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Metallic Closed-Cell Foam Filled Tube Uniaxial Crushing Behavior Analysis Using Voronoi Approach

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ABSTRACT: Porous materials especially metallic foams are novel materials with high energy absorption and strength to weight ratio capability. In the present paper, we investigate quasi-static uniaxial compression and crushing behavior of closed-cell graded aluminum foams and foam-filled tubes, both numerically and experimentally. To model the mentioned specimens, we place cubes with several densities and strengths to generate functionally graded specimens. Specimens are considered to be graded with two and three layers and non-graded single layer, with and without tubes. Various standard uniaxial compression experiences are conducted for numerical model calibration and validation and also for non-linear mechanical properties and hardening characterization. To enhance strength and energy absorption capability and also tailoring purpose, we layout the cubic foams in tubes with square profile. The 3D Voronoi diagrams approach is manipulated to model stochastic foam microstructure. Also Novel unit cell is proposed based upon Kelvin cell. We implement the hybrid finite element analysis and Voronoi diagram using Python script and Abaqus 2017 commercial finite element method based code for more convenient modeling and efficient analysis. Finally, and after numerical model calibrations, numerical and experimental results showed good agreement.

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1- Introduction

Cellular solids and closed-cell foams have complex microstructure with a random distribution of voids and cells [1] . Therefore, microstructural modeling is essential for mechanical behavior analysis using Finite Element Method (FEM). There are different methods for cellular structures modeling. Kelvin and other unit cells, Voronoi diagrams, Computerized Tomography (CT) scan images geometric reconstruction, stochastic placement of voids and soap froth are some of these methods. Furthermore, there are standard methodologies for material identification such as uniaxial loading, and Nano-indentation. Microstructural damage investigation using electron microscopes and optical methods have conducted by Yuan [2]. They model microstructure using Kelvin cell with thin faces and simulate uniaxial loading and effect of material properties by finite element method and experiments. Kadkhodapour et. al. [3] presented an approach connecting micro-scale displacement to macro-mechanical behavior in closed cell metallic foams using numerical methods and experiments.

In the present paper, firstly several geometrical models of cubic closed-cell foam specimen are generated and then graded foam filled tubes with these foam layers are modeled within square tubes. The specimens are 2 and 3 layered graded arrangements of foam specimens in tube and without tube. Furthermore, simple 1 layer specimens with and without tubes are also investigated. Numerical models are verified using uniaxial compression tests. Hence, analyzing several graded structures yield to tailoring ability and also micro-macro crashworthiness properties prediction of closed-cell foam filled tubes. Finally, good agreement between test and simulation results are shown.

2- Methodology

The focus of present work is on modeling concept. In other words, the Voronoi based Finite Element (FE) models are generated to enhance the homogeneous model's accuracy. So, several tetrakaidecaheron or Kelvin cells with controlled irregularities are modeled and their relative error with experimental results are minimized. Finally using computed tomography images, and optimization procedures, morphological parameters such as edge and face thicknesses and solid material volume fractions are obtained. The calibrated FE models are used in mechanical behavior investigations. Furthermore, Kelvin cells are modified using beam elements on their edges to increase accuracy. Cubic specimen with 20% irregularity is shown in Fig. 1. Abaqus FE code is used for simulation purpose and the S4R and B31 elements are used for modeling faces and edges of microstructures respectively [4, 5].

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