COMPARATIVE STUDY OF HYBRID FOAM MICROSTRUCTURE MODELS

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Abstract

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. 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. Due to developments in material science and manufacturing techniques, advanced foams have found potential for use in automobile, aircraft, and space vehicle structures. In the paper the comparative study of the hybrid foam microstructures is presented. Hybrid foam is a new, still developed material that is built of the aluminum open cell foam matrix filled with other material (here: elastomer). The numerical models based on cubic geometry in different configurations are developed. The FE analysis of the compression test is carried out. The results are presented and analyzed due to the microstructure geometry influence on the material behaviour.

Keywords: *FEM modeling, foam structure, elastomer filament, geometry orientation*

1. Introduction

For purposes of numerical modeling of foam materials there are used various techniques and methods. Numerical models may be constructed on base of the real structure image that may be a 2D photograph or 3D scan. 3D scans may be obtained by use of X-ray or neutron tomography technique. Models may have smooth shape or may be based on a grid technique [1, 4, 9]. Also idealized models are used which are suitable for investigations of influence of particular geometrical or material parameters onto global properties of a foam [11]. They may be built on the base of geometrical solids (i.e. Kelvin's polyhedron [2, 5, 6] (Fig. 1).

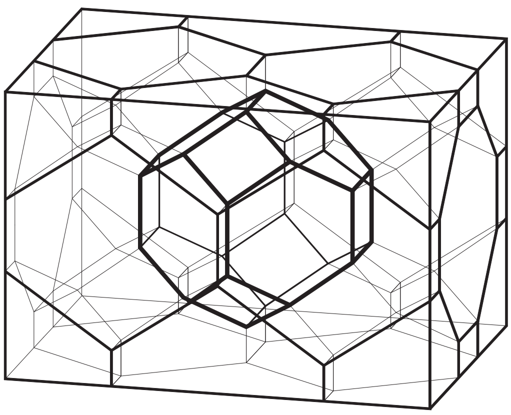


Fig. 1. The structure based on Kelvin's polyhedrons

Model can be built as composition of different polyhedrons (Fig. 2), Weaire-Phelan 8-cell repeatable structure [5, 6] (Fig.3) or on the way of Voronoi 3D tessellation [2, 7]. Idealized models may represent multi cell structures or may be reduced to repeatable fragment of geometry – single cell or their part [2, 10, 3] (Fig.4), which are convenient for fast comparative analysis of long series of differentiated models. There may be found models which deal with the problem of random distributions of shapes and sizes of foam cells [8].

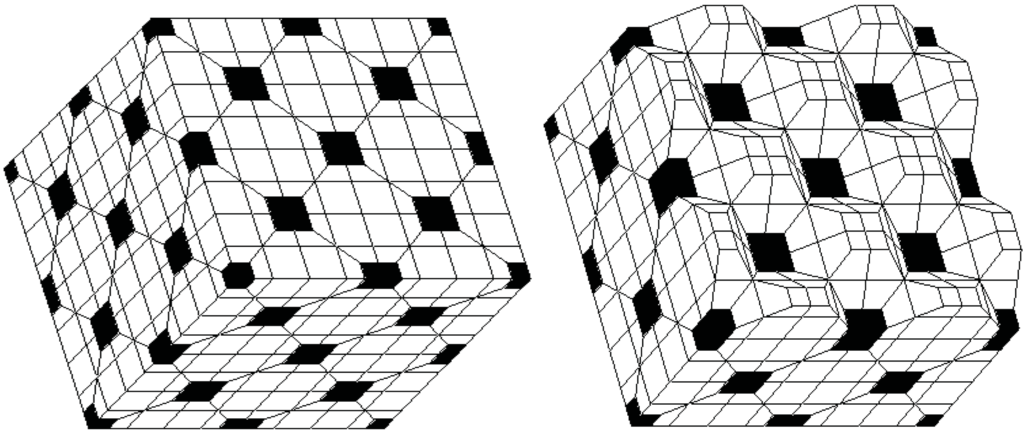


Fig. 2. Model of ceramic composite based on cubes and 18-faced polyhedrons – their geometry may be adapted for building of foam models

