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NUMERICAL AND EXPERIMENTAL STUDY OF REAL FOAM MICROSTRUCTURE MODELS

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Abstract

Metal foams are new, as yet imperfectly characterized, class of materials with low densities and novel physical, mechanical, thermal, electrical and acoustic properties. They offer a potential for lightweight structures, for energy absorption, and for thermal management; and at least some of them are cheap. Such characteristics have been appreciated by the automotive industry in the aspect of crash and impact phenomenon. Energy absorption capacity of foams under dynamic load was analytically confirmed based on a rigid-perfectly plastic-locking foam model. In this paper the development process of a real closed cell foam microstructure based on finite element model with the use of 3D scanning is shown. Computed tomography (CT) is a medical imaging method employing tomography created by computer processing. Digital geometry processing is used to generate a three-dimensional image of the inside of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation. The numerical analyses carried out with the usage of LS Dyna computer code of the quasi static and dynamic compression tests are presented. The most important mechanisms and phenomena that appeared in the microstructural sample are described. In the final part of these investigations the comparison process between numerical and experimental test was performed. The results confirmed the good correspondence between both tests.

Keywords: *microstructure, aluminium foam, 3D scanning*

1. Introduction

Cellular solids are materials made out of solid strut or thin plate like structures bridged together. They occur in nature in the form of honeycombs, wood, bone, cork etc. These materials possess a unique combination of properties such as low thermal conductivity, low density and high energy-absorption [1]. Foams are a class of cellular solids, generally made by dispersing gas into a liquid material and then cooling it to solidify. They are categorized as open-cell and closed-cell foams. Depending on the solid materials that are made into foams, they are also categorized as polymeric foams, metallic foams, and ceramic foams [1]. Due to developments in material science and manufacturing techniques, advanced foams have found potential for use in the automobile, aircraft, and space vehicle structures. A special example is the use of foams in external fuel tanks and thermal protection system TPS) of space vehicles. It has been accepted that packed in a BCC structure, a tetrakaidecahedron – a 14-faced polyhedron – meets the minimum surface energy condition for mono-dispersed bubbles [2]. The microcellular graphitic carbon foams were first developed at the US Air Force Research Laboratory in the 1990s [3]. It has been proven that the repeating unit cell of this foam can be approximated by a regular tetrakaidecahedron [4].

In the paper the development process of a closed cell foam microstructure based on finite element model with the use of the 3D scanning is presented. The numerical analyses carried out with the usage of LS-DYNA computer code of the quasi static and dynamic compression tests are presented. The most important mechanisms and phenomena that appeared in the microstructural sample are described. In the final part of these investigations the comparison process between numerical and experimental test was performed. The results confirmed the good compatibility between both tests.

2. Experimental researches

A uniaxial static compression test for aluminium foam sample was carried out. The scheme of the test was shown in Fig. 1. The relation between stress and strain is presented in Fig. 2.

