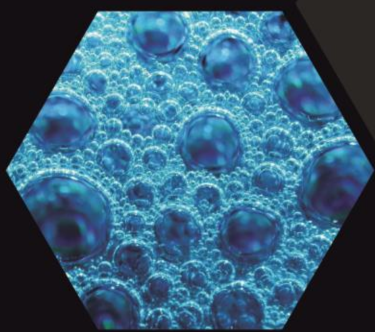

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