New Method for Creating Tough Metallic Glass Composites

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Scientists at the California Institute of Technology have developed a new strategy for creating "liquid metal" that makes it able to bend significantly without breaking, while retaining a strength twice that of titanium. It is among the toughest, or least brittle, known materials, and could be used anywhere that strong metal alloys are traditionally found, but may prove most useful in the aerospace industry, where lower density means fuel savings.

When commercialized metallic glass known as Liquidmetal and Vitreloy hit the market several years ago in the forms of golf clubs and baseball bats, it was too brittle to withstand much duress. Now, says Douglas Hofmann, a Caltech materials science graduate student and lead author of a paper presenting the method for making the new material, it can be made to flex and can be produced at relatively low cost. "Metallic glasses now have among the highest toughness of any materials," he says.

Like window glass, metallic glass has no crystalline structure, but it is made with combinations of zirconium, titanium, copper, nickel, platinum, or other metals. Although the random arrangement of elements makes the material as strong as some of the strongest known metals, it also makes it very brittle. Most other metals deform plastically, meaning that under a heavy load, the deformation before ultimate fracture is permanent. Metallic glass behaves like an elastic band, which regains its original shape when released, but snaps when stretched past a certain point. A piece of metallic glass with any substantial thickness shattered easily when it was bent, and, Hofmann points out, "you couldn't build a bridge out of it. It breaks with no visual precursor.

"Many researchers in metallic glasses are trying to make them useful in structural applications," Hofmann says. He and his colleagues at Caltech have finally accomplished exactly that. They experimented with different combinations of metals to create a new version by manipulating the ratios of starting materials. They were guided by previous work by coauthor William Johnson, Caltech's Mettler Professor of Engineering and Applied Science, and his collaborators. Over the past two decades, these scientists had found that ductility--the ability of a material to deform in tension before breaking--was linked to the formation of branching, crystalline structures called dendrites within the metallic glass.

The team experimented first with the size of the dendrites. Hofmann and Johnson started by noting that when metallic glasses are bent, 10-nanometer-wide features called shear bands rip right through glass that is thicker than one millimeter, but are stabilized in thin glass. "The bending experiments told us that the size of the particles we need to add is proportional to the length scale of the shear bands before they become catastrophic," Hofmann describes.

In this time of exploding interest in nanotechnology, Hofmann was surprised to find that the dendrites had to be on the order of hundreds of microns in size, many thousands of times the size of the shear bands. The second major insight was that they also had to be softer than the surrounding metallic glass.

Because they are crystalline, the dendrites deform plastically, and their size blocks a single shear band from growing into a catastrophic crack. "It takes more energy to move a shear band forward than it takes to form a new shear band," notes Hofmann. "We took an alloy that broke with one shear band and made it make countless shear bands.

"We took a metallic glass, which is considered a brittle material, and showed that by making a designed composite out of it, we can span the entire space of toughness," Hofmann remarks. "The tougher it is, the harder it is to drive a crack through it. Now we have ductility and toughness," he claims.

Because the new metallic glass is tough and strong and has relatively low density, its obvious applications would be in any structure that incorporates titanium. In aerospace technology, these properties are crucial to minimizing weight and saving fuel costs.

But, says Hofmann, "we're not trying to replace titanium; we're trying to find applications where a stronger material would be useful," particularly because the material is still difficult to make. Still, he points to one particularly alluring quality: "you can use less of it because it's stronger."

The paper appears in the February 28 issue of the journal *Nature*. All experiments were performed in Caltech's Keck Laboratory of Engineering Materials. The other authors are material scientists Jin-Yoo Suh, Aaron Wiest, and Gang Duan, Caltech graduate students; Mary-Laura Lind, a visiting scientist; and Marios D. Demetriou, a senior research fellow.

Source: California Institute of Technology