ALUMINIUM FOAM TESTING FOR IMPACT ENERGY ABSORPTION AIMS

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Abstract

Aluminium foams are a new group of materials used for impact energy absorbing elements. They are light (typically 10-25% of the density of the metal they are made of) and stiff, and are frequently proposed as a lightweight structural material. That is why they often are applied in automotive and transport industry solutions, for example as parts of bumpers.
The methods of numerical modelling for open and closed cell aluminium foams are presented in the paper as well as closed and open cell foam microstructure model.
The numerical models of foam ideal microstructures created with shell finite elements are shown. The models were developed on the basis of Kelvin tetrakaidecahedrons - structures consisting of six squares and eight hexagons. In the case of closed cell foams, the polyhedron with full walls was adopted. In the case of open cell foams the circle wholes were removed from polyhedron surfaces.
Then the numerical analysis of a created models compressive test was carried out with the usage of LS Dyna computer code. The nonlinear procedures were applied.
The results were analyzed in the scope of energy absorbing properties of aluminium foams.

Keywords: *aluminium foam, microstructure modelling, open cell foam, closed cell foam*

1. Introduction

One of the possible options as a material for protective layers is aluminum foams which have become also very popular due to their lightweight and excellent plastic energy absorbing properties. Such characteristics have been appreciated by the automotive industry with continued research into further understanding of foam properties.

Compressed foaming materials exhibit an extensive plastic response, while the initial elastic region is limited in tension by a tensile brittle-failure stress. Aluminum foams have become an attractive material as blast protective layers due to their desirable compressive properties. Using different material engineering techniques (as, for example double-layer foam cladding) they can be customized to achieve the most desirable properties. The energy absorption capacity of foams under the blast load was analytically confirmed based on a rigid-perfectly plastic-locking foam model. Initial research indicates that energy absorbed by the cladding is much larger than that under quasi static conditions due to a shock wave effect.

The paper presents the methods of numerical modelling for open and closed cell aluminium foams.

The numerical models of foam ideal microstructures created with shell finite elements are also shown. The models were developed on the basis of Kelvin tetrakaidecahedrons - structures consisting of six squares and eight hexagons. In the case of closed cell foams, the polyhedron with full walls was adopted. In the case of open cell foams the circle wholes were removed from polyhedron surfaces.

Then the numerical analysis of a created models compression test was carried out with the usage of LS Dyna computer code. The nonlinear procedures were applied.

The results were analyzed in the scope of energy absorbing properties of aluminium foams.

2. Overview of foams microstructural modeling

The problem of partitioning space into equal-volume cells, using the least interface area, was considered in 1887 by Sir William Thomson, Lord Kelvin [1]. He proposed the solution which yields foam with cells of a single shape, tiling space by the translations of the body-centered cubic lattice (Fig. 1). It is a typical method for creation of closed cell foams microstructures.

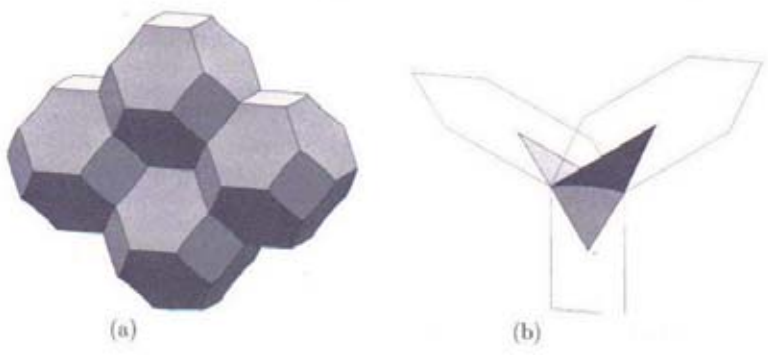


Fig. 1. Four cells in the Kelvin foam (a), and one fundamental piece (b), consisting of a fourth of one square and sixths of two hexagons, the region near a particular triple edge

Figure 2 shows a typical model for an open cell porous material, which is assumed to represent the properties of the aggregate (voids and struts) of foams.

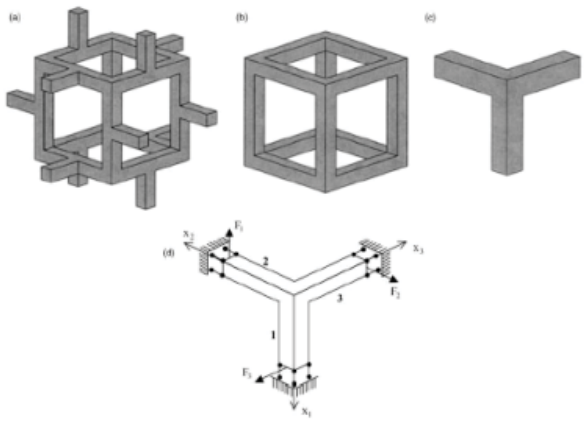


Fig. 2. Unit cell geometry and boundary conditions: (a) open structure; (b) simplified; (c) one-eighth; (d) under triaxial loads [2]

Another method of creating the foam structure is to form a model from a tetrahedron and spheres which are cut out from its four vertices. The radii of the spheres will determine the porosity of the unit cell of the foam. Figure 3 presents this methodology. The methodology is based on typical Boolean geometry.

