Source : www.thehindu.com Date : 2022-12-15

STUDY FINDS TOUGHEST-KNOWN ALLOY, WHICH GETS TOUGHER IN THE COLD

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December 14, 2022 05:07 pm | Updated 06:54 pm IST

Microscopy-generated images showing the path of a fracture and accompanying crystal structure deformation in the CrCoNi alloy at nanometer scale during stress testing at 20 kelvin (-253.3°C). | Photo Credit: Robert Ritchie/Berkeley Lab

An alloy made from chromium, cobalt and nickel has been found to be the toughest material ever recorded. And CrCoNi only gets tougher as the temperature drops.

Scientists at the Lawrence Berkeley National Laboratory (Berkeley Lab) and Oak Ridge National Laboratory (ORNL) have tested the alloy for strength and ductility and found that it has the highest toughness ever recorded, a press release said.

The alloy is a subset of a class called high entropy alloys (HEAs) which is made by mixing equal amounts of allelements while other alloys are made with high amounts of one element along with low amounts of others. This equal mix makes the CrCoNi alloy exceptionally strong and ductile when tested, the study, published in the journal *Science*, noted.

These materials, though expensive to make, can be used to build structures which can withstand extreme cold conditions, such as those in deep space.

“When you design structural materials, you want them to be strong but also ductile and resistant to fracture,” said project co-lead Easo George, the Governor’s Chair for Advanced Alloy Theory and Development at ORNL and the University of Tennessee. “Typically, it’s a compromise between these properties. But this material is both, and instead of becoming brittle at low temperatures, it gets tougher.”

Demonstrating the strength of the alloy, Robert Ritchie, research co-lead, said that the toughness of the metal is as high as 500 megapascal square root meters when the temperature is at 20 kelvin or -253.3°C (near liquid helium temperatures).

“In the same units, the toughness of a piece of silicon is one, the aluminium airframe in passenger aeroplanes is about 35, and the toughness of some of the best steels is around 100.

So, 500, it’s a staggering number,” he added.

The secret of the alloy’s strength lies in its internal structure. Atoms in solid substances like metal are arranged in a crystalline form that has a recurring three-dimensional atomic pattern called the unit cell. Many unit cells together form a lattice. The physical properties of this lattice, in turn guided by the defects in the unit cells, determine the material’s strength. The meeting point of a deformed lattice and an undeformed lattice is called a dislocationand may causein a change in the shape of the metal by moving when force is applied.

A material where the dislocations can move easily is softer. However, if these movements are blocked by lattice irregularities, the material generally becomes stronger, although this might generally also make it more brittle.

Scientists studied pristine and fractured samples of the metal alloy at room temperature and at 20 kelvin using neutron diffraction, electron backscatter diffraction, and transmission electron microscopy.

The results showed that the alloy’s extreme toughness could be attributed to three dislocation obstacles that take place in a definite order when force is applied. Firstly, moving dislocations causes portions of crystals to slip away from other areas on parallel planes. This moves the layers of unit cells such that the patterns no longer match in the direction perpendicular to the slipping movement.

When more force is applied, a phenomenon called nanotwinning occurs, where portions of the lattice create a mirror symmetry with a border between them. If more force is applied, the CrCoNi atoms use this energy to rearrange the unit cells from a face-centred cubic crystal to hexagonal close packing.

Explaining how the cascading effect stops the metal from snapping, Dr Ritchie said, “So as you are pulling it (the metal), the first mechanism starts and then the second one starts, and then the third one starts, and then the fourth. Now, a lot of people will say, well, we’ve seen nanotwinning in regular materials, we’ve seen slip in regular materials. That’s true. There’s nothing new about that, but it’s the fact they all occur in this magical sequence that gives us these really tremendous properties.”

The development of high-tech electron microscopesallowed them to differentiate between the various types of crystals forming the metal and the defects in them, the scientists said. These microscopes offered resolutions of one nanometer— equal to the width of few atoms but big enough to detect the dislocations and obstacles in CrCoNi samples.

This result comes after almost a decade’s work by Dr. George and Dr. Ritchie, who started by experimenting with two strong alloys—CrCoNi and CrMnFeCoNi, which contains manganese and iron in addition to chromium, cobalt and nickel.

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