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MECHANICAL PROPERTIES OF CLOSED CELL Al FOAMS BASED ON TETRAKAIDECAHEDRONAL MODEL OF STRUCTURE

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Abstract – Compressive strength of AlSi10 closed cell foams was studied experimentally and theoretically using the finite element method. For the processing of metallic foams a powder metallurgy method was applied. For the numerical studies a regular tetrakaidecahedronal structure was chosen as the closest to the real cell shape. It has been found that the developed model well follows the experimental characteristics. Some differences such as more flat and longer plateau range, as well as higher stress characteristics are generally due to rather not regular structure and the presence of structural defects in the real foams. Formation of small pores in the foam walls, together with increased stiffness of the walls are responsible for the deformation hardening effect observed in the experimental compressive characteristics.

Keywords: aluminium foams, compressive strength.

1. INTRODUCTION

Metallic foams attract recently much scientific and technological interest due to their exellent mechanical and physical properties such as: ability of energy absorption, low specific gravity, high stiffness, fire resistance, low thermal and electrical conductivity, easy recycling etc.. Their properties strongly depend on relative density, however structural homogeneity and pore geometry play also an important role [1,2]. These properties are generally determined by the processing technique and its parameters. Although the relation between mechanical properties and structure are obvious, not all phenomena are completely explained. Therefore much effort has been put into theoretical prediction of structure and macroscopic properties of metallic foams [3,4]. Computer modelling using finite element method gives possiblilities to simulate the material behaviour under compressive stress. Relation between experimental and computer modelled results could be important for processing and various applications of metallic foams.

2. MODEL DESCRIPTION

Calculations show that the minimization of unit cell surface energy, where unit cell is restricted to have planar faces (created by contacting bubbles), results in a number of faces to be equal to 14 for single polyhedra [5] or 13.3973... as the average for set of them [6,7]. According to this result, many structural models have been proposed in order to analyze foam behavior theoretically. Some of the most extensively exploited unit cell shapes are: cube [1,8], pentagonal dodecahedron [9], and tetrakaidecahedron [10,11]. For our studies a regular tetrakaidecahedronal structure was chosen (Fig. 1).

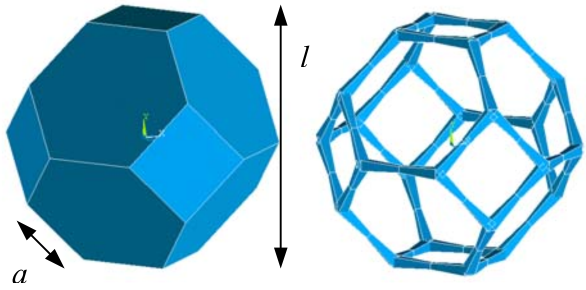


Fig. 1. Tetrakaidecahedronal unit cell model for closed – cell and open – cell foams.

This structure, which has in average 14 faces per unit cell seems to be more close to a sphere geometry than the dodecahedron and to be in good accordance with many foam structures reported. The tetrakaidecahedron has 6 square and 8 hexagonal faces of equal edges. Wall thickness was assumed to be minimum in the middle and to grow linearly towards the nodes. A finite element method (FEM) was applied to calculate the displacements, strains and stress fields in structural model of the foams exposed to standard loading compressive tests. The model of structure was formed by periodic repetition of unit cell within three orthogonal direction. From this structure was cut - out a cubic segment for further calculations. This element is in the form of a cube having site length l equal to the tetrakaidecahedronal cell unit height (Fig. 2). The number of edges and the total surface of the cube are equal to those of a tetrakaidecahedronal cell. The relation between the cube side, l, and the edge-length, a, of the tetrakaidecahedronal unit cell is given by the equation:

