Nanostructured composite material may replace depleted uranium

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Armor-piercing projectiles made of depleted uranium have caused concern among soldiers storing and using them. Now, scientists at the U.S. Department of Energy's Ames Laboratory are close to developing a new composite with an internal structure resembling fudge-ripple ice cream that is actually comprised of environmentally safe materials to do the job even better.

Ames Laboratory senior scientist Dan Sordelet leads a research team that is synthesizing nanolayers of tungsten and metallic glass to build a projectile. "As the projectile goes further into protective armor, pieces of the projectile are sheared away, helping to form a sharpened chisel point at the head of the penetrator," said Sordelet. "The metallic glass and tungsten are environmentally benign and eliminate health worries related to toxicity and perceived radiation concerns regarding depleted uranium."

Depleted-uranium-based alloys have traditionally been used in the production of solid metal, armor-piercing projectiles known as kinetic energy penetrators, or KEPs. The combination of high density (~18.6 grams per cubic centimeter) and strength make depleted uranium, DU, ideal for ballistics applications. Moreover, DU is particularly well-suited for KEPs because its complex crystal structure promotes what scientists call shear localization or shear banding when plastically deformed. In other words, when DU penetrators hit a target at very high speeds, they deform in a "self-sharpening" behavior.

"It's very desirable to have this type of behavior together with high density, so that's why DU is used, but there has been strong global interest in replacing it since the start of the Gulf War in 1991." said Sordelet.

A popular replacement for DU is tungsten because at 19.3 grams per cubic centimeter, it's a little bit denser than DU. However, tungsten has a very simple crystal structure known as a body-centered cubic structure. "If I made the same solid projectile out of tungsten and plastically deformed it, I'd get a mushroom shape at the impacting face when the projectile hit the target because tungsten is notoriously resistant to forming shear bands," explained Sordelet. "It can be compared to taking a Tootsie Roll and pushing it against something flat and hard -- you get this mushroom-head effect."

Sordelet said that researchers have been looking at ways to utilize tungsten for at least the last 15 years. They've created tungsten heavy alloys, for example, W-Fe-Ni (tungsten-iron-nickel), in the hope of forming shear bands during high-rate deformation, but that goal hasn't been adequately achieved yet. "There are several types of tungsten-based penetrators, but they don't perform as well as DU," he said.

In the last few years, Sordelet said research has focused on mixing tungsten with bulk metallic glasses because glass, as a consequence of not having ordered planes of atoms, is naturally very susceptible to shear banding. "The problem is no one has come up with an economically viable metallic glass that has a sufficiently high density to form a composite that can compete with DU," he said. "People have made all kinds of different, interesting structures, but they all have coarse-grain tungsten of a micron or above in them, and that leads back to this mushroom-head effect."

Sordelet said the ideal approach would be to make the whole penetrator from a metallic glass matrix composite reinforced with nanocrystalline tungsten because researchers from the Johns Hopkins University and the Army Research Laboratory have recently demonstrated that when the grain size of tungsten is reduced to the nanometer scale, it's propensity to shear localize is significantly increased. So Sordelet and his Ames Laboratory co-workers, Ryan Ott, Min Ha Lee and Doug Guyer, decided to use a mechanical milling approach to reduce the grain size of coarse-grain tungsten and intimately blend it on a submicron scale with a metallic glass.

"We first physically blend the two powders in a tumbler and then mechanically mill the mixture to synthesize composite particles," explained Sordelet. According to him, the composite particles are composed of alternating nanoscale layers of tungsten and metallic glass that have an uncanny resemblance to fudge-ripple ice cream. "What was amazing to us was that in forming the composite powder structure with this nanolayering, nothing has changed in the two different layers," he said. "The metals do not blend together -- no alloying is going on between the two, and the metallic glass structure remains unchanged. The layer spacings and grain structures are just remarkably small."

In tests at low strain rates (low rates of deformation), Sordelet's nanostructured metallic glass+tungsten composite shows susceptibility to shear localization. "The fact that this occurred at low strain rates is very remarkable," said Sordelet. "It's extremely suggestive that you would see it at dynamic deformation rates, as well, which is what's needed for KEPs."

Sordelet is optimistic about the potential for the nanostructured metallic glass+tungsten composites not only for KEPs but also as an initial step in the development of similar composites for high-precision machining of advanced materials. But because the density of typical metallic glasses is fairly low, he knows they must get about 70 volume percent of tungsten into the composite, which will make it challenging to extrude in order to achieve a composite density that is acceptable to his colleagues at the Army Research Laboratory.

Contemplating that problem, Sordelet wonders, "What if we replace the glass with something that has a higher density and still might have a susceptibility to shear localization? The metallic glass is just a material that's along for the ride because of its strong propensity for shear localization," he noted. "But work at the Army Research Lab and Johns Hopkins University has shown that a lot of body-centered cubic metals have a susceptibility to shear localization if you get the grain size small enough." That being the case, Sordelet is now looking at a blend of tungsten and other high-density metals, but that's another story.

Source: Ames Laboratory

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