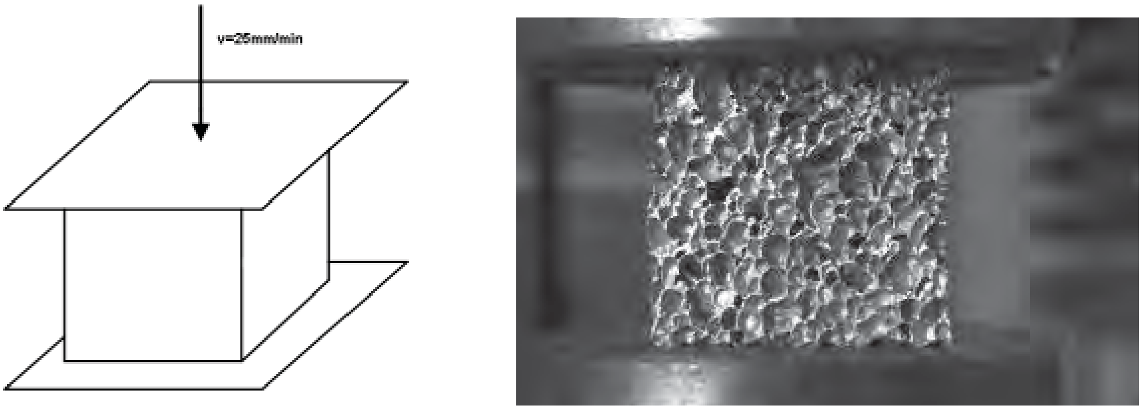

Fig. 1. Scheme of static compression test of aluminium foam sample

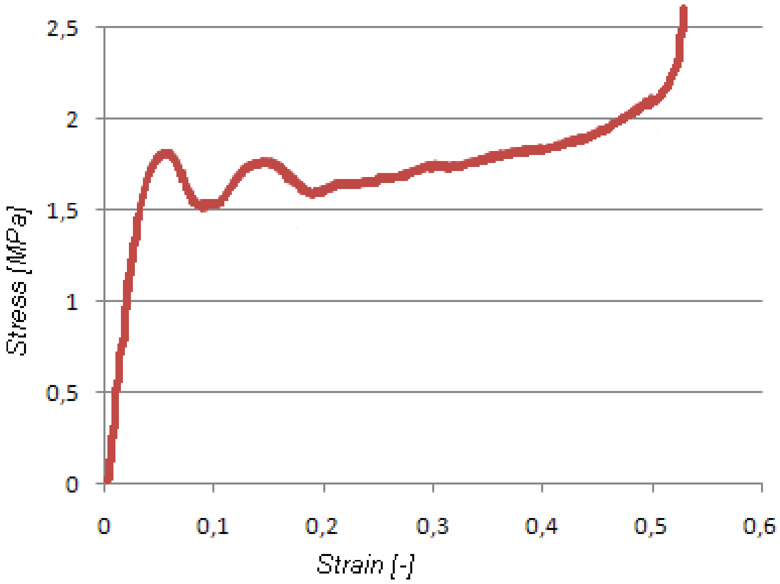

Fig. 2. Results for static compression test of aluminium foam sample

3. Numerical model development

Various techniques and methods are used for purposes of foam materials numerical modelling. Numerical models may be constructed on the base of a real structure image that is available as 2D photo or 3D scan. The 3D scans may be obtained with the use of X-ray or neutron tomography technique. Models may have smooth surfaces or may be based on the grid technique [5-7]. Idealistic models which are suitable for investigations of particular geometrical or material parameters influence on global properties of foam are also used. They may be built on the base of geometrical structures (i.e. Kelvin's polyhedron [8, 9]).

The presented model was built with the use of computed tomography carried out on the X-ray micro-CT scanner SkyScan 1174.

Computed tomography (CT) is an imaging method employing computer processed scans. Digital geometry processing is used to generate a three-dimensional image of the inside of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation.

The first stage of the numerical model development was creation of computed tomography of the closed-cell aluminium foam sample. The pixel size of 14.51 μm and 50 mm aluminium radiation filter was used. The results of the tomography are presented in Fig. 3 and 4.

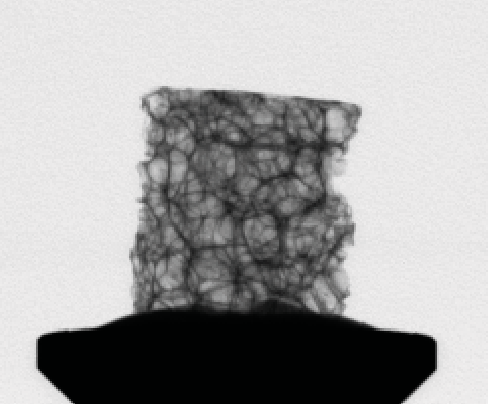

Fig. 3. View of sample from scanner camera

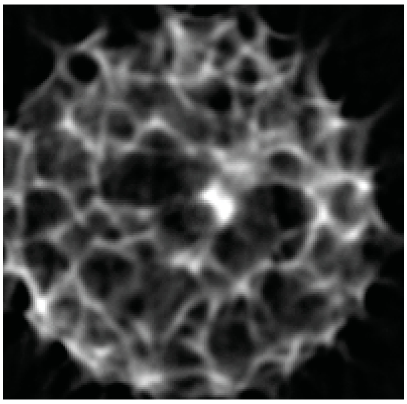

Fig. 4. Cross-section of sample resulted from tomography

With the use of the SkyScan software, the cross-sections were transformed into the monochrome bitmaps (Fig. 5).

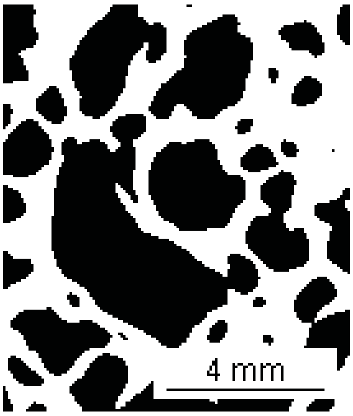

Fig. 5. Example of monochrome bitmap of sample cross-section

A Visual Basic application was developed to convert the information from bitmaps to the list of finite elements. Thanks to applying solid elements Hex8 [10], a numerical model based on a position of pixels in each bitmap was built. Each white pixel representing the material was transformed to a finite element. The reconstructed cube had a dimension of 7×7×7mm and

401068 solid elements (Fig. 6). The porosity of the numerical model was 78% in comparison to the porosity of real foam of 82%. The difference resulted from the limitations of the applied research method (e.g. a tomograph size of pixels).

Fig. 6. Numerical model of aluminium foam microstructure

4. Numerical analysis description

A dynamic numerical analysis was carried out with the use of LS-DYNA computer code. A compression was performed with two rigid plates - stationary and moving (v = 28 mm/s) one. The external walls of the model were locked to reconstruct the effect of the low Poisson ratio as in the real foam experiment. A piecewise linear plastic material model was used for aluminium (Young modulus E=71000 MPa, Poisson ratio ν=0.33, yield stress Re=250 MPa). Although a numerical analysis was dynamic, small differences between the static and the dynamic compression processes of foams allow comparing it with the experiments.

