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NUMERICAL STUDY ON CLOSED CELL FOAM STRUCTURE DAMAGE MECHANISMS

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Abstract

Metallic foams are currently being looked at as a new material for automobiles. The main goal of the use of metallic foams in vehicles is to increase sound dampening, reduce the weight of the automobile, and increase energy absorption in case of crashes, or in military applications, to combat the concussive force of IEDs.

The metallic foams that are being looked at currently, are aluminum and its alloys due to their low density (0.4–0.9 g/cm^3). In addition these foams have a high stiffness, are fire resistant, do not give off toxic fumes, are fully recyclable, have high energy absorbance, have low thermal conductivity, have low magnetic permeability, and are efficient at sound dampening, especially in comparison to light weight hollow parts. In addition, partial addition of metallic foams in hollow parts of the car will decrease weakness points usually associated with car crashes and noisy vibrations. These foams are cheap to cast by using powder metallurgy (as compared to casting of other hollow parts).

The aim of the research was to describe and to assess the main mechanisms that appear in the foam structure during the compression. The development process of the finite element model of the closed cell foam microstructure is presented in the paper. The model geometry was based on the real structure research, which was carried out with the use of computed tomography. The model was built with the use of a unique computer code created to transform the scan point cloud into FE raster model based on solid 8-node elements. The experimental and numerical compression test results were compared and showed good compatibility. The stress distributions were studied to describe the main mechanisms in the structure.

Keywords: *closed cell foam, finite element method, X-ray tomography, damage*

1. Introduction

Metal foams ("metfoams") are a new, yet imperfectly characterized, class of materials with low densities and novel physical, mechanical, thermal, electrical and acoustic properties. They offer potential for lightweight structures, for energy absorption, and for thermal management; and some of them, at least, are cheap.

The possible applications of metal foams are presented in Tab. 1.

Various techniques and methods are used for the purposes of foam materials numerical modelling. Numerical models may be constructed on the base of the real structure image that is available as 2D photo or 3D scan. The 3D scans may be obtained by use of X-ray or neutron tomography technique. Models may have smooth surfaces, or may be based on a grid technique [1-3]. 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 [4-6].

In the paper, the main mechanisms that appear in the foam structure during the compression were described and assessed. The development and analysis of the FE model of the aluminium foam microstructure based on computed tomography was presented.

Tab. 1. Applications of metfoams [7]

Application	Comments
Lightweight structures	Excellent stiffness-to-weight ratio when loaded in bending
Sandwich cores	Metal foams have low density with good shear and fracture strength
Strain isolation	Metal foams can take up strain mismatch by crushing at controlled pressure
Mechanical damping	The damping capacity of metal foams is larger than that of solid metals
Vibration control	Foamed panels have higher natural flexural vibration frequencies than solid sheet of the same mass per unit area
Acoustic absorption	Reticulated metal foams have sound-absorbing capacity
Energy management: compact or light energy absorbers	Metal foams have exceptional ability to absorb energy at almost constant pressure
Packaging with high-temperature capability	Ability to absorb impact at constant load, coupled with thermal stability above room temperature
Artificial wood (furniture, wall panels)	Metal foams have some wood-like characteristics: light, stiff, and ability to be joined with wood screws
Thermal management: heat exchangers/ refrigerators	Open-cell foams have large accessible surface area and high cell-wall conduction giving exceptional heat transfer ability
Thermal management: flame arresters	High thermal conductivity of cell edges together with high surface area quenches combustion
Thermal management: heat shields	Metfoams are non-flammable; oxidation of cell faces of closed-cell aluminium foams appears to impart exceptional resistance to direct flame
Consumable cores for castings	Metfoams, injection-melded to complex shapes, are used as consumable cores for aluminium castings
Biocompatible inserts	The cellular texture of biocompatible metal foams such as titanium stimulate cell growth
Filters	Open-cell foams with controlled pore size have potential for high-temperature gas and fluid filtration
Electrical screening	Good electrical conduction, mechanical strength and low density make metfoams attractive for screening
Electrodes, and catalyst carriers	High surface/volume ratio allows compact electrodes with high reaction surface area
Buoyancy	Low density and good corrosion resistance suggests possible floatation applications

2. Numerical model and analysis

SkyScan 1174 (Fig. 1) compact micro-CT is equipment designed for materials microstructural testing. It was used in the presented work for aluminum foam research.

SkyScan 1174 was utilized to carry out the tomography for two samples made of closed cell aluminum. The samples dimensions were 10x10x10 mm. The scanning parameters were as follows: pixel size of 80.19 μm, rotation step of 1 degree.

