NUMERICAL MODELLING OF THE FOAMED MATERIALS STRUCTURES WITH THE USAGE OF THE 2D AND BEAM ELEMENTS

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Abstract

The possible options as materials for protective layers are aluminium foams which 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 to further understand foam properties. Compressed foaming materials exhibit extensive plastic response, while the initial elastic region is limited in tension by a tensile brittle-failure stress. Aluminium foams have become an attractive material as blast protective layers due to their desirable compressive properties. With different material engineering techniques (as, for example double-layer foam cladding) they can be customized to achieve the most desirable properties. Energy absorption capacity of foams under 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 shock wave effect.

The methods of numerical modelling for open and closed cell aluminium foams are presented in the paper.

The numerical models of foam ideal microstructures created with shell and together shell and beam 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 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 MSC.Marc computer code. The nonlinear procedures were applied.

The results were analyzed in the scope of the assessing the behaviour of the open cell aluminium foam unit cell under the compressive load.

Keywords: *foamed aluminium, microstructure, FE modelling, Kelvin structure*

1. Introduction

Aluminium foams have the potential for use in lightweight structural components and in energy absorption. They may be subjected to multiaxial loads in these applications and thus a criterion to determine the failure of Aluminium foams is essential [1].

As foam is a cellular material, several challenges exist in the material modelling of foam. Contrary to metals, which maintain the same volume when loaded plastically, the volume changes for foams during loading due to internal buckling and collapse of cell walls. A material model for foam should therefore include the possibility of yielding under hydrostatic load conditions. Another important characteristic of Aluminium foam, is the inhomogeneity of the pores, which are of different sizes and are not distributed evenly, see Fig. 1 [2].

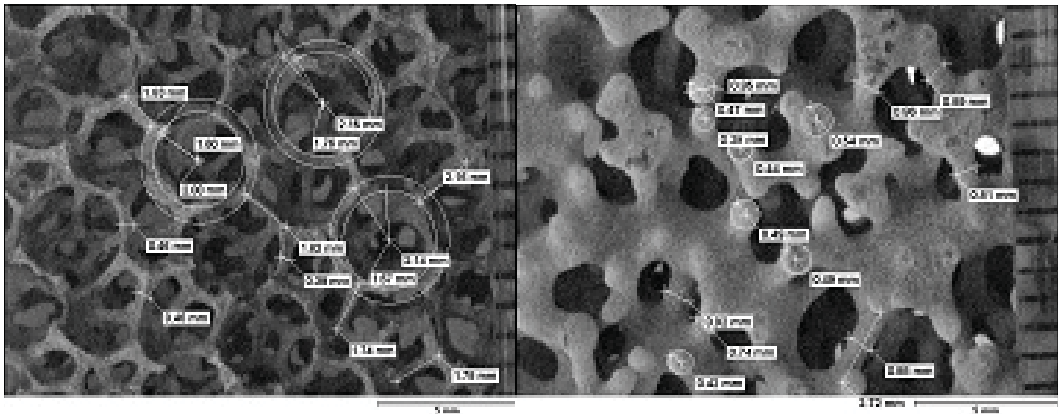

Fig. 1. Differents in real foam structures

In the paper the method of the modelling of the open cell Aluminium foam microstructure with the usage of shell and beam finite elements and the results of the static numerical analysis carried out in the MSC.Marc computer code are presented.

2. Brief overview of the open cell foams modelling methods

The problem of partitioning space into equal-volume cells, using the least interface area, was considered in 1887 by Sir William Thomson, Lord Kelvin [3]. He proposed the solution which yields foam with cells of a single shape, tiling space by the translations of the body-cantered cubic lattice [Fig. 1]. It is a typical method for creation of closed cell foams microstructures.

The Kelvin foam (10), the three-dimensional analog of the honeycomb, is a perfectly ordered structure composed and obtained of identical bubbles that have the same shape and orientation. The Kelvin foam has cubic symmetry and the bubbles sit on a body-cantered cubic (bcc) lattice. All of the films with the same number of sides and all of the edges have the same. The Kelvin foam is the only perfectly ordered structure known that satisfies Plateau's laws. A Kelvin cell is a tetrakaidecahedron with six planar quadrilateral faces with curved edges and eight nonplanar hexagonal faces. Note that nonplanar films do not have to be spherical sections. The faces in Kelvin foam have zero mean curvature because identical bubbles have equal pressure. [4]