$$l = 2 * a\sqrt{2} \tag{1}$$

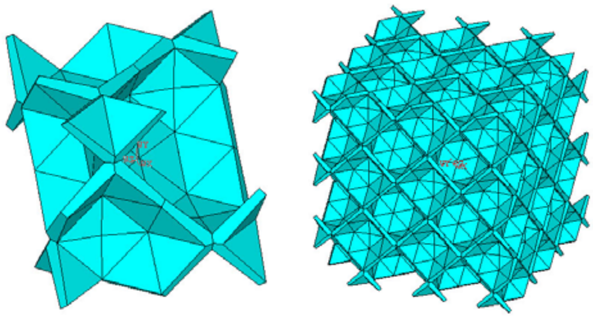
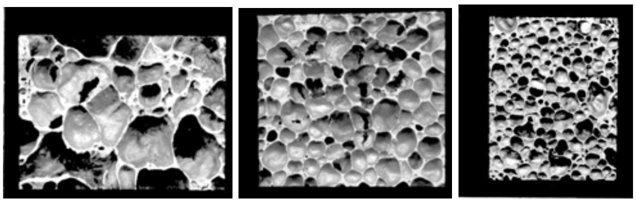


Fig. 2. The model cube and
foam structure made by multiplication of the basic cube.

Such model structure was subjected to deformation. Each point in a cell moved in the same way as the identical point of a neighbouring cell.

3. EXPERIMENTAL

In this work compressive strength of aluminium alloy foams, having different density, was studied experimentally and theoretically using a finite element method. The precursor for this study, having composition AlSi10 + 0.9 % TiH_2, was provided by Institute of Materials & Machine Mechanics from Bratislava. The foams were produced in steel forms at temperature range 600 – 800 ^{o}C . Three foams having diffrrent relative density: 0.13, 0.16, 0.21 were chosen for the compressive tests (Fig. 3). The tests were performed using MTS 810, at a ram speed 0,1 mm/s.



d = 0,21 d = 0,16 d = 0,13

Fig. 3. Foams for experimental compressive tests having different relative densities d.

4. RESULTS AND DISCUSION

The deformation behaviour, in the case of uniaxial compression, of foams having relative densities 0.13, 0.16, 0.21 was computer – modelled, as well as experimentally studies (Fig. 4). According to the computer model, deformation of metallic foams under compressive stress comprised five steps:

1. elastic deformation,
2. initial plastic deformation of cell walls,
3. formation of plastic hinges in the walls,
4. high deformations and rotation of walls, combined with an elasto – plastic buckling (stability loss),
5. close contact of walls (loss of porosity).

In the numerical analysis of the deformation process only steps 1- 4 were considered.

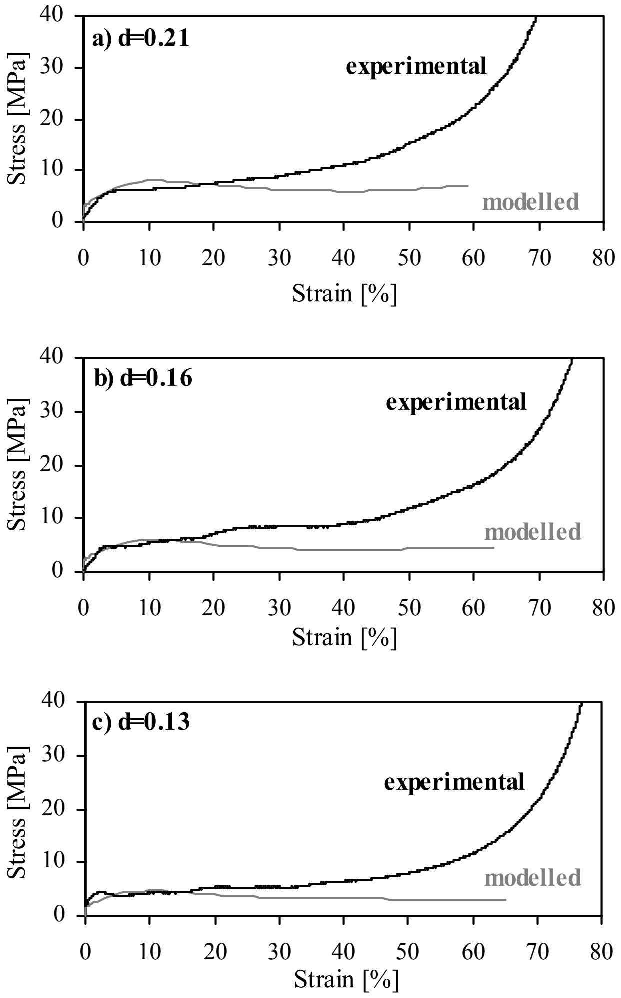


Fig. 4. Stress – strain curves for modelled and experimental foams for relative density: a) 0.21, b) 0.16, c) 0.13.