3. Experimental results

A one-axial compression test for an aluminum foam sample was carried out. The results are presented in Fig. 4.

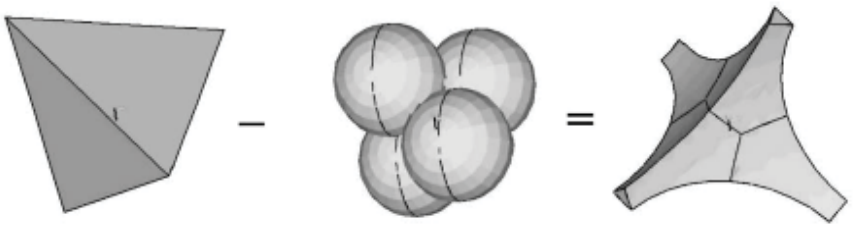


Fig. 3. A tetrahedron and spheres to generate a unit cell of a foam [3]

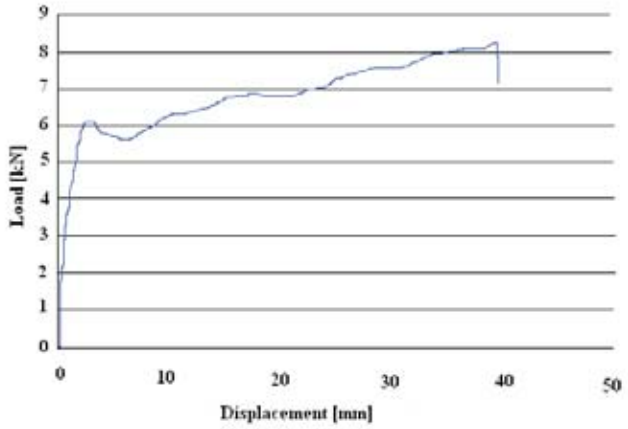


Fig. 4. Experimental results for the one-axial compression test

3. FEM models and analysis

The numerical models of closed and open cell foam microstructures based on Kelvin polyhedrons were created. The models had the dimension of 3x3x3 unit cells. The closed cell foam model is shown in Figure 5.

Fig. 5. Closed cell foam microstructure model

The open cell foam model is based on the implementation of Kelvin tetrakaidecahedrons with circular holes cut in their walls. The circles were cut out according to the rule of appropriate segments equality (Fig. 6).

Two types of such geometry were created, one with small holes and the other with big holes, what is presented in Fig. 7.

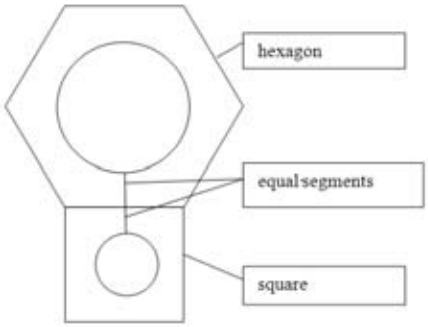


Fig. 6. The rule of model geometry creating

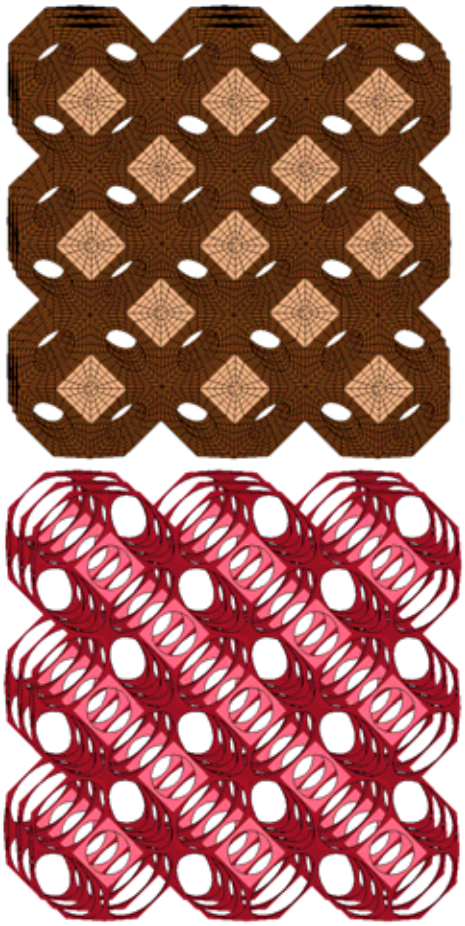


Fig. 7. Open cell foam microstructure models

FEM model was accomplished with the usage of shell four-nodal elements *Quad4* [4]. The total number of elements in each model was 89185. The thickness of shell elements was 0.2 mm (it was calculated in accordance to the porosity of real foam).

