Mechanical Properties of Copper Octet-Truss Nanolattices

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Mechanical Properties of Copper Octet-Truss Nanolattices

ZeZhou He[a], FengChao Wang[a], YinBo Zhu[a], HengAn Wu[*,a], Harold S. Park[*,b]

[a]CAS Key Laboratory of Mechanical Behavior and Design of Materials, Department of Modern Mechanics, CAS Center for Excellence in Nanoscience, University of Science and Technology of China, Hefei, Anhui 230027, China

[b]Department of Mechanical Engineering, Boston University, Boston, Massachusetts 02215, USA

Abstract

We investigate the mechanical properties of copper (Cu) octet-truss nanolattices through a combination of classical molecular dynamics (MD) simulations and theoretical analysis. The MD simulations show that Cu nanolattices with high relative density are stronger than bulk Cu, while also achieving higher strength at a lower relative density as compared to Cu meso-lattices. We demonstrate that modifying the classical octet-truss lattice model by accounting for nodal volume and bending effects through the free body diagram method is critical to obtaining good agreement between the theoretical model and the MD simulations. In particular, we find that as the relative density increases, nodal volume is the key factor governing the stiffness scaling of the nanolattices, while bending dominates the strength scaling. Most surprisingly, our analytic modeling shows that surface effects have little influence on the stiffness and strength scaling of the nanolattices, even though the cross sectional sizes of the nanowires that act as the lattice struts are on the order of 6 nm or smaller. This is because, unlike for individual nanowires, the mechanical response of the nanowire struts that form the nanolattice structure is also a function of bending and nodal volume effects, all of which depend nonlinearly on the nanolattice relative density. Overall, these results imply that nanoscale architected materials can access a new regime of architected material performance by simultaneously achieving ultrahigh strength and low density.

Key words: nanolattice, single crystal, surface effect, metamaterials

1. Introduction

Architected structural materials have been investigated both experimentally and theoretically for many years. This has provided a compelling approach to obtaining structures that are simultaneously lightweight and strong. Numerous studies on architected structural materials have shown that the strength and stiffness of cellular materials depends on their structural arrangement (Deshpande et al., 2001a; Fleck et al., 2010; Gibson and Ashby, 1999). Architected materials can deform by either bending or stretching of the individual elements, which is determined by the topology of the lattice and its nodal connectivity, and this bending or stretching behavior defines the deformation mechanisms of architected structural materials (Fleck et al., 2010). Three dimensional lattice structures with connectivity of Z=12 at the nodes are