Neutron scattering charts moves of memory-shape alloys that change structure in response to environmental cues

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NASA scientists Santo Padula (left) and Othmane Benafan (right) and Central Florida University student Doug Nicholson are using the VULCAN instrument at SNS to study the atomic-level structure and behavior of shape-memory alloys such as nickel titanium. Their aim is to create more robust SMAs that can be commercialized for aerospace and other uses.

(Phys.org) -- Shape-memory alloys (SMAs) are an engineer's dream, able to shape-shift spontaneously to accommodate changing operating conditions. A research team from the National Aeronautics and Space Administration and the University of Central Florida is studying the internal mechanisms of these real-life "Transformers" at the Spallation Neutron Source at the Department of Energy's Oak Ridge National Laboratory, with an eye toward increasing their use in everyday scenarios.

"These are materials that can change phase and change their structure in response to mechanical and thermal conditions in their environment. We're trying to take advantage of that to use them in aerospace and other applications," says NASA's Othmane Benafan. In mechanical systems, components made from SMAs micro-engineered to deform precisely in response to heat or pressure would avoid the need for complex hydraulic or pneumatic actuators. They would change shape predictably and then return to their original configuration as conditions around them returned to normal (that's where the shape memory comes in).

Othmane and Santo Padula II, materials scientists at NASA; Doug Nicholson, a Ph.D. student at UCF; and his advisor Raj Vaidyanathan make up the team. They're examining the microstructure and micromechanics (i.e., atomic structure and atomic-level behaviors) of a sample of the SMA nickel titanium using the VULCAN Engineering Materials Diffractometer. "VULCAN's unique multi-axial load frame enables simultaneous testing of samples under tension, compression, and torsion, a capability not available anywhere else," says Ke An, lead scientist at VULCAN. "That's very important for problems under complex loading, which are real-world applications."

Some SMAs are commercially available, says Santo, but they operate only up to temperatures of about 90°C. "There are no alloys available that can transform at higher temperatures, other than the ones NASA-Glenn is creating. We have suites of alloys that go all the way up to 350°C, and we're pushing for even hotter. Eventually, we'll commercialize those." The work at SNS will provide information needed to do so, he says.

The idea behind SMA applications is to use the structural transformation to replace hydraulic and pneumatic systems, Santo explains. "You could replace an entire hydraulic actuator, pump, fluids and lines, with a simple piece of material that you heat or cool. For applications like aerospace, where you need to reduce volume and weight, it's the perfect way of doing it."

Another advantage of SMAs is they can reshape without being actively driven, Santo says. "By changing the alloying, you can design these materials so that as soon as they experience a specific temperature or pressure, they immediately respond with actuation force." He cites as an example a flap on an airplane wing. Replacing the classic flap design, controlled by a complex hydraulic system, with an SMA flap that changes position autonomously with temperature and air pressure would save hundreds of pounds. It would also be more reliable, notes Doug, because the electronically controlled hydraulics have numerous failure points.

"But if the material isn't stable and you don't design it correctly, you would run into failure problems there, too. That's why we're here: we want to design a set of materials that perform a function repeatedly and correctly every time, over many cycles," adds Othmane.

Neutron scattering illuminates fundamental mechanisms that govern the deformation behavior of various SMAs, says Othmane. It shows how materials behave at the atomic scale, which can be correlated with the microscopic deformation a material experiences in use, which in turn controls responses in the bulk material. Once materials scientists understand how to structure alloys to transform appropriately in use, they can determine the type of thermomechanical processing that will give a material the required structure. The microscopic deformation information obtained by neutron diffraction at VULCAN also will be used to develop computational models to predict how specific alloys will perform under scenarios with different temperatures, loads, and other variables.

The intensity of the SNS time-of-flight neutron beam and the high resolution of VULCAN "let users generate data efficiently and get down to limits they can't get anywhere else," says Ke. VULCAN's capability for multi-axial measurements also makes it uniquely valuable. In conventional metals like steel or aluminum, "if you know what it does in tension or compression, you largely know what it's going to do in shear. SMAs aren't like that. If we don't study a specific mode, we can't safely extrapolate what's going to happen." says Santo.

The team plans further experiments at VULCAN, using the neutron data in conjunction with work at NASA, UCF and other facilities to build an information database on SMA response under different conditions of stress and temperature. "We'll use that data to develop components and hardware to move these applications into the real world," Santo says. "All this work will extend into developing better alloys, better components, and more adaptive technologies."

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