A dynamic numerical analysis was carried out with the use of LS Dyna computer code. The compression was performed with two rigid plates -stationary and moving one. Two velocities of the plate were applied: 12 m/s and 28 m/s. An elastic plastic material model (MAT_PLASTIC_KINEMATIC [5]) was used for aluminum (Young modulus E=71000MPa, Poisson ratio ν=0.33, yield stress R_e=250MPa).

The influence of the rest part of a foam structure was simulated by locking the perpendicular degrees of freedom at external model surfaces.

4. Results

During the analysis the relation between the load and the reaction time was studied. The results for the numerical analysis and for the experiment are presented in a chart below (Fig. 8).
The deformations of the whole structures are also presented in Tab. 1.

The differences between the responses of each structure are strictly visible. The smallest load value was noticed for an open cell structure with big holes, the biggest for closed cell foam. It is caused by different mechanisms during the compression of each sample. For closed cell foam and open cell foams with big holes it is a membrane mechanism that appears on the surfaces of those structures. On the other hand, in the open cell structure with small holes the most important is a pin joint mechanism of the reaction of structure surfaces to the compressive load.

Also the shape of curves on the charts below is different for each sample and for each velocity value. For the same sample when the velocity of hitting plate has higher value, the compression process is shorter and the load- time curve becomes smoother.