Fig. 1. SkyScan 1174 compact micro-CT

The results of the computed tomography are presented in Fig. 2. The strain – stress characteristics for that foam are shown in Fig. 3. The comparison of energy absorption experimental results for the compression of 40% (Fig. 4) proved that the structure geometry influences the foam properties.

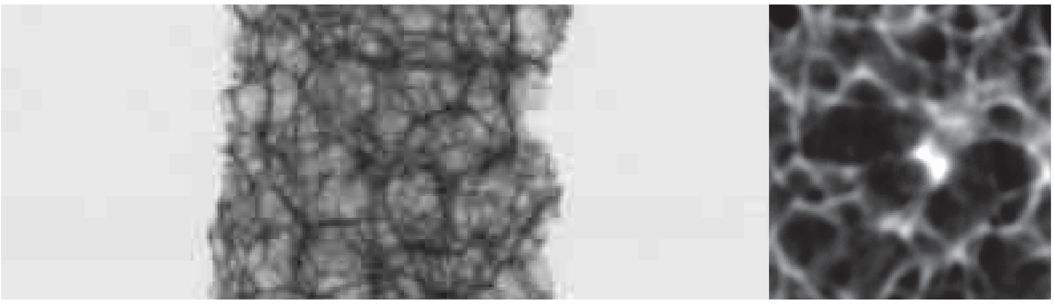

Fig. 2. Computed tomography of aluminum foam samples

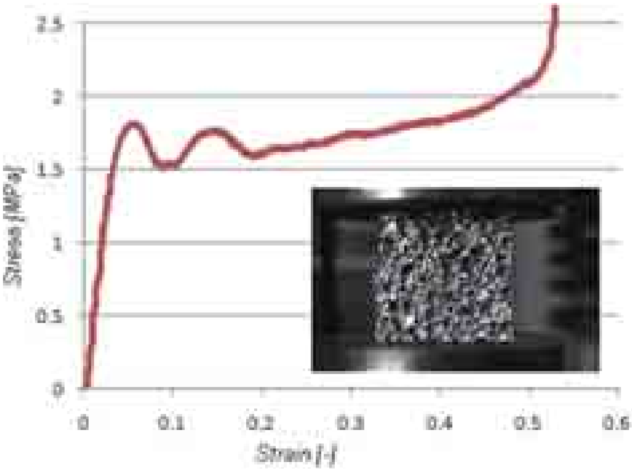

Fig. 3. Strain – stress characteristics for experimental tests [8]

For the purpose of numerical model development, the pictures of cross sections were replaced with the monochromatic bitmaps (using the CT Analyzer software). It was assumed that one pixel at the bitmap is the middle layer of one hexagonal finite element in the numerical model. The special application that transforms the numbers of pixels into the numbers of finite elements was created. This process resulted in the raster numerical model of open cell foam (Fig. 4).

The numerical compression test was carried out with the use of LS Dyna computer code. The compression was made with the use of rigid walls (stationary and moving one). The load speed was 50 mm/min as in the experiment. The dynamic friction coefficient in the model was 0.1.

The models were built from 8-nodal brick finite elements [9]. The number of elements in each model was about 1 600 000.Density of models was 21%.

The elastic-plastic material model with hardening was used for the foam base material (aluminum alloy) – Tab. 2.

