3D printed titanium structure shows supernatural strength

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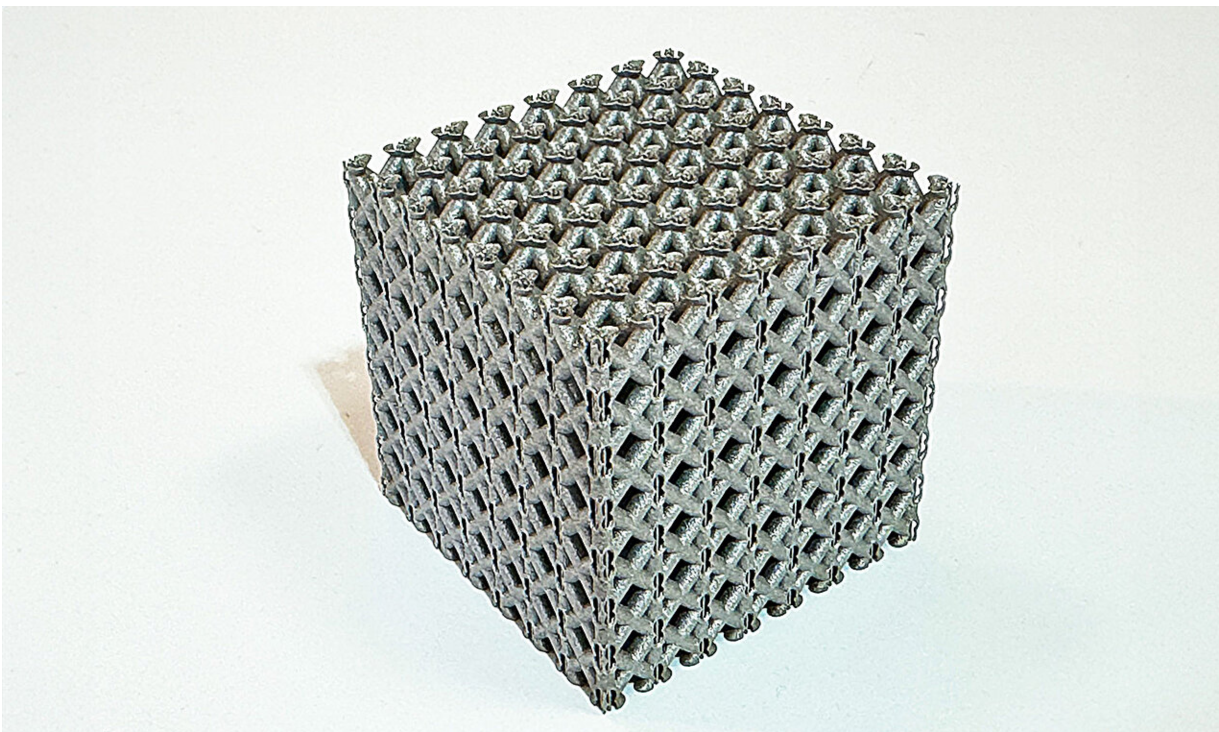


A sample of the new titanium lattice structure 3D printed in cube form. Credit: RMIT

A 3D printed 'metamaterial' boasting levels of strength for weight not normally seen in nature or manufacturing could change how we make everything from medical implants to aircraft or rocket parts.

RMIT University researchers created the new metamaterial—a term used to describe an artificial material with unique properties not observed in nature—from common titanium alloy.

But it's the material's unique lattice structure design, recently revealed in the journal *Advanced Materials*, that makes it anything but common: tests show it's 50% stronger than the next strongest alloy of similar density used in aerospace applications.

Improving on nature's own design

Lattice structures made of hollow struts were originally inspired by nature: strong hollow-stemmed plants like the Victoria water lily or the hardy organ pipe coral (Tubipora musica) showed us the way to combine lightness and strength.

However, as RMIT's Distinguished Professor Ma Qian explains, decades of trying to replicate these hollow 'cellular structures' in metals have been frustrated by the common issues of manufacturability and load stress concentrating on the inside areas of the hollow struts, leading to premature failures.

"Ideally, the stress in all complex cellular materials should be evenly spread," Qian explained.

"However, for most topologies, it is common for less than half of the material to mainly bear the compressive load, while the larger volume of material is structurally insignificant."

Metal 3D printing provides unprecedented, innovative solutions to these issues.

Ph.D. candidate Jordan Noronha holding a sample of the new titanium lattice structure 3D printed in cube form. Credit: RMIT.

By pushing the 3D printing design to its limits, the RMIT team optimized a new type of lattice structure to distribute the stress more evenly, enhancing its strength or structural efficiency.

"We designed a hollow tubular lattice structure that has a thin band running inside it. These two elements together show strength and lightness never before seen together in nature," said Qian.