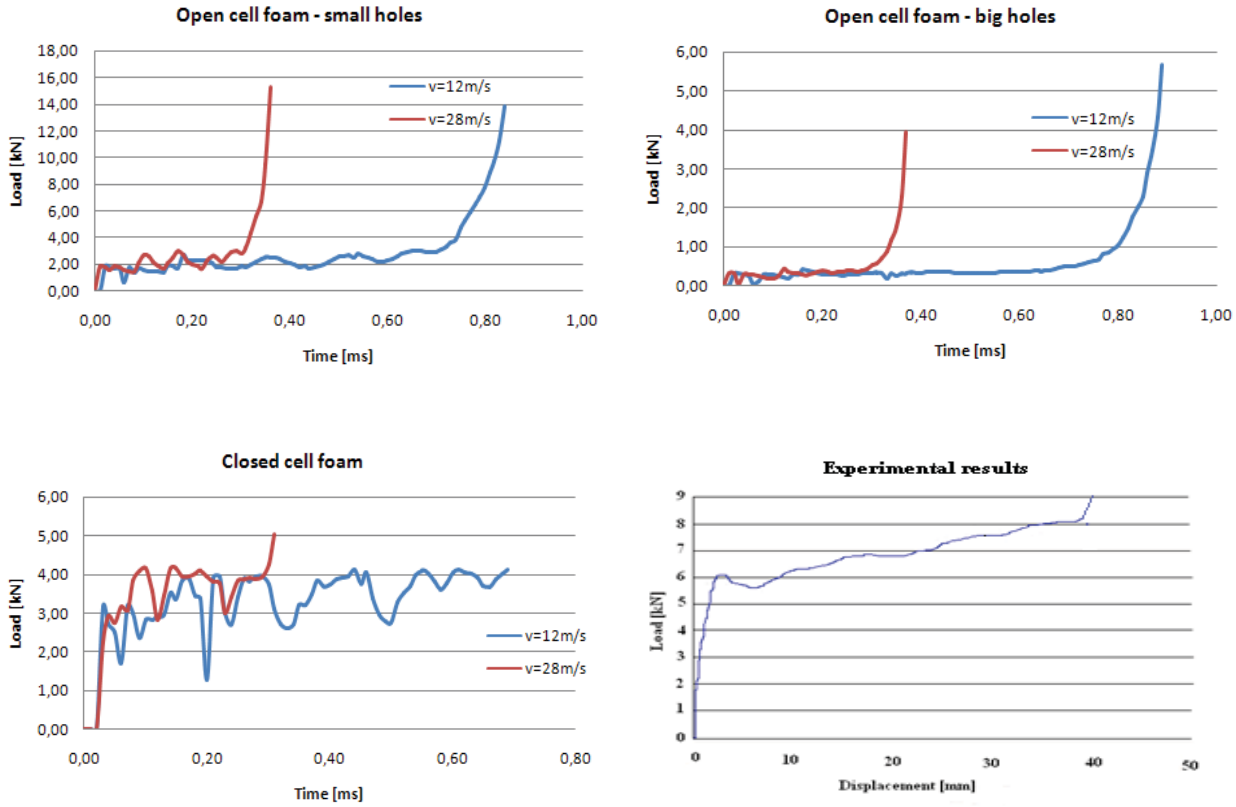


Fig. 8. Load- time charts for the numerical analyses and the experiment

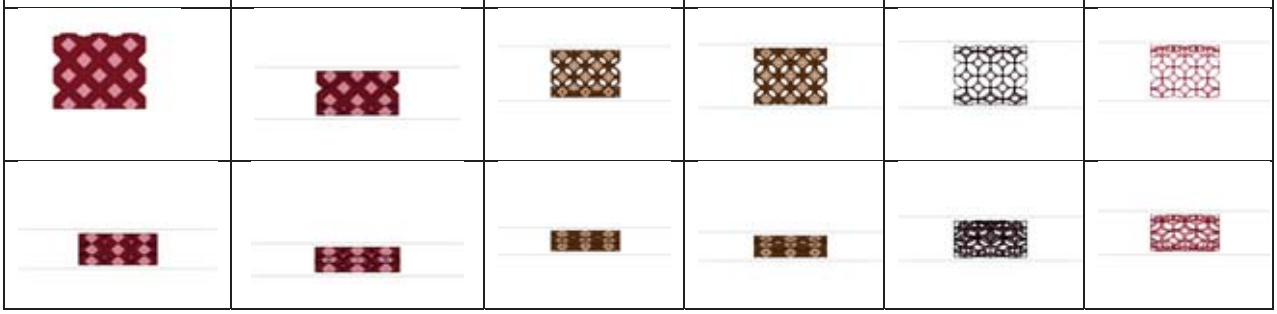
In comparison to the experiment only the behavior of the closed cell structure can be assessed (presented experiment is for closed cell aluminum foam). One can conclude that the accuracy of the model and the experiment is high. The differences are caused by another boundary conditions (quasi static for experiment, dynamic for FEM analysis) and by the idealistic geometry of pores in a numerical sample.

Watching the deformations in Tab. 1, the differences between structures behaviour are observed. In the closed cell structure the deformation begins at the bottom of the sample, for open cell structure – uniformly at the bottom and top of the sample.

Finally, the energy absorbed by the each sample (for full compression) was calculated. The results are presented in Tab. 2.

It is strictly shown that absorbed energy (absolute and per mass unit) reaches always the biggest value for a closed cell foam model. The reason of that fact is that this model has the largest mass and has a membrane compression behavior model.

Tab. 1. The comparison of deformations of analysed structures

Deformations					
Closed cell FEM model		Open cell FEM model (small holes)		Open cell FEM model (big holes)	
v=12m/s	v=28m/s	v=12m/s	v=28m/s	v=12m/s	v=28m/s
					

The smallest value of energy absorbed during the process is always observed for the sample with open celled with big holes geometry. It is caused by its pin joint compression mechanism and lightweight. However, small differences appeared between the closed cell and the open celled with the small holes geometry model.

It can also be observed that there is only a small fall down in the absorbed energy value with the rise of the hitting plate velocity. However, better energy absorption is reached with the reduction of the impact velocity.

Tab. 2. Total absorbed energy

Absolute absorbed energy [J]					
Closed cell FEM model		Open cell FEM model (small holes)		Open cell FEM model (big holes)	
v=12m/s	v=28m/s	v=12m/s	v=28m/s	v=12m/s	v=28m/s
43.7	41.2	30.7	27.3	5.38	4.79
Absorbed energy per mass unit [kJ/kg]					
Closed cell FEM model		Open cell FEM model (small holes)		Open cell FEM model (big holes)	
v=12m/s	v=28m/s	v=12m/s	v=28m/s	v=12m/s	v=28m/s
53.8	47.8	28.3	25.2	54.2	50.2

5. Conclusions

Energy absorption of foams strictly depends on the microstructure geometry. Different mechanisms of the microstructures behavior were observed. The most energy absorbing models are of a closed cell geometry type, because of its membrane mechanism behavior.

Energy absorption also depends on the velocity of the hit process. Better absorption is reached with the smallest velocity values.

A selection of the model should be based on real foam geometry measurements. The next step of such analysis will be the comparison of the idealistic foams to real ones.

Reference

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The paper supported by a grant No 15-469 , financed in the years 2008-2011 by Ministry of Science and Higher Education, Poland