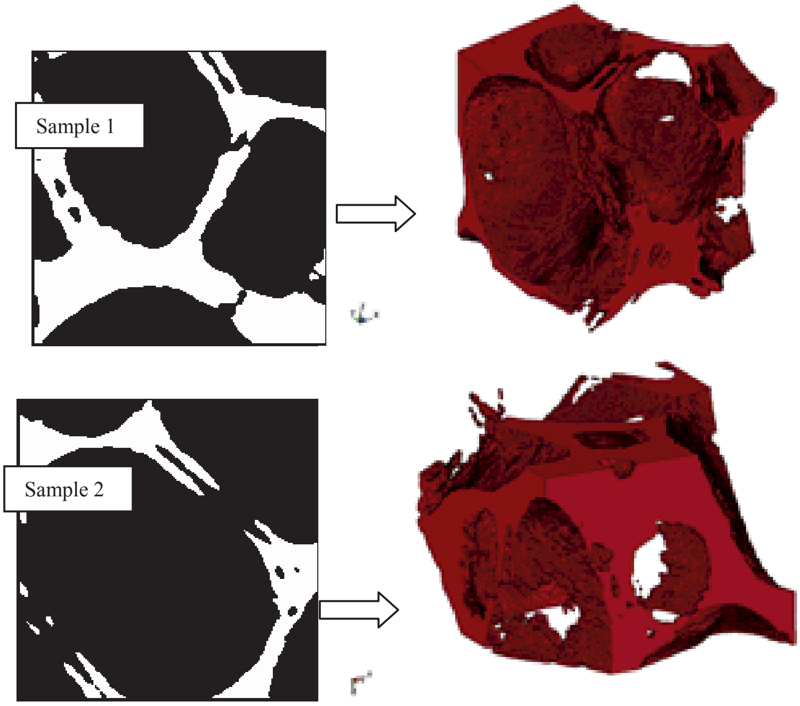

Fig. 4. Numerical model development

Tab. 2. Material properties for aluminum foam base material

Aluminum alloy	Young modulus [GPa]	Poisson's ratio	Yield stress [GPa]	Strength limit [GPa]	Elongation [-]
PA25	71	0.33	0.318	0.488	0.14

3. Results and discussion

The comparison of numerical and experimental tests is presented as stress – strain curves (Fig. 5). The presented results showed a very high correspondence. The differences result from the different porosity values and material model and properties approximations.

Due to the high correspondence between numerical and experimental tests, the main mechanisms appearing in the foam microstructure were assessed on the base of the von Mises stress distributions and deformations (Fig. 6-9).

