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Researchers report on metal alloys that could support nuclear fusion energy

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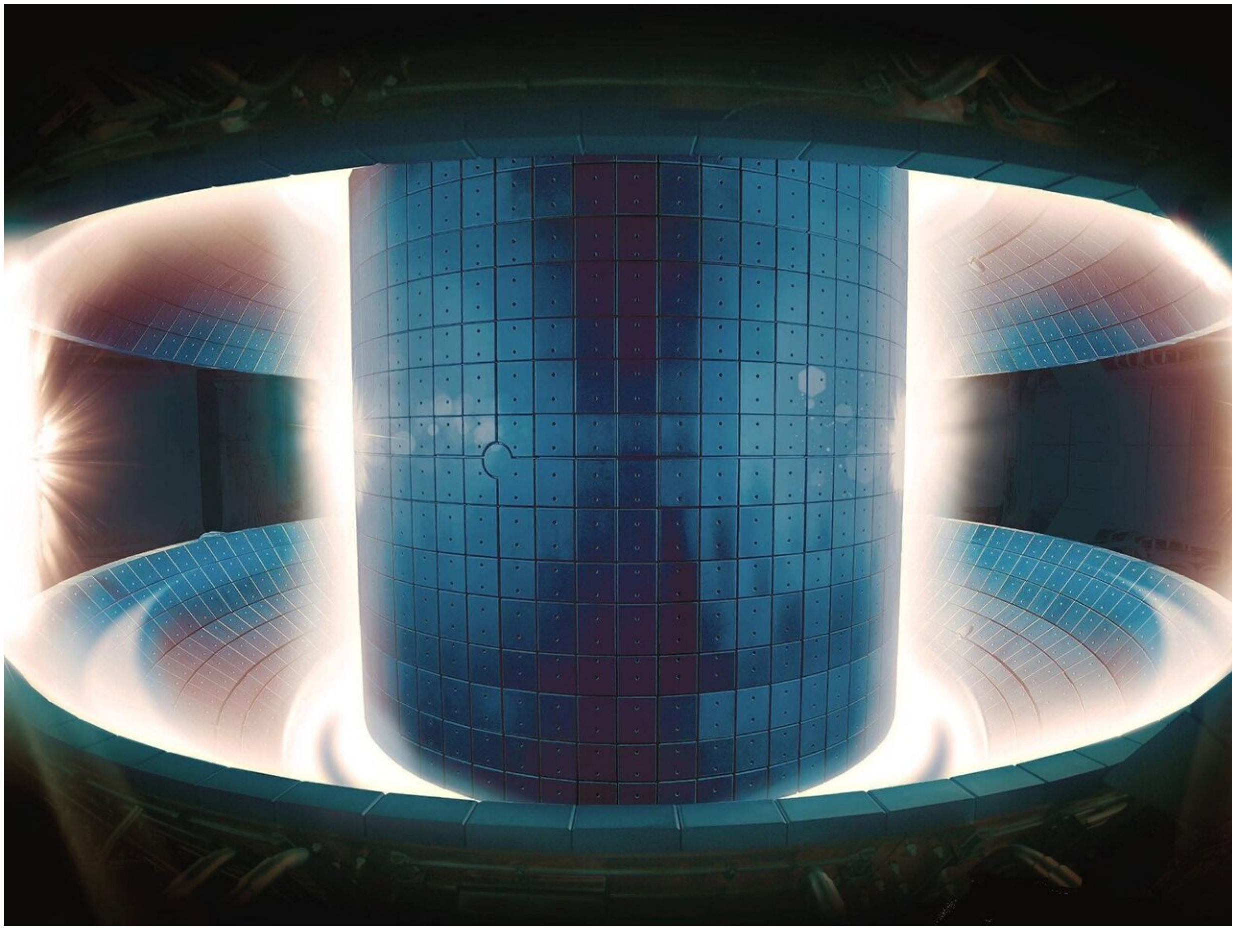

Extraordinarily tough and strong materials are required to withstand high heat and radiation inside nuclear fusion reactors, such as the one seen here. Credit: Korea Institute of Fusion Energy

At the end of 2022, researchers at Lawrence Livermore National Laboratory announced they had observed a net energy gain through nuclear fusion for the very first time. This monumental milestone toward fusion energy represents a huge leap forward in powering our homes and businesses with the carbon-neutral energy source. But converting this scientific achievement into a practical power source also requires new technologies to make a fusion-powered society a reality.

