NANOCHEMISTRY

Lightweight Metal Stands Up to Heavy Loads

by Nancy McGuire

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Conventional and social media outlets were buzzing this October about a short Boeing video in which researcher Sophia Yang blows away a piece of metal mesh the size of a deck of playing cards with a quick puff of air. Boeing calls this springy, nanostructured microlattice material “the lightest metal ever”. It’s 99.99% air and has a density ≈1% that of polystyrene foam.

The video came out the day after an HRL Laboratories (Malibu, CA) press release announced that NASA’s Game Changing Development Program selected its proposal to develop ultra-lightweight materials for future aerospace vehicles. The HRL proposal centered on sandwich panels that feature cores of metal microlattice material between carbon fiber composite face sheets.

This announcement marked the latest stage of maturation in a technology that HRL Labs (co-owned by General Motors and Boeing) developed in partnership with the University of California, Irvine (UCI), and the California Institute of Technology (Caltech; Pasadena). The first generation of the metal mesh was developed for the Defense Advanced Research Projects Agency and published by HRL’s T. A. Schaedler and colleagues at UCI and Caltech in 2011. (*Science* DOI: 10.1126/science.1211649)

Properties change at the nanoscale

HRL’s microlattice consists of nanosized hollow tubes made from an alloy of 97% nickel and 3% phosphorus. It is made by the autocatalytic electroless plating of a polymer template with the alloy and subsequent removal of the template.

Its geometry and performance properties are still being characterized. Ladan Salari-Sharif at UCI and her colleagues combined nano–computed tomography scanning and finite element analysis to provide a quantitative description of the effects of manufacturing defects on compressive strength. This information will be used as input for statistical methods to develop more realistic predictions of material properties.

This material is similar to ultralight metal foams, which have porosities as high as 99.9%. Metal foams tend to be costly, and they are difficult to produce at large scale. In addition, the random cellular structures of foams sacrifice stiffness, strength, energy absorption, and conductivity for light weight and high surface area.

Complete recovery

Introducing structural order and size hierarchy into the microlattice mesh allows it to recover completely from >50% compressive strain. Its resistance to elastic deformation (Young’s modulus) increases with the square of the density (like denser random open-cell foams), in contrast to the density-cubed scaling observed for ultralight aerogels and carbon nanotube foams. Schaedler and colleagues compared their material to the Eiffel Tower, which has an overall density comparable to low-density aerogels but can support the weight of as many as 5000 people.

Other researchers, including Seok-Woo Lee and coauthors at Caltech, the University of Connecticut (Storrs), and the Institute of High Performance Computing (Singapore), have made hollow-tube structures. Lee’s group prepared copper–zirconium metallic glass nanolattices that exhibit extraordinary shape recovery behavior because of the hierarchy of structural feature sizes. Figure 1 is a scanning electron microscope (SEM) image of a $Cu_{60}Zr_{40}$nanolattice. (*Nano Lett.* DOI: 10.1021/acs.nanolett.5b01034)

Bulk metallic glasses are brittle, and, because they do not have plasticity mechanisms that suppress the initiation and propagation of shear bands and cracks, they fail catastrophically rather than gradually. At the nanoscale, these materials become ductile, even under tensile stress.

Because walls of the microlattice tubes are <100 nm thick, most of the atoms are at the surface. Surface atoms are more mobile than atoms in the bulk, so materials made from these tubes undergo elastic buckling or plastic deformation under compression rather than brittle failure. Figure 2 shows how Lee's group's lattices (a) deform (b) and recover (c) at ambient temperature.

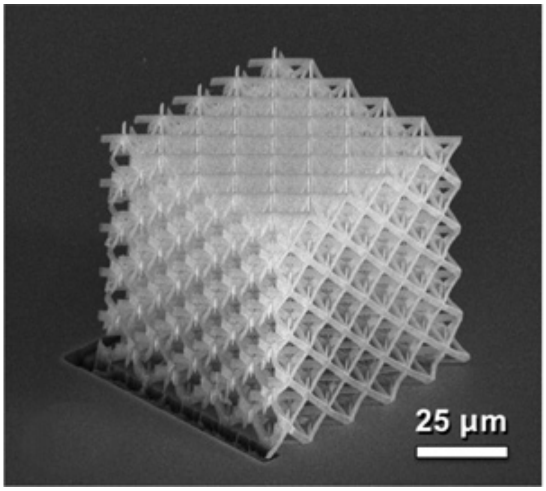

Figure 1

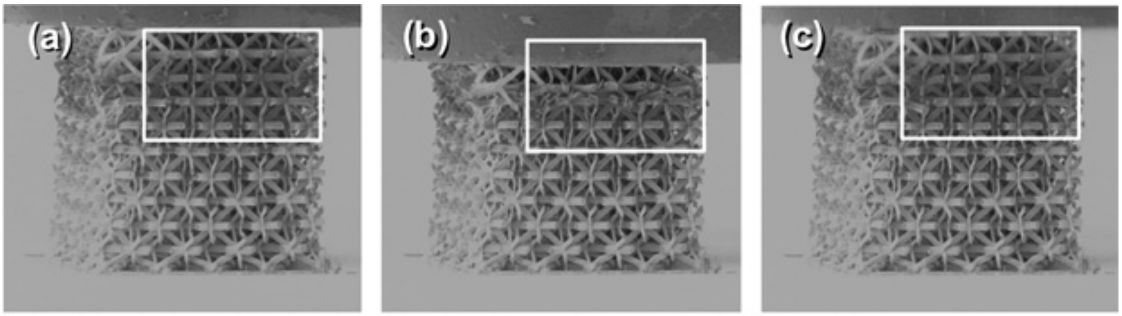

Figure 2

N. Pradeep and coauthors at the National Institute of Standards and Technology (Gaithersburg. MD), the University of Lodz (Poland), the University of Maryland (College Park), and the US Army Research Laboratory (Aberdeen Proving Ground, (MD) showed that any cracks that form travel very short distances before they are stopped by a surface. (*Appl. Phys. Lett.* DOI: 10.1063/1.2815648)

The HRL material shows 1–2% residual strain after the first compression cycle. The authors attribute the strain to stable "relief cracks" that form at the nodes of the lattice. Afterward, the material can undergo large compressive strains without incurring additional fractures or plastic deformation.

Microlattices in the marketplace and beyond

Some high-end automobiles already use metal foams for sound insulation and vibration damping. Thomas Fiedler and co-workers at the University of Newcastle (UK) are experimenting with the use of newer, less expensive foams as impact absorbers in roadside barriers.

HRL's microlattice materials are too expensive to use in automobiles. However, Boeing foresees that they may be used inside aircraft cabins for light, sturdy overhead luggage bins, sidewall panels, or floor supports. And NASA hopes that they will make the trip to Mars.

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