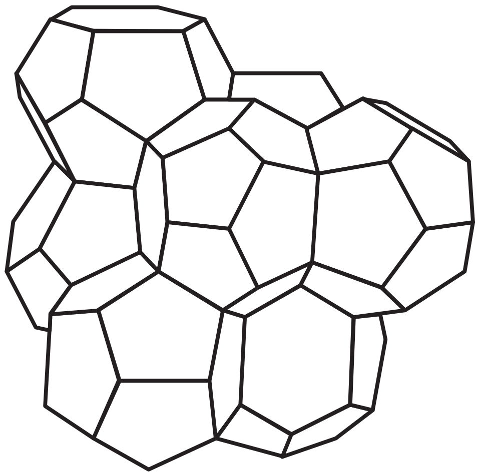


Fig. 3. Weaire-Phelan repeatable structure consisting of 8 cells – it is difficult to close such structure in cuboidal volume

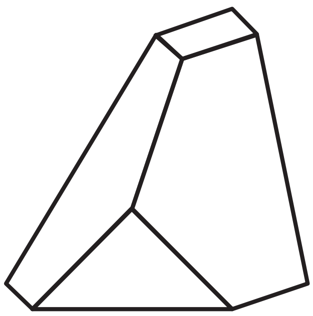


Fig. 4. Model of closed cell foam which is the fragment of Kelvin's grain

The advantage of models based on regular geometries is that they allow obtaining averaged results. It is possible to conduct comparative investigations upon the influence of geometry parameters onto mechanical properties of a structure (Fig. 5).

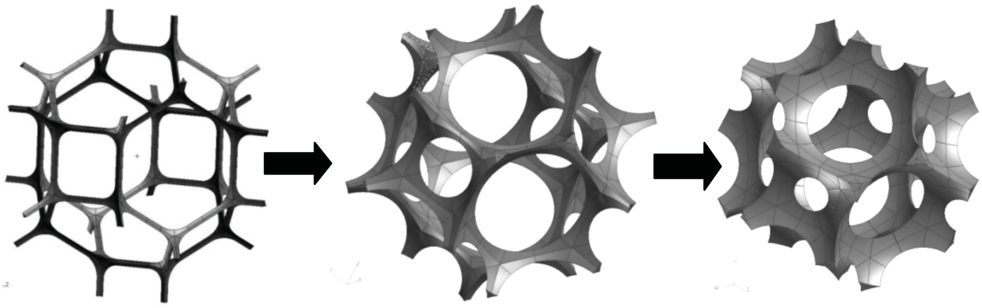


Fig. 5. Series of base Kelvin geometries of foam models of different density obtained thanks to change in dimensions of cross sections of connections between nodes of the structure

But they have also undesirable mechanical properties i.e. they may have different stiffness along particular axes of symmetry. Kelvin's polyhedron presents different stiffness when compressed in the directions perpendicular to the hexagonal or square walls. Another problem is that they may be significantly stiffer than the real material due to their regular, repeatable shape. This repeatable shape may be responsible for specific irregularities visible in failure characteristic obtain from uniaxial compression tests. The origin of such behaviour is that they are destroyed layer by layer of regular matrices of particular parts (edges) of uniform cells. In the Fig. 6 a Kelvin cell model is presented. In the Tab. 1 particular stages of damage are collated. In the Fig. 7 the characteristic force versus displacement is presented. The characteristic shows out irregularities originating from consecutive destruction of the cell edges layers.

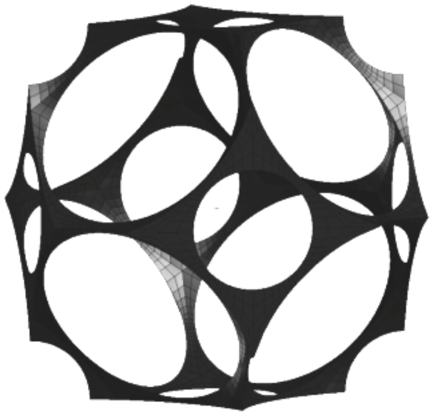
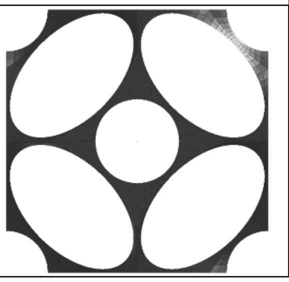
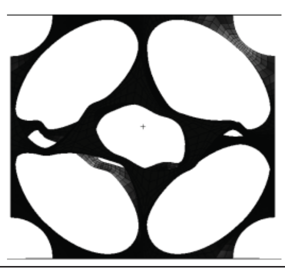
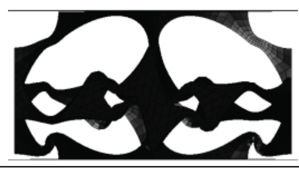
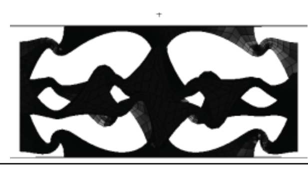