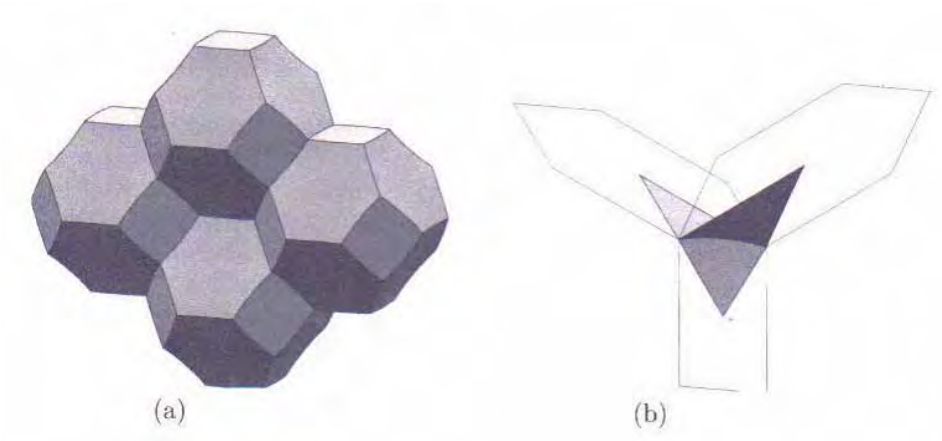

Fig. 2. Four cells in t he Kelvin foam (a), and one fundamental piece (b), consisting of a fourth of one square and sixths of two hexagons, the region near a particular triple edge

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.

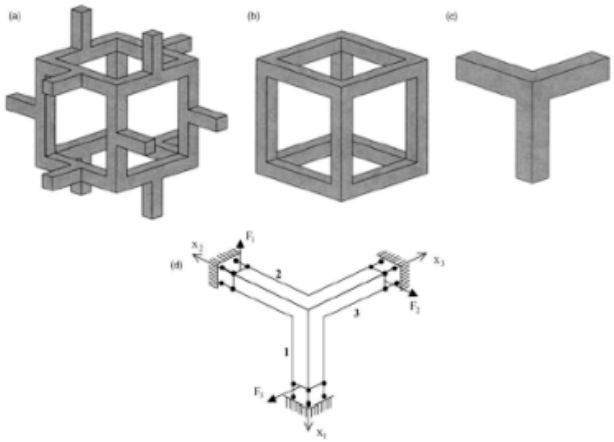

Fig. 3. Unit cell geometry and boundary conditions: (a) open structure; (b) simplified; (c) one-eighth; (d) under triaxial loads [5]

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. Fig. 3 presents this methodology. The methodology is based on typical Boolean geometry.

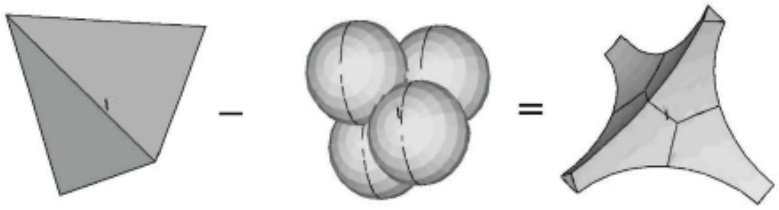

Fig. 4. A tetrahedron and spheres to generate a unit cell of a foam[6]

3. Numerical model and analysis

The open cell foam model is based on the implementation of Kelvin tetrakaidecahedrons with circular holes cut in their walls. The geometry of the model is presented in Fig. 5. The sample considers the single unit cell of the foam.

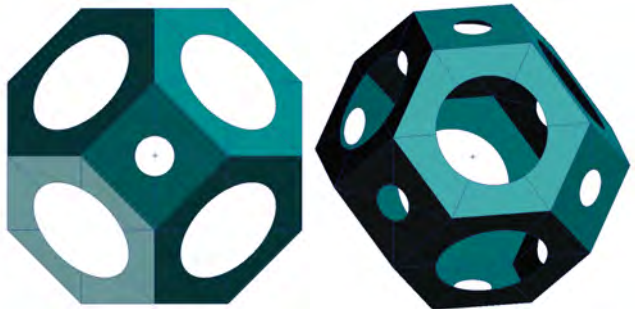

Fig. 5. The model geometry

The first FE model was accomplished with the usage of shell four-nodal elements [7]. The total number of elements in each model was 4608. The thickness of shell elements was 0.2 mm (it was calculated in accordance to the porosity of real foam). The meshed structure is presented in Fig. 6.

The next development of the model was to implement the beam elements on the edges of the Kelvin unit cell (see Fig. 6).

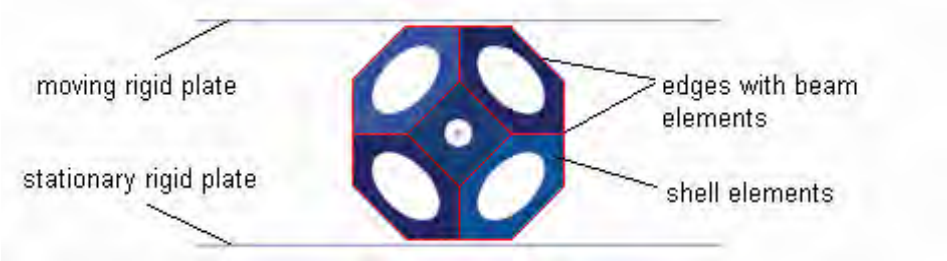

Fig. 6. The numerical model – finite elements and boundary conditions

The static numerical analysis was carried out in MSC.Marc computer code. The compression was performed with two rigid plates -stationary and moving one. An elastic plastic material model was used for Aluminium (Young modulus E=71000 MPa, Poisson ratio ν=0.33, yield stress R_e=250 MPa). The surface to surface contact with the friction coefficient 0.2 was applied.