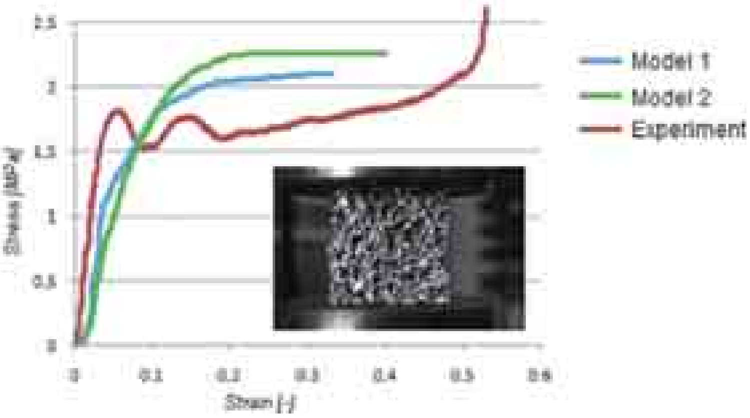

Fig. 5. Comparison of numerical and experimental tests

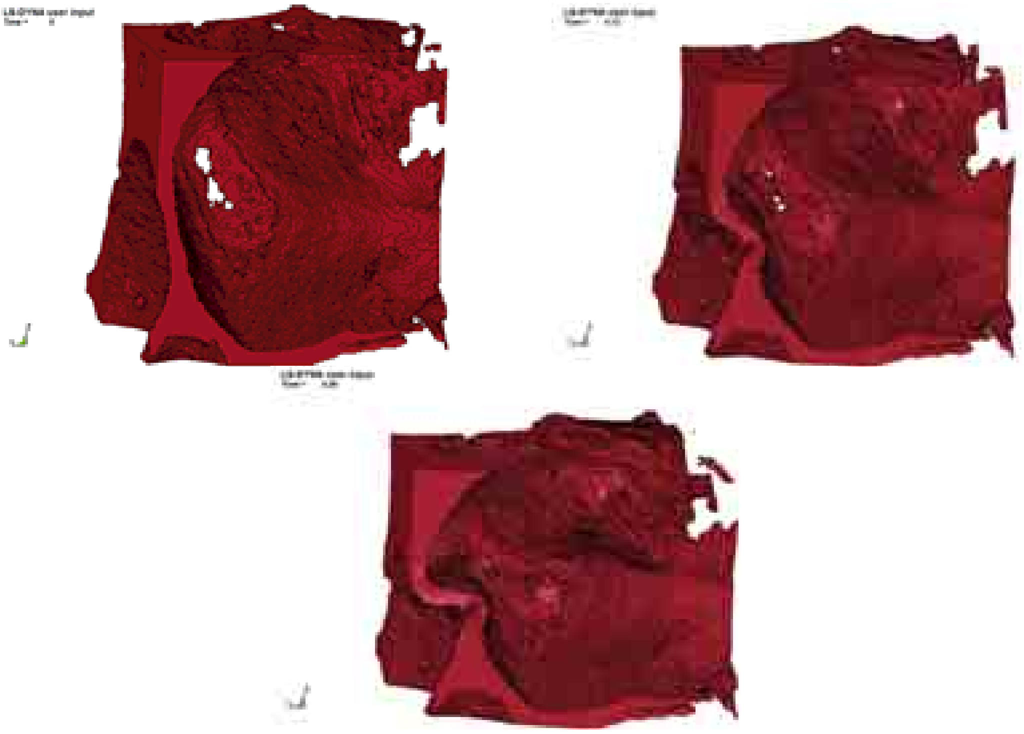

Fig. 6. Numerical analyses results as deformations for Sample 1

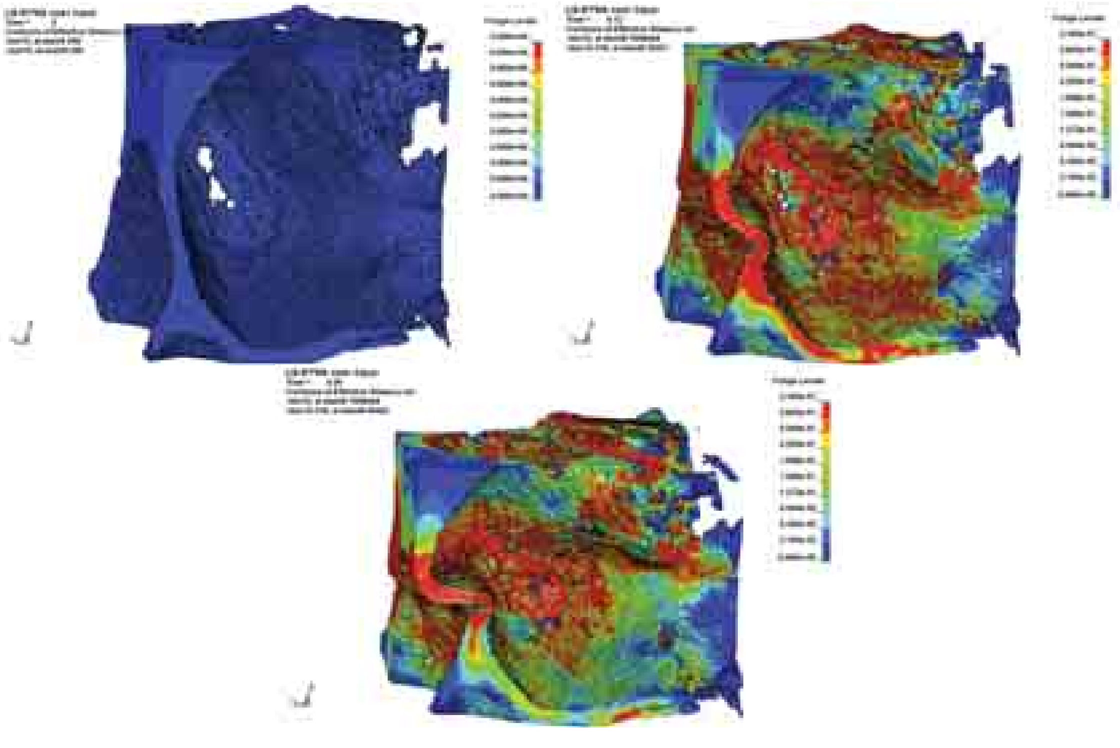

Fig. 7. Numerical analyses results as von Mises stress distributions for Sample 1

On the base of von Mises stress distribution development the main mechanisms in closed cell aluminium foam structure were described. It is strictly visible that the largest and most important for foam damage regions are the plasticity regions placed on the thin parts of pores walls (marked in red in Fig. 8 and 10). The thicker parts of foam structures (connection between pores) have stress values almost 0 (marked in blue in Fig. 8 and 10). Finally, it can be concluded that the damage of the aluminium foam is caused by the instability phenomena that appear in the thin walls of pores and are caused by the plasticity of that regions.