4.1. Elastic deformation

The walls of the tetrakaidecahedronal structure exhibit elastic properties within the strain range from 0 up to 0.15 %, for all the densities studied. The deformation characteristics are linear and the process is fully reversible. Stress – strain curves in the strain range 0–10 % for all densities studied are shown in Fig.5. The maximum stress within the elastic range was determined (Table 1).

TABLE I. Maximum stress values in the elastic range for tetrakaidecahedronal model.

Relative density [-]	Maximum stress in elastic range [MPa]
0.21	2.7
0.16	2
0.13	1.6

The experimental values of these maximum elastic range stresses were much smaller than the modelled ones in the cases of densities 0.16 and 0.21.

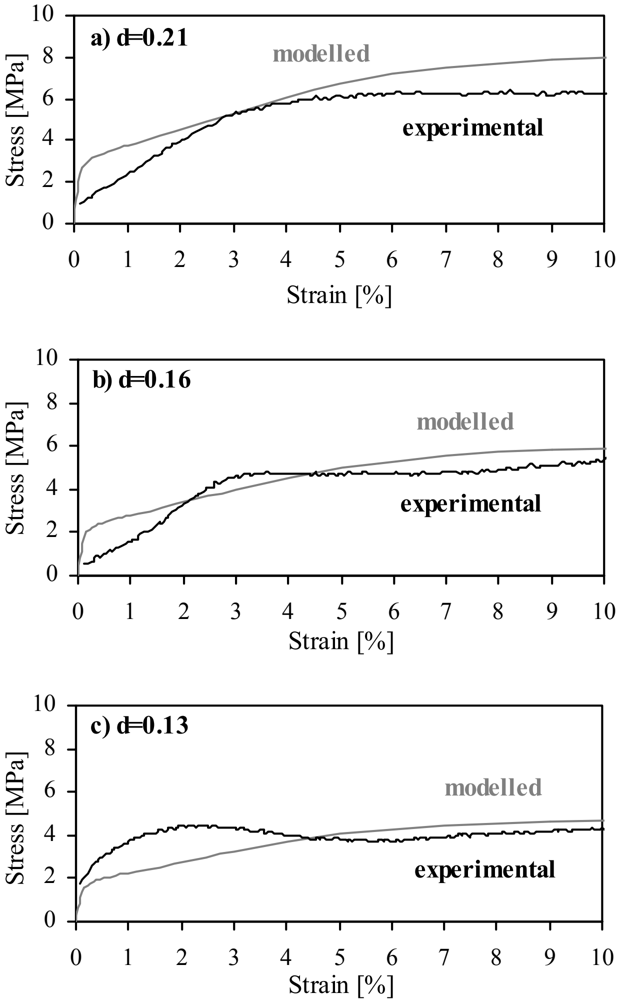


Fig. 5. Stress – strain curves for modelled and experimental foams up to 10% of strain for relative density: a) 0.21, b) 0.16, c) 0.13.

4.2. Plastic deformation

The area, in which the foam tends to deform plastically, while the stiffness of the tetrakaidecahedronal model structure is maintained, ranges from 0.15 % to 5-6 % of strain. The deformation originates in the centres of square walls. The stress – strain characteristics changes its slope but keeps the linear shape. The slope change is caused by deformation hardening of the wall material and by combined movement of the deformation zones from the surface to the entire volume. As the deformation at this stage is relatively small the effect of structure geometry on the foam stiffness is negligible. In the case of the experimentally tested foams of relative densities 0.16, 0.21, this area ranges up to 2 % of strain, while for that of density 0.13 this area ranges up to 0.5 % of strain.