Fig. 6. Single cell model of open cell foam taken into considerations

It is in opposition to typical experimental characteristics which are smoother. In the real structure that is randomly differentiated in shapes, dimensions and orientations of particular cells such local effects are averaged and are not visible in characteristics obtained from experimental examinations.

Tab. 1. Subsequent stages of single model cell deformation during quasi-static compression test

1	2	3	4
			

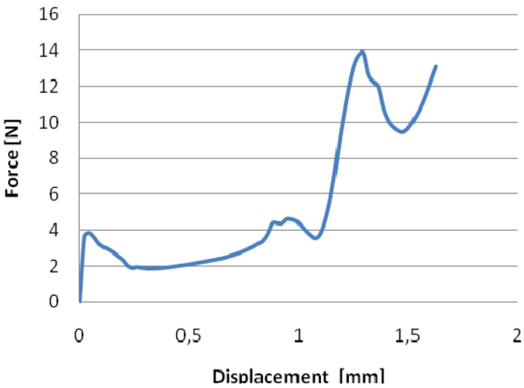
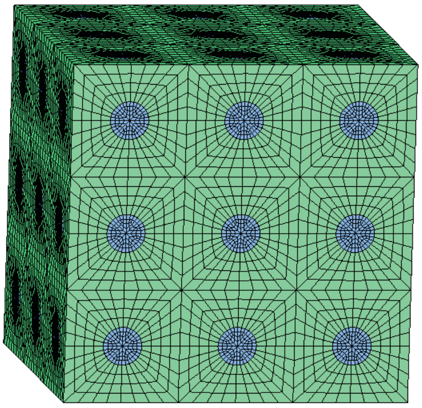
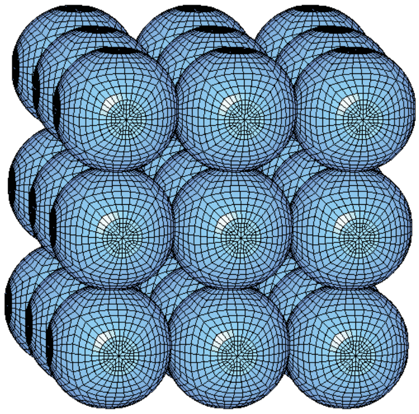
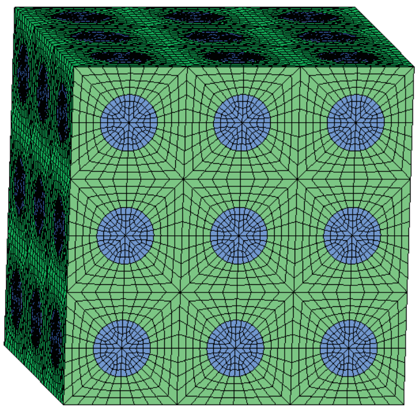
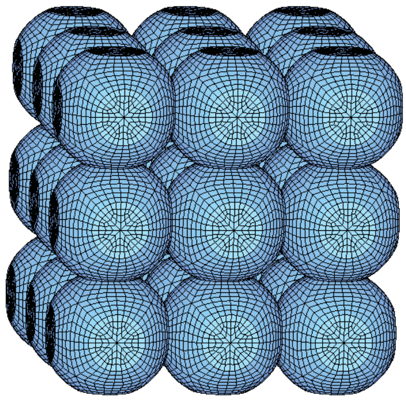
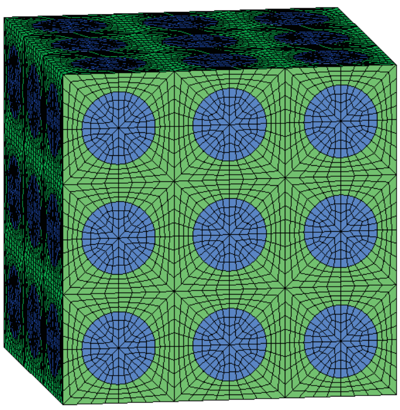


