Researcher describes new type of strong, lightweight metallic material

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A new type of laminate performed spectacularly in depth-of-penetration ballistics tests, but its greatest potential may derive from its ability to be tailored to meet specific engineering requirements

An engineering professor at the University of California, San Diego has described in the March issue of JOM (the Journal of the Minerals, Metals and Materials Society) the unique properties of a new type of metallic laminate that can serve as armor and as a replacement for beryllium, a strong but toxic metal commonly used in demanding aerospace applications.

"The new material we developed is environmentally safe, and while its stiffness equals that of steel, it's only half as dense," said Kenneth S. Vecchio, author of the paper and a professor of mechanical and aerospace engineering in UCSD's Jacobs School of Engineering. "It performs spectacularly in our depth-of-penetration ballistics tests, but we think its greatest potential may derive from its unique ability to have its structure and properties tailored to meet a wide variety of application-specific engineering requirements."

The new material is made primarily of two lightweight metals. Vecchio alternated layers of aluminum and titanium alloy foils, and compressed and heated them in an inexpensive energy-conserving process. The resulting reaction generated a laminate with two layers: a hard ceramic-like "intermetallic" layer of titanium aluminide, and a pliable layer of residual titanium alloy. The layers can be stacked like 1-millimeter-thick pages of a book, and even contoured into desired shapes prior to heating.

The laminate architecture was chosen by Vecchio to mimic the internal structure of the tough shell of the red abalone. This science-mimicking-biology approach is one of an increasing number of biomimetic research efforts at the Jacobs School of Engineering. Faculty members are studying structural and functional designs of everything from mollusk shells and bird bills to sea urchin spines and other biocomposites in the development of new smart materials and devices.

The red abalone, a seaweed-eating snail prized as a source of mother-of-pearl jewelry, is found off the coast of California. The mollusk makes its dome-shaped home by slowly adding layers of brittle calcium carbonate, each about one-thousandth the thickness of a strand of human hair, between even thinner layers of a stretchy protein adhesive.

"The intermetallic phase of titanium aluminide is the complement of the mollusk's hard calcium carbonate phase, and the titanium alloy layer mimics the abalone shell's compliant protein layers," said Vecchio.

In order to test the bullet-stopping capability of his new material, Vecchio fired a heavy tungsten alloy rod into a three-quarters-inch (2 centimeters) thick sample at a velocity of about 2,000 mph (900 meters per second). The rod penetrated only half the thickness of the test sample. Vecchio said the laminate performs surprisingly well as armor and has potential as a structural metal.

He said other types of metallic foils containing vanadium, chromium, manganese, nickel, cobalt, and iron have been successfully fabricated into laminates using the same stacked foil technique. "We've only begun to explore the possible combinations and potential uses of these promising new materials," said Vecchio.

He described in his paper the production of cavities within his laminate layers, which were made by cutting out parts of the foil prior to heating. In one case, he filled cavities with steel beads, which were free to bounce within their confines and act as highly efficient vibration dampeners. "This vibration-dampening characteristic could be extremely valuable in jet engines and other high-performance applications prone to noisy vibration," said Vecchio.

It's also possible to include electrical pathways within the laminates by embedding metal or ceramic wires or fibers during fabrication, and those components could both strengthen the material and act as built-in sensors. In addition, Vecchio said the laminates could be further enhanced with the addition of materials that generate an electric charge when mechanically deformed. Conversely, these so-called piezoelectric materials also deform when an electric field is applied to them.

Source: University of California - San Diego