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Compressive behavior of tailor-made metallic foams (TMFs): Numerical simulation and statistical modeling

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ABSTRACT

In this work, the compressive behavior of tailor-made metallic foams (TMFs) was qualified and quantified under quasi-static compressive loading. Response surface methodology (RSM) based on a central composite design (CCD) was successfully employed for development quadratic polynomial regression models between the response variables (structural stiffness, yield and compressive strength) in terms of three variables (cell size, cell wall thickness and height of cell layers). These models were then used for finite element simulation of TMFs under compression conditions by considering a representative unit cell. There was an adequate agreement between the simulation data and the experimental measurements within 3.5% confidence interval. The analysis of the statistically developed models revealed that ratio of wall thickness to the size of cell (t/D) has the most significant influence on the compressive behavior of TMFs.

1. Introduction

The major disadvantage of the conventional closed cell metal foams is the inhomogeneity of the structure which results in the deviation of the mechanical properties of the foams from what predicted by the scaling relations. This is mainly due to the morphological defects such as missing or wavy distortions of the cell walls and non-uniform shape and size of the cells [1,2]. Many efforts have been conducted for the elimination of such defects and attaining the full advantages of these light materials. It is worthy of note that the hollow spheres and syntactic foams are the most favorable structures regarding their periodic and relatively defect-free structures. The mechanical properties and energy absorption capability of metal matrix syntactic foams (MMSFs) have key roles in their applications especially as the energy and sound absorbents [3–5]. Many researchers have focused on the different combinations of reinforcement and matrix while some others are dealing with the effects of hollow sphere size and distribution on the mechanical properties and energy absorption capability [3,6]. It has been reported that energy absorbing properties of MMSFs can be customized by the appropriate selection of matrix and heat treatment procedure as well as the reinforcement composition, wall thickness, diameter and volume fraction [7–10].

Besides these experimental efforts, numerical studies have been conducted to predict and model the mechanical properties of MMSFs [10–13]. It should be pointed out that although the thickness of hollow spheres has been considered in these models, the mechanical properties of the spheres were ignored; moreover such developed models are generally based on the system-dependent empirical constants which limit the applicability for the prediction of mechanical properties of MMSFs with different compositions. Orbulov and Májlinger [14] and Antunes et al. [15] describe a mathematical model of compressive behavior of MMSFs by the use of a multi-phase model. Their results showed that size and volume fraction of the hollow spheres, elastic properties of the spheres and matrix and thickness of the hollow spheres are the setting parameters while the rigidity of the matrix was found to be the most influential. Recently, Santa Maria and his colleagues developed a model based on theoretical and experimental investigations to predict the mechanical properties of metal matrix syntactic foams based on the mechanical and physical properties of the matrix and the ceramic hollow spheres and volume percentage of the hollow spheres [4,6,16].

Despite the various modeling/simulation techniques developed for achieving a precise mechanical response, there is always a deviation between the experimentally measured data and the results obtained via simulation/modeling; these differences effectively stem from non-controllable distribution of the hollow spheres inside the metallic matrix. Also, an important point regarding the failure of MMSFs is the composition of the matrix, the hollow sphere, and the bonding layer between them which was not considered in the previously proposed models. Recently, Nayyeri et al. [17] have presented a novel technique to examine a new generation of metallic foams based on tailor making cell architecture. In this novel technique, the mechanical effects of hollow spheres and bonding layer on the overall properties of tailor-made metallic foams (TMFs) are minimized by the use of low density polymeric spheres as the space holders.

The aim of this study is to develop the models for the prediction of the compressive response of TMFs. In order to clarify the simultaneous

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