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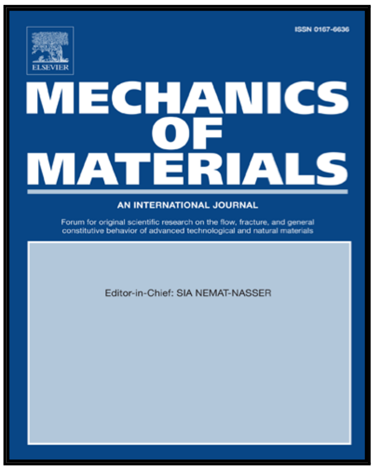

Shape memory response of cellular lattice structures: unit cell finite element prediction

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Shape memory response of cellular lattice structures: unit cell finite element prediction

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Abstract: NiTi, known as Nitinol, is the most common shape memory alloy which offers relatively low modulus of elasticity, shape memory properties, superelastic behavior, biocompatibility and low corrosion rate. In some applications, such as actuators and biomedical implants, it is common to use cellular lattice structure (CLS) to decrease the weight as well as equivalent modulus of elasticity (i.e., stiffness). The focus of this research is to model, at macro scale, the behavior of NiTi CLS (e.g., BCC and BCC-Z) processed through selective laser melting (SLM) additive manufacturing (AM) process. First, BCC and BCC-Z structures were fabricated and subjected to thermomechanical experiment to investigate their shape memory properties. Next, finite element analysis was performed using unit a cell model with appropriate boundary conditions. The model is based on a three - dimensional constitutive model derived from the Souza theory. Finally, the stress-strain curves obtained from finite element simulations were compared with those generated from mechanical tests. The comparison showed good agreement between the model prediction and experimental results for BCC ($R>0.98$, RMSE=1.79 MPa, $p<0.05$) and BCC-Z ($R>0.97$, RMSE=6.28 MPa, $p<0.05$) structures. It was also revealed that the developed model was computationally more efficient, than other multi-cell models.

Keywords: Shape memory alloys, NiTi, Cellular lattice structures, BCC, BCC-Z, Constitutive model, Souza theory.

1. Introduction

Metal cellular lattice structures (CLSs) have attracted much attention in biomedical (e.g., metallic implants) and industrial applications (e.g., aircraft fuselage, wings) since they offer a combination of high strength-to-weight ratio, relatively low mass, low heat conductivity, high energy absorption, and appropriate thermal and acoustic insulation properties [1-4]. CLSs are categorized into two different types: stochastic and periodic. Since periodic CLSs exhibit superior characteristics compared to the stochastic, they are more favorable to be used for high value engineering products [5, 6]. In addition, the mechanical properties of periodic CLSs can be tuned to the required level due to the existence of a regular structure, while it is not the case with stochastic structures [7]. Up to now, different types of periodic CLSs have been investigated, including octet-truss [1], triangulated planar truss faces [4], pyramidal core structure [4], simple cube, BCC [2], BCC-Z [2], F_2FCC [2], and F_2FCC-Z [2].

Different materials have been used to produce CLSs, including Stainless Steel, Ti-6Al-4V, and NiTi [8, 9]. NiTi (i.e., Nitinol is the most common shape memory alloy (SMA). NiTi lattice structures offer other benefits such as shape memory properties [10, 11], superelasticity behavior [12], and low modulus of elasticity [13, 14]. NiTi CLSs have a wide range of potential applications in aerospace and medical products [15, 16].

So far, various conventional techniques have been implemented to produce CLSs, including casting, deformation forming [17], brazing [18], and metal wire approach [19]. Multiple steps are often involved in realizing the fabrication of CLSs which makes the process time consuming and costly [3, 20, 21]. Further, there exist numerous limitations with these techniques in terms of the resolution of the structure, the actual cell geometry, and the number of cells possible inside the core [9, 22]. On top of these, the production of CLSs with NiTi make the