Fig. 7. Characteristics: force versus displacement

Tab. 2. Series of models with structure orientation U1 for different porosities

Porosity %	Geometry orientation U1	
	Entire model	Elastomeric filament
60		
70		
80		

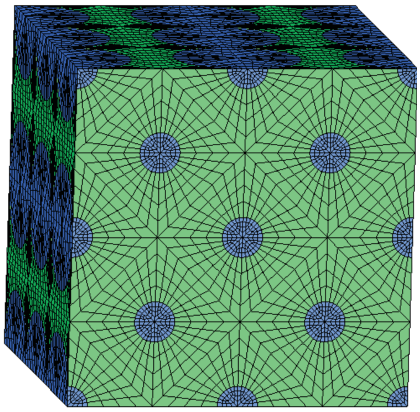
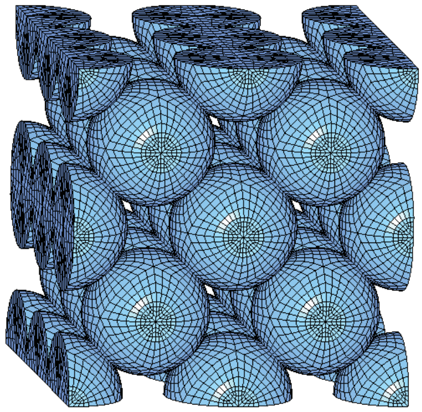
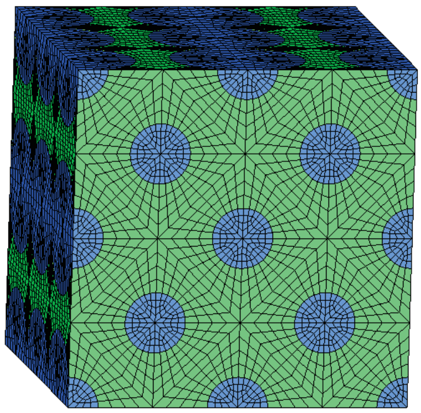
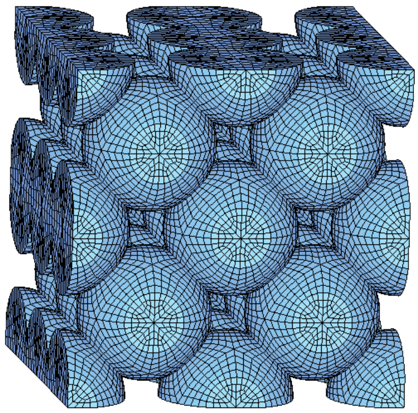
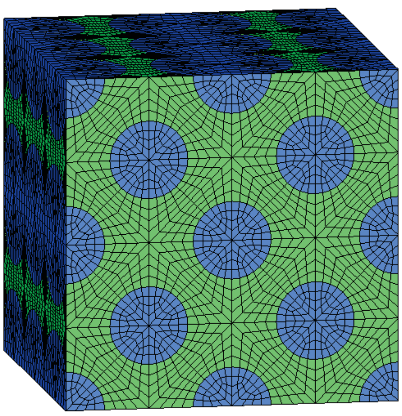
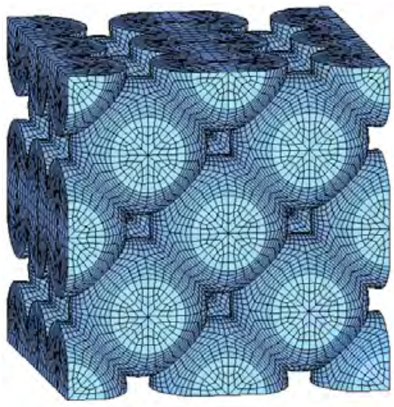
2. Models of open cell foam filled with elastomer

Similar problem may be presented on the example of a model of an aluminum foam structure that is filled in with an elastomer. Regular structures based on cuboids were used for the series of models building with porosities of 60, 70 and 80%. Two different orientations of cubical structure were considered (Tab. 2 and 3).

Table 2 contains collation of U1 series of models and configuration of elastomer filament volumes. Particular cells of the structure build regular columns. Such arrangement is stiffer than that presented in the Tab. 3.

Table 3 contains U2 series of models which have the same geometry like U1 but in a different orientation. Such arrangement of structure cells is more realistic.