"By effectively merging two complementary lattice structures to distribute stress evenly, we avoid the weak points where stress normally concentrates."

Laser-powered strength

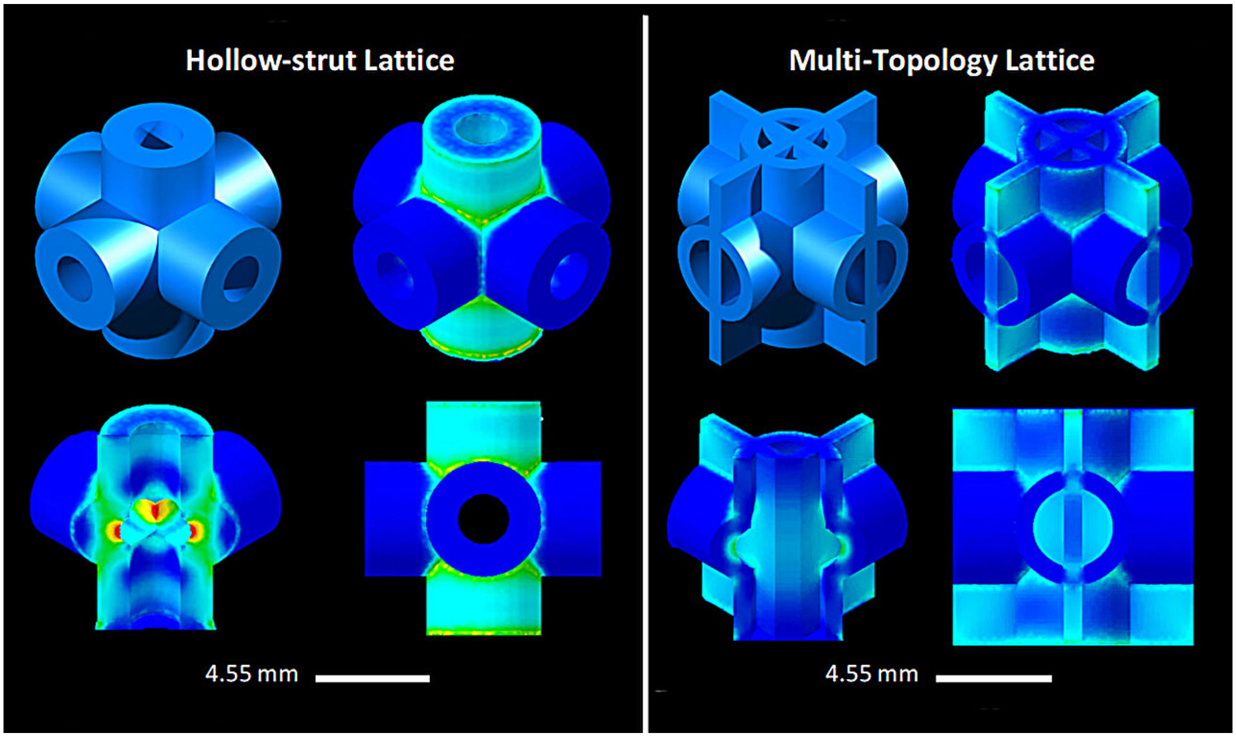
The team 3D printed this design at RMIT's Advanced Manufacturing Precinct using a process called laser powder bed fusion, where layers of metal powder are melted into place using a high-powered laser beam.

Testing showed the printed design—a titanium lattice cube—was 50% stronger than cast magnesium alloy WE54, the strongest alloy of similar density used in aerospace applications. The new structure had effectively halved the amount of stress concentrated on the lattice's infamous weak points.

The double lattice design also means any cracks are deflected along the structure, further enhancing the toughness.

Study lead author and RMIT Ph.D. candidate Jordan Noronha said they could make this structure at the scale of several millimeters or several meters in size using different types of printers.

This printability, along with its strength, biocompatibility, corrosion, and heat resistance, makes it a promising candidate for many applications, from medical devices such as bone implants to aircraft or rocket parts.



Compression testing shows (left) stress concentrations in red and yellow on the hollow strut lattice, while (right) the double lattice structure spreads stress more evenly to avoid hot spots. Credit: RMIT

"Compared with the strongest available cast magnesium alloy currently used in commercial applications requiring high strength and lightweight, our titanium metamaterial with a comparable density was shown to be much stronger or less susceptible to permanent shape change under compressive loading, not to mention more feasible to manufacture," Noronha said.

The team plans to further refine the material for maximum efficiency and explore applications in higher-temperature environments.

While currently resistant to temperatures as high as 350 °C, they believe it could be made to withstand temperatures up to 600 °C using more heat-resistant titanium alloys for applications in aerospace or firefighting drones.

As the technology to make this