Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(6) (2021) 857-860
DOI: 10.22060/mej.2020.18265.6795

A new method for estimating the compressive strain of cellular structures using microstructure of foams based on Laguerre tessellations

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ABSTRACT: In this study, energy absorption behavior of cellular structures such as foams will be investigated. In this paper, developing microstructural modeling of cellular structures and analyzing their plastic behavior through the finite element method is the main goal. In this research, a unit cell is first developed for numerical computation reduction as well as modeling that has the desired foam statistical properties, and then the dynamic behavior of this unit cell under simulated impact will be analyzed. An analytical method to obtain the compressive strain value of the foams with the help of numerical solution results will be presented. In other words, using the analytical method, the finite element method and the simulation will be evaluated. Then, using simulated experiments, a model using the response surface methodology to obtain the compressive strain will be presented and the results of this model will be evaluated by numerical method. The results of this study showed that it is possible to model and analyze the energy absorption of the foams using the method presented in this study and as a result, suitable structural equation for microstructural analysis of foams can be obtained in future researches.

Review History:

Received: Apr. 20, 2020
Revised: Jul. 10, 2020
Accepted: Aug. 18, 2020
Available Online: Aug. 28, 2020

Keywords:

Energy absorption
Closed-cell foams
Response surface method
Compression strain, Laguerre method.

1- Introduction

Filling the thin-walled structures with a lightweight material such as foam or composite with the aim of increasing the Specific Energy Absorption (SEA), is one of the important topics that has attracted the attention of researchers. Asgari and Shiravand in 2019 [1], the effect of various parameters of metal and composite on the crushing behavior of the structure is studied. The energy absorption analysis of a cellular structure was performed using the three-dimensional Voronoi model and the finite element method by Song et al [2]. Redenbach et al. [3] analyzed the dependence of the elastic modulus on the relative density for a closed-cell structure using Laguerre microstructure modeling. Jabour [4] analyzed the elastic behavior of foam using theoretical relationships belonging to microstructure.

In all the studies mentioned, a precise mechanical model of the microstructure of the foams has not been done so that the properties of plastics and their energy absorption behavior can be estimated by analyzing the micromechanical parameters of the foams without the need for experimental testing. In this research, a suitable method for modeling the microstructure of foams is proposed so that the micromechanical properties of foams such as cell density, size and thickness are used to estimate the amount of densification strain of cellular structures. Access to this type of analysis for foams reduces the costs associated with experimental analysis.

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2- Methodology

In the Laguerre model, each cell has a weight that determines the size of the cell. A set of random spheres is designed according to a specific algorithm so that no volume of two spheres overlaps. The diameter of these spheres determines the weight of the cell that surrounds the sphere, and the center point of the sphere represents the grain points for each cell. In Laguerre model, the thickness of each cell can also be entered into the model. Therefore, using the Laguerre layout, the microstructure of a foam can be effectively modeled close to the real state [5, 6].

First, a number of points are placed randomly as the centers of the spheres. These spheres will be in a cube range of volume $(L)^3$. To properly distribute the spheres in the specified cube volume, the actual material distribution method proposed by Raines et al. [7] has been used. The method of obtaining this type of distribution is in accordance with Eq. (1).

$$probability = \frac{e^{\frac{-(\ln V-\mu)^2}{2\sigma^2}}}{\sqrt{2}(V\pi\sigma)} \quad (1)$$

The values of μ and σ will be determined according to the following equations, and V is a variable of the volume of the respective spheres, indicating that the above equation is a function of the volume of the spheres.

$$\mu = \ln V_m - \sigma \tag{2}$$

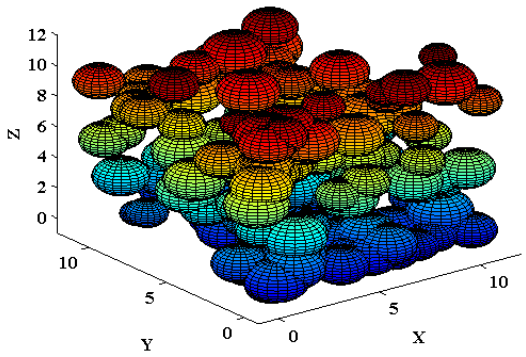
$$\sigma = \sqrt{\ln(C_v^2 + 1)} \tag{3}$$

The value of C_v is also considered to be 0.8 and the value of V_m is the value of the average weight of the spheres. The distribution of spheres with different volumes is in accordance with the lognormal distribution. The volume of the spheres overlapped (V_{ov}) is calculated. In this algorithm, the goal is to reduce this volume. The overlap of the spheres can be created in two general and partial forms. In this step, the spheres move one by one and calculate the volume value V_{ov}, and if the volume ratio calculated in this step is not less than the previous step by a value of ε, the spheres must continue to move again, and this The process continues until the overlapped volume of the spheres be minimum value. If the displacement of the spheres does not cause much change in the amount of volume desired, then the change in the diameter of the spheres should be done. Finally, a cube range is formed which is filled with a number of spheres of different diameters, which is presented in Fig. 1.