5. Results

During the analysis the stress vs. strain relation was studied. The results for the numerical analysis are presented in the chart below (Fig. 7). The deformations of the whole structures are presented in Fig. 8. The very high correspondence between experimental and numerical analyses is clearly visible.

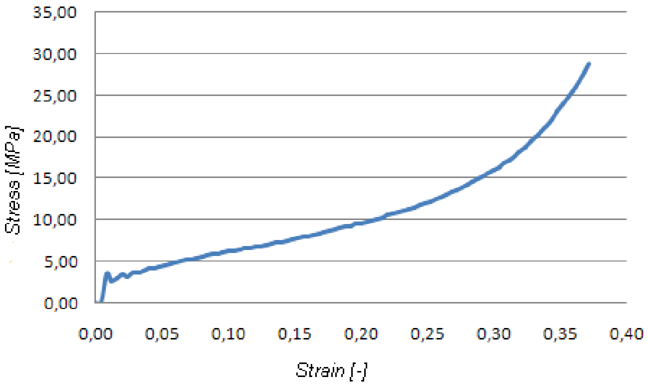

Fig. 7. Results for numerical compression test of aluminium foam microstructure sample

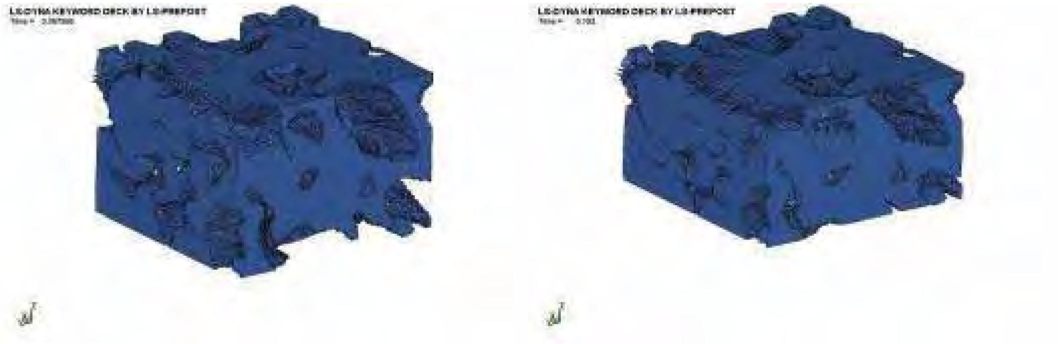

Fig. 8. Deformations of the sample in numerical compression test

Also, the effective stress distribution in the numerical model was analyzed. The example of such distribution is shown in Fig. 9. One can conclude that the stress distribution in a researched sample is almost homogeneous, only local concentrations may be found.

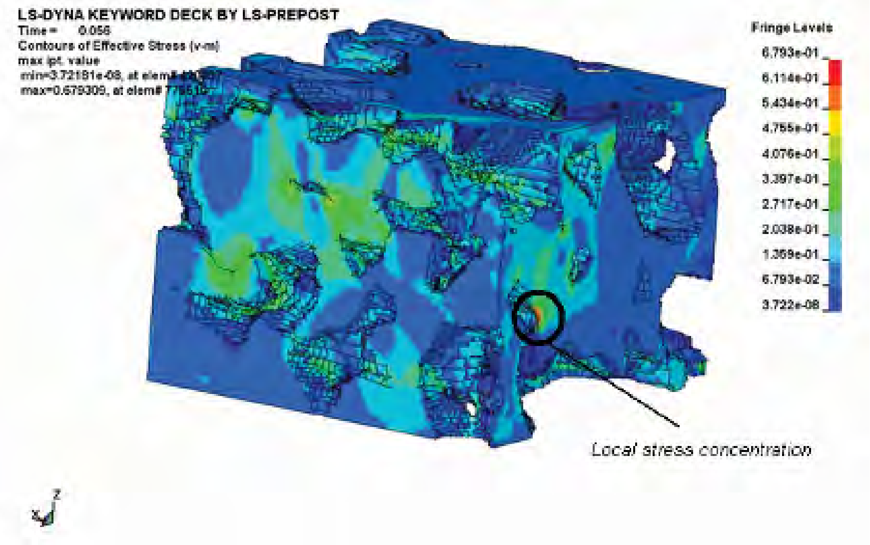

Fig. 9. Effective stress distribution in numerical model

6. Conclusions

In the paper the research methodology of the aluminium foam microstructure was presented. The development process of the numerical model of the real foam structure was shown. The numerical analysis of the created model was carried out with the use of LS-DYNA computer code and compared with the experimental result. A high correspondence between both tests was achieved, which confirms the correctness of the presented research methodology.

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