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

4. Beam and shell elements description

Two types of the finite elements were used: bilinear thin-shell (element 139 in MSC.Marc [7]) and beam elements (element 14 [7]).

The bilinear thin-shell element is a four-node, thin-shell element with global displacement and rotations as degrees of freedom. Bilinear interpolation is used for the coordinates, displacements and rotations. The membrane strains are obtained from the displacement field; the curvatures from the rotation field. The element can be used in curved shell analysis as well as in the analysis of complicated plate structures. For the latter case, the element is easy to use since connections between intersecting plates can be modelled without tying. The element is defined geometrically by the (x, y, z) coordinates of the four corner nodes. Due to the bilinear interpolation, the surface forms a hyperbolic paraboloid which is allowed to degenerate to a plate. The stress output is given in local orthogonal surface directions, V_1, V_2 and V_3 (see Fig. 7).

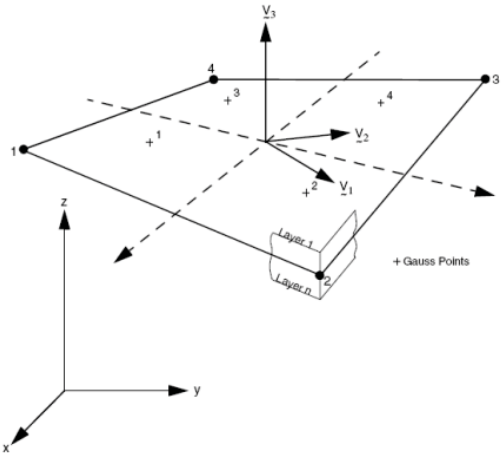

Fig. 7. Form of the bilinear thin-shell element

The closed section thin-walled beam (element 14) is a two-noded beam element written in the global x-y-z space as shown in Fig. 8.

Fig. 8. Beam element

The interpolation functions can be summarized as linear along the axis, cubic normal to the axis and linear twist. The element is integrated using tree-point Gaussian integration along the beam axis as shown in Fig. 9.

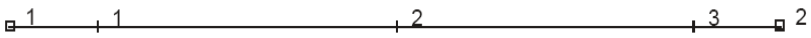

Fig. 9. The three-point Gaussian integration for the beam element

The stress-strain law is integrated using Simpson's rule through the cross section of the element.

5. Results

During the analysis the relation between the load and the displacement was studied. The results for the numerical analysis of both models (with shell elements and with shell and beam elements) are presented in a chart below (Fig. 10).

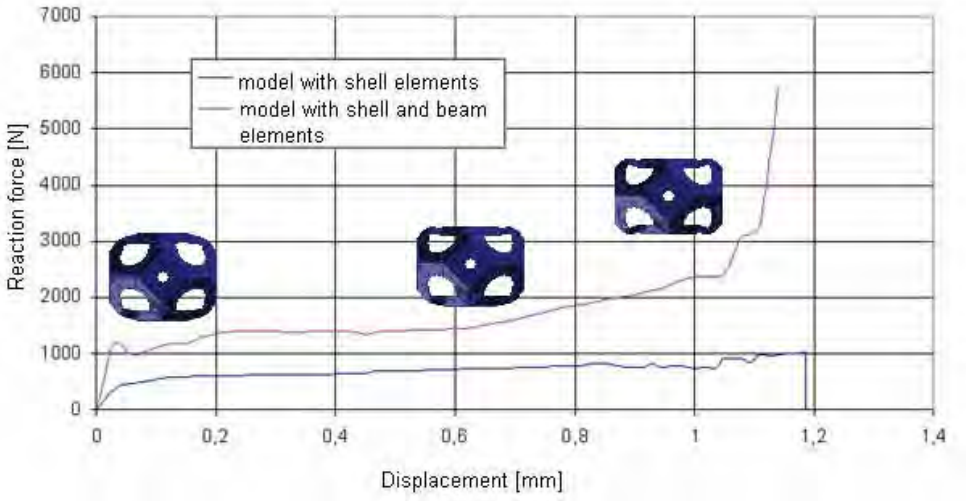

Fig. 10. The comparison of the reaction force – displacement charts for two numerical models of the open cell foam microstructures (made of shell and beam and shell elements) resulted from the FE analysis

The visible differences between both models answer to the compression load. The model built of the shell elements reaches smaller values of the reaction forces and losses the stability (the reaction force rapidly falls down) for the displacement value of 1.18 mm. The model built of the shell and beam elements behaves almost like real foam. The characteristic regions on the force – displacement charts are noticeable – the first region of elastic deformations of the Aluminium pores walls, the second region of the Plateau deformation (pores closing) and the third region of the force increasing. Also the values of the reaction forces are similar to the real foam compression test.

6. Conclusions

In the paper the numerical compression test of the single unit cell of the open celled aluminium foam was presented. The FE model was accomplished with the shell elements and to improve the behaviour under the compression load – with shell and beam elements. The results received from the numerical analysis allow to state that using the single unit cell of the foam structure meshed with shell and beam elements can be useful in assessing the behaviour (e.g. the energy absorption) of the metal foams.

References

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Acknowledgements

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