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Special Issue on Cellular Materials

Geometrical and mechanical analysis of various types of cellular metals

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Abstract

The paper gives a short overview of geometrical characterization, experimental testing, computational modelling and finite element analysis of various cellular metals: Advanced Pore Morphology (APM) foam, open-cell aluminum foam, Metallic Hollow Sphere Structure (MHSS) and cellular metals with uni-directional pores (UniPore). The geometrical analysis and characterization is based on the analysis of micro computed tomography scans and proper recognition of their internal cellular structure, taking into account statistical distribution of morphological and topological properties. The results of conducted geometrical analysis provided means to develop methodology for proper 2D and 3D geometrical modelling of irregular cellular structures and consequent formation of computational models. These were used to study the compressive and bending behavior of analyzed cellular structures by means of quasi-static and dynamic nonlinear computational simulations (using engineering codes ABAQUS and LS-DYNA), validated by experimental tests.

Keywords: cellular metals; mechanical characterization; geometrical analysis; advanced pore morphology (APM) foam; metallic hollow sphere structure (MHSS); UniPore structure.

1. Introduction

A cellular/porous material is made of an interconnected network of solid struts or plates which form the cell's edges and faces [1,2]. Their mechanical behavior mainly depends on the relative density (the density of the cellular structure, divided by the base material density) and the base material which can be either metal, polymer, glass or ceramics. The other important parameters of the cellular structures are morphology (open or closed cells, size and shape of cells), topology (regular or irregular cell structure) and possible filler type. To achieve adequate properties of the cellular material, the base material has to be carefully chosen regarding to its mechanical (strength, stiffness) and thermal properties (thermal conductivity). The advantages of cellular materials in general are low density (light-weight structures), high acoustic insulation and damping, high energy absorption capabilities, durability at dynamic loadings and recyclability [1-3].

Cellular materials have a characteristic stress-strain relationship in compression, which is characterized by large strains at almost constant stress in plastic region (stress plateau) until the cells completely collapse (densification) [1,4-6]. With the strain increase, the cells become oriented with the loading direction, increasing the stiffness of the cellular material until the tensile failure. The mechanism of cell deformation and collapse also depends on the cellular's structure relative density.

The micro- and macroscopic properties of cellular materials make them very attractive for use in automotive, rail, naval and aerospace industry as heat

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exchangers, filters, bearings, acoustic dampers, core material in sandwich structures, bio-medical implants and elements for energy absorption. To further expand their application potentials the cellular materials are often used as parts or cores in composite structures, e.g. sandwich structures, foam filled tubes [7-9]. Sandwich structures are usually comprised of two face sheets with cellular material as a core in between. Such sandwich structures have an increasing relevance in various engineering applications due to their high stiffness, strength and reduced mass (light-weight). In some cases single cellular material elements (metallic hollow sphere structures, advanced pore morphology foam) are joined together using different technologies such as sintering, soldering and adhering. Adhering provides the most economical way of joining and allows for further cost reduction and therefore the expansion of potential applications.

The understanding of cellular material behavior under quasi-static and dynamic loading is valuable for engineering applications such as those related to mechanical energy absorption through deformation [10,11]. Proper characterization of all influential parameters is particularly important and can be best achieved through combination of dedicated experimental testing program and computational simulations. However, the structure of industrial cellular materials in terms of shape, size and distribution of pores cannot be fully controlled with existing mass production technologies. The structural characterization techniques significantly contributed to describe such complex structures (pore morphology and topology) [12-14]. Random pore geometry can result in a certain scatter of mechanical and thermal characteristics of these materials and their components. Some recently developed fabrication methods of cellular metals result in more homogeneous pore structures [15-19].

This paper provides a short overview of mechanical and geometrical characterization of different types of cellular materials based on experimental testing, computational simulations and computed tomography.

2. Unidirectional cellular structure - UniPore

Some innovative manufacturing approaches have been investigated recently in search of cellular materials with more regular distribution of pores, constant wall thickness and pore sizes. One such an approach is explosive compaction of thin-walled tubes, which after treatment form a cellular structure with straight unidirectional pores – the UniPore structure [20,21]. This manufacturing procedure results in making a cellular material with perfectly parallel unidirectional pores (Fig. 1). The advanced geometrical properties of the UniPore structure assure wide opportunities for its application due to its unique mechanical and thermal properties (e.g. heat sinks using phase change materials [22]). Mechanical behavior of the UniPore structure with unidirectional pores can be influenced by size, thickness and base material of original tubes.

Fig. 1. UniPore samples with different porosities (p = 0.32, 0.49, 0.58).

The compressive mechanical properties of UniPore structure have been investigated by means of experimental (two specimens for each loading direction, Fig. 2) and parametric computational simulations considering various materials and geometrical parameters using the LS-DYNA finite element system [23]. The engineering stress has been calculated by dividing the reaction force with the maximal cross-section area.

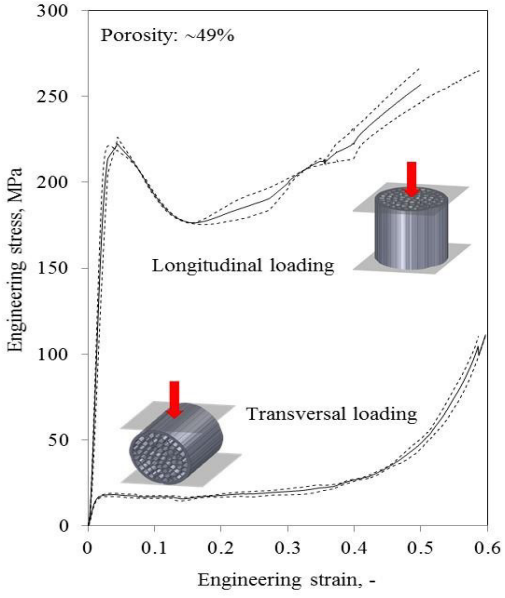

Fig. 2. Longitudinal and transversal compressive behavior of UniPore structures [20].