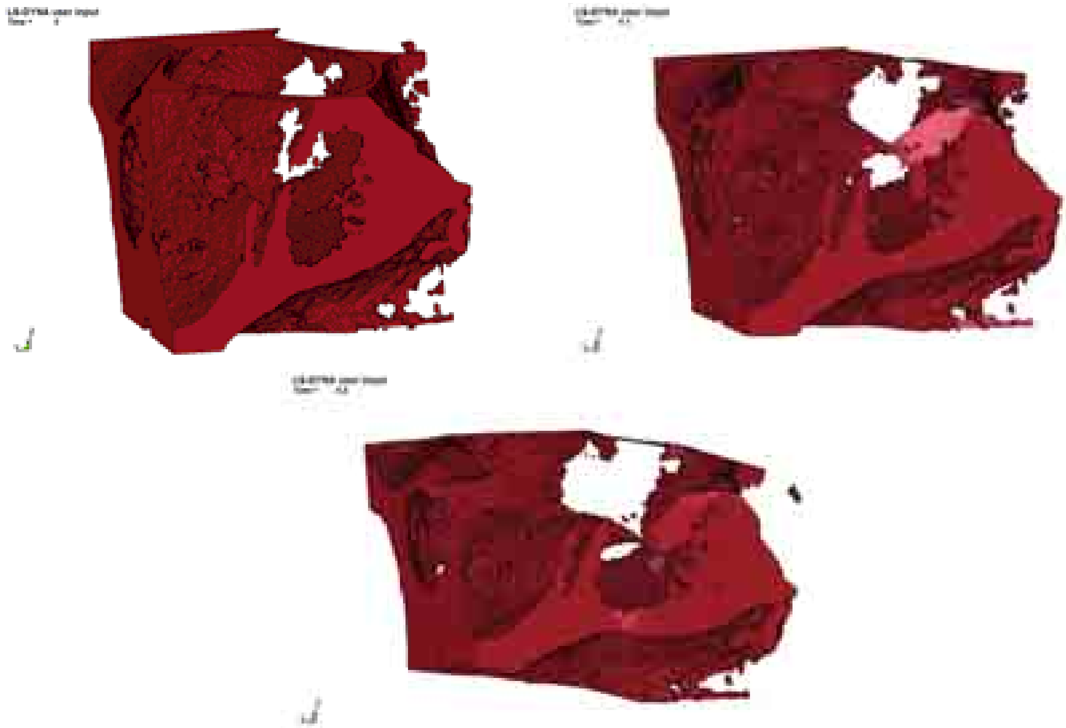

Fig. 8. Numerical analyses results as deformations for Sample 2

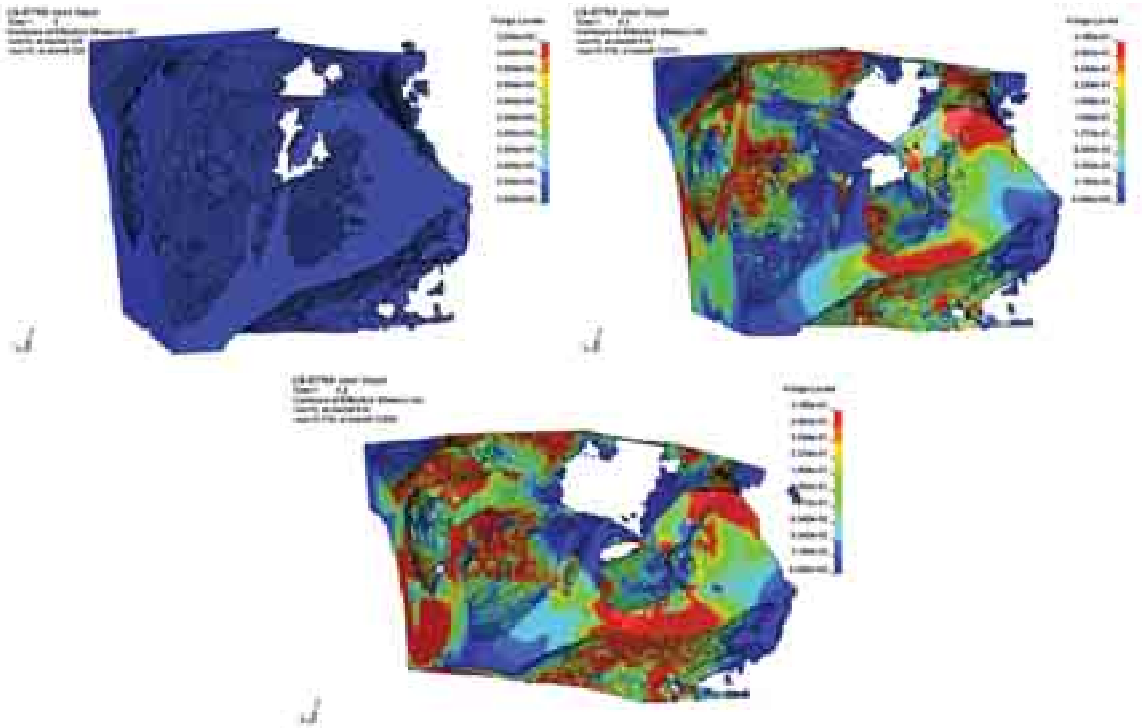

Fig. 9. Numerical analyses results as von Mises stress distributions for Sample 2

4. 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. The presented method allows describing the main mechanisms that appear in the foam structure and influence the foam energy absorbing properties.

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