Tab. 3. Series of models with structure orientation U1 for different porosities

Porosity %	Geometry orientation U2	
	Entire model	Elastomeric filament
60		
70		
80		

3. Results of calculations

Calculations were conducted with the use of LS DYNA code. Simulations of uniaxial compression tests were performed. It was assumed that the samples were placed between the two rigid plates. Upper plate attacked the models with the constant velocity of 0.1 mm/s to meet criteria of quasi static tests. Side walls were kept planar during the simulations. Piecewise linear plastic material model was used for aluminum foam structure with density of 7291 kg/m^3, Young's modulus 70 GPa, Poisson's coefficient 0.3. Elastic material model was used for the elastomer filament with density 1080 kg/m^3, Young's modulus 0.2 MPa, Poisson's coefficient 0.45.

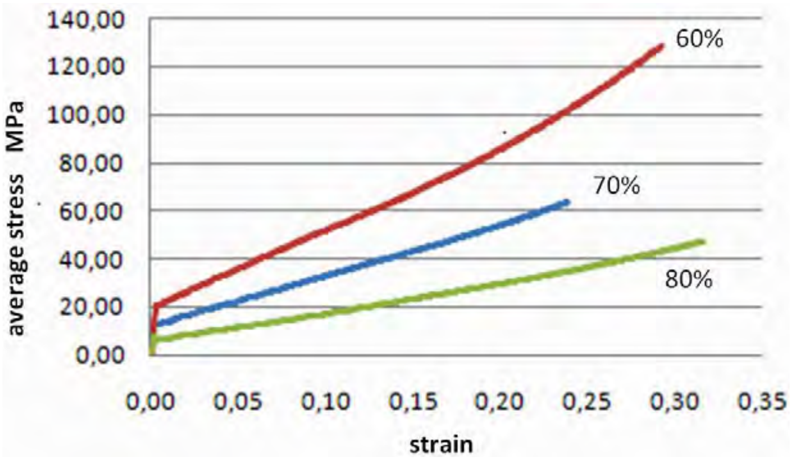


Fig. 8. Failure characteristics of the U1 series of models for porosities of 60, 70 and 80%

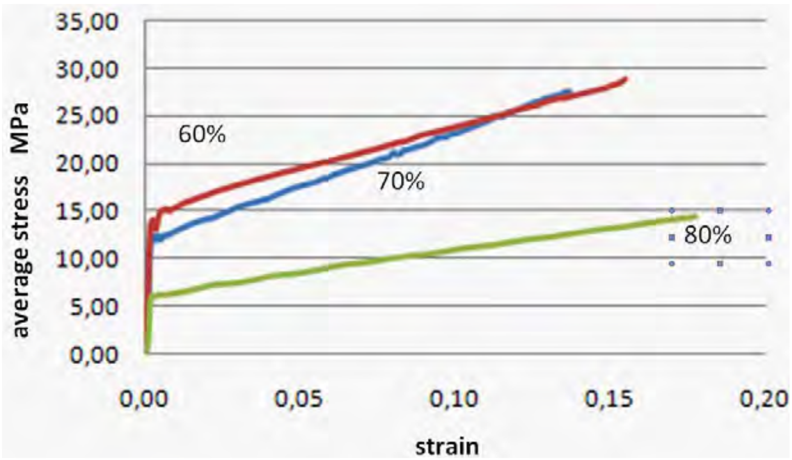


Fig. 9. Failure characteristics of the U2 series of models for porosities of 60, 70 and 80%

Comparison of results for considered series of models shows that the U2 models are significantly less stiff than U1 ones. For example, the level of failure initiation for the U1 model with the porosity of 60% was 20 MPa. For the same porosity U2 model started to fail when the value of 13 MPa of average stress was achieved.

4. Conclusions

Numerical models based on idealized geometries may be effective in investigations of structural materials like foams. But they may produce distorted results. It depends on possibility of proper definition of boundary conditions. In comparison to real materials geometries idealized models show out privileged directions and planes which are responsible for characteristic calculated mode of destruction (step by step). This phenomenon exists also in models built by multiplication of singular cells. Distortions oscillates around the real material characteristics which are smoother due to their irregular structure and distribution of dimensions and random orientation of particular cells. It also should be kept in mind that the same idealized geometries may have different mechanical properties accordingly to their different orientations. Models based on idealized geometries should be applied with respect to this fact to provide agreement with averaged properties of real structures.

Acknowledgements

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