Scientists at Pacific Northwest National Laboratory (PNNL) and Virginia Polytechnic Institute and State University (Virginia Tech) are helping bring this goal to fruition through their materials research efforts. Their recent work, published in *Scientific Reports*, makes the case for tungsten heavy alloys and shows how they can be improved for use in advanced nuclear fusion reactors by mimicking the structure of seashells.

"This is the first study to observe these material interfaces at such small length scales," said Jacob Haag, first author of the research paper. "In doing so we revealed some of the fundamental mechanisms which govern material toughness and durability."

Withstanding the heat

The sun—with a core temperature of around 27 million degrees Fahrenheit—is powered by nuclear fusion. Thus, it should come as no surprise that fusion reactions produce a lot of heat. Before scientists can harness fusion energy as a power source, they need to create advanced nuclear fusion reactors that can withstand high temperatures and irradiation conditions that come with fusion reactions.

Of all the elements on Earth, tungsten has one of the highest melting points. This makes it a particularly attractive material for use in fusion reactors. However, it can also be very brittle. Mixing tungsten with small amounts of other metals, such as nickel and iron, creates an alloy that is tougher than tungsten alone while retaining its high melting temperature.

It isn't just their composition that gives these tungsten heavy alloys their properties—thermomechanical treatment of the material can alter properties like tensile strength and fracture toughness. A particular hot-rolling technique produces microstructures in tungsten heavy alloys that mimic the structure of nacre, also known as mother-of-pearl, in seashells. Nacre is known to exhibit extraordinary strength, in addition to its beautiful iridescent colors. The PNNL and Virginia Tech research teams investigated these nacre-mimicking tungsten heavy alloys for potential nuclear fusion applications.

"We wanted to understand why these materials exhibit nearly unprecedented mechanical properties in the field of metals and alloys," said Haag.

Examining microstructures for major toughness

To get a closer look at the microstructure of the alloys, Haag and his team used advanced materials characterization techniques, such as scanning transmission electron microscopy to observe atomic structure. They also mapped the nanoscale composition of the material interface using a combination of energy dispersive X-ray spectroscopy and atom probe tomography.

Within the nacre-like structure, the tungsten heavy alloy consists of two distinct phases: a "hard" phase of almost pure tungsten, and a "ductile" phase containing a mixture of nickel, iron, and tungsten. The research findings suggest that the high strength of tungsten heavy alloys comes from an excellent bond between the dissimilar phases, including intimately bonded "hard" and "ductile" phases.

"While the two distinct phases create a tough composite, they pose significant challenges in preparing high-quality specimens for characterization," said Wahyu Setyawan, PNNL computational scientist and co-author of the paper. "Our team members did an excellent job in doing so, which enable us to reveal the detail structure of interphase boundaries as well as the chemistry gradation across these boundaries."

The study demonstrates how crystal structure, geometry, and chemistry contribute to strong material interfaces in tungsten heavy alloys. It also reveals mechanisms to improve material design and properties for fusion applications.

"If these bi-phase alloys are to be used in the interior of a nuclear reactor, it is necessary to optimize them for safety and longevity," said Haag.

Building the next generation of fusion materials

The findings presented in this study are already being further expanded upon in many dimensions within PNNL and in the scientific research community. Multiscale material modeling research is underway at PNNL to optimize structure, chemistry, and test the strength of dissimilar material interfaces, as well as experimental investigations to observe how these materials behave under the extreme temperatures and irradiation conditions of a fusion reactor.

"It is an exciting time for fusion energy with renewed interests from the White House and the private sectors. The research that we do in finding material solutions for prolonged operations is critically needed to accelerate the realization of fusion reactors." said Setyawan.

Additional PNNL authors are Jing Wang (formerly of PNNL), Karen Kruska, Matthew Olszta, Charles Henager, Danny Edwards, and Mitsu

Murayama, who also holds a joint appointment with Virginia Tech.

More information: J. V. Haag et al, Investigation of interfacial strength in nacre-mimicking tungsten heavy alloys for nuclear fusion applications, *Scientific Reports* (2023). DOI: 10.1038/s41598-022-26574-4

Provided by Pacific Northwest National Laboratory

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