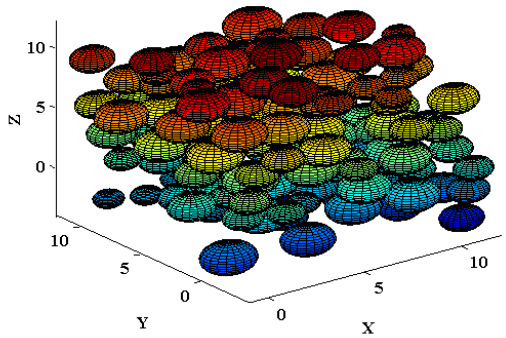
3- Discussion and Results

using the topological information obtained from these algorithms, which contains the coordinates of the center of the spheres, the coordinates of the points corresponding to the cell plates and their connection points, it is completely modeled in a CAD software. The unit-cell is formed according to these specifications provided and is shown in Fig. 2.

After meshing the cell structure in Abaqus software, FE model are provided for studding. The stress and strain diagram of the cell structure under dynamic impact is presented in Fig. 3. The amount of stress at each point is equal to the cross-sectional area of the cell structure. The amount of strain in each step is also determined using the ratio of deformation to initial length.



a)



b)

Fig. 1. Unit cell of random spheres a) Before Relocating b) After Relocating ε=10^{-5}

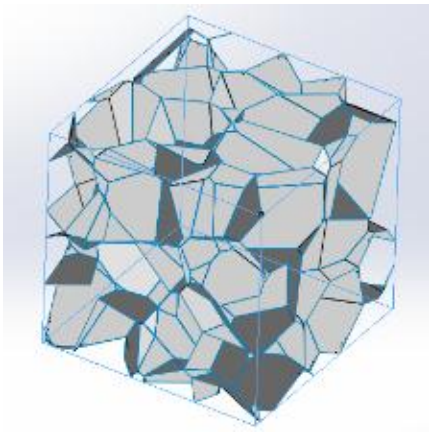


Fig. 2. Laguerre model prepared by SolidWorks

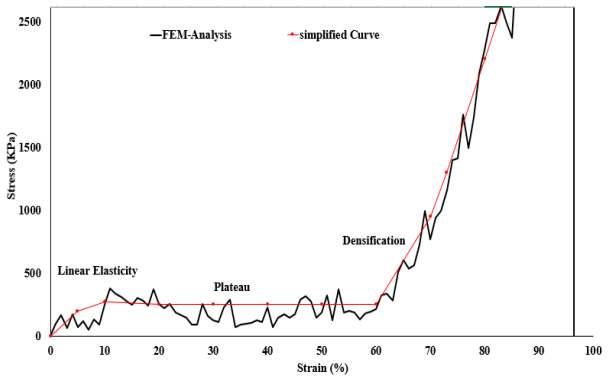


Fig. 3. Stress-Strain diagram (FEM Analysis)

4- Conclusions

In this research, an aluminum foam with closed cells was dynamically modeled and simulated using the formation of a unit cell using the Laguerre cell modeling method. The dynamic behavior of the impact foam has been simulated using Abaqus finite element solver and the results of this analysis have been validated with experimental results. After confirming the results of finite element analysis, an analytical method is presented. Also, the dynamic behavior obtained from finite element analysis indicates the appropriate model of the unit cell, which can help in future researches The results of the RSM are in good agreement with the results of theoretical and finite element analysis. The finite element method fully provides the elastic-plastic behavior of the desired cellular structure, which can lead to the achievement of a main equation of foam that is a function of the microstructure of the foam. The proposed analytical method is used to obtain the approximate compression strain value of the designed cell structures.

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HOW TO CITE THIS ARTICLE

A. Shiravand, M. Asgari , .A new method for estimating the compressive strain of cellular structures using microstructure of foams based on Laguerre tessellations ,Amirkabir J. Mech. Eng., 53(6) (2021) 857-860.

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