4.3. Formation of plastic hinges

Formation of plastic hinges occurs within the strain range from 6% up to 10%. The stress – strain plot clearly bends. In the physical meaning substantial parts of the walls volume deform plastically. Wall stiffness dramatically decreases and the deformation is strictly localised in particular sections of walls, what leads to formations there of plastic hinges. The walls start to bend along these hinges. The stress attains local maximum around 10 % of strain. For metallic foams these stresses are considered to be the compressive strengths σ_c (Fig.6) [12].

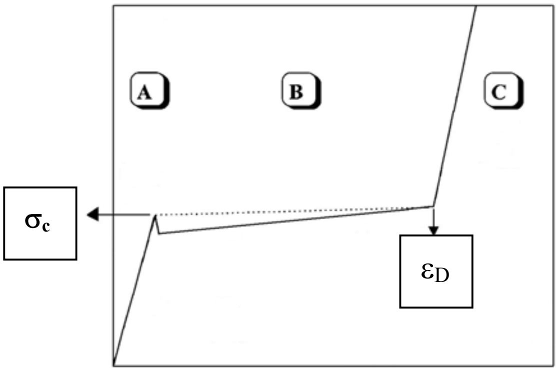


Fig. 6. Scheme of densification foam: A – elastic range, B – plateau, C – foam densification, σ_C – compressive strength, ε_D – densification strain.

The experimentally tested foams reach maximum stresses at lower strains, from 2 to 6 %, depending on the foam density (strain values increase with increase of density). Both experimental and modelled compressive strength values increase with increasing density (Fig. 7), the modelled strength values were higher than the experimental ones. Difference between modelled and experimental strength values increases with increase of density.

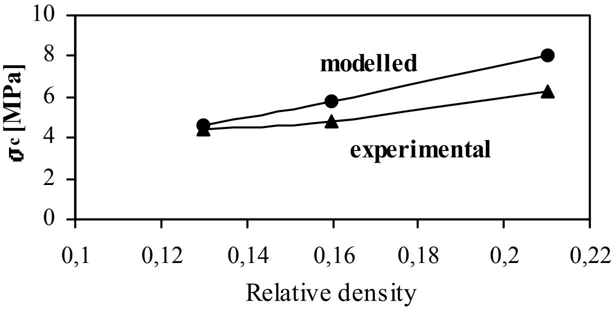


Fig. 7. Compressive strength for modelled and experimental foams versus relative density

4.4. High deforamtion and walls rotation

For the modelled structures, in the strain range from 10 to 24 – 28 %, stresses slightly decrease and subsequently turn into constant plateau range. Large plastic walls lose their stiffness and tend to lose stability under compressive force. The mode, in which the structure loses its stability, depends on the foam density. For lower density foams the walls initially bend, while the walls of the higher density foams collapse. Loss of stability causes that the force, necessary for deformation of vertical walls, which so far experienced major loads, decreases. The hexagonal walls, placed under high angles with respect to the acting force, are unable to transport compressive loads. All these factors lead to a form of extended plateau of the stress – strain curve. For the experimentally tested foams, the plateau is unstable and the stress – strain curves present steep plateau, shorter than those for the modelled ones. Generally, the higher the density, the shorter the plateau. This results from thicker walls, therefore the densification occurs earlier. As the real structure of the foams is inhomogeneous the weakest links (interconnected chains of pores) yield first, while in the model structure all cells undergo the same deformation. Therefore the experimentally tested foams deform gradually, which results in simultaneous densification and stiffness increase.

4.5. Close contact of walls (loss of porosity)

For the model structure, densification starts at about 60 – 65 % of strain (Fig. 4). The densification, in the case of experimentally tested foams, starts at about the same strains as in the model structures, but at higher stresses, because the densification occurs earlier in the weakest links.

5. CONCLUSION

1. It was found that the developed tetrakaidecahedronal structure model well follows the experimental behaviour of the foams under compressive stress.
2. The model characteristics are longer and more flat in the plateau range than the experimentally obtained curves.
3. In both cases compressive strength increased with increase of density.
4. For the model structures the strength values were slightly higher.
5. The densification starts at about the same strains for both cases, but at higher stresses for the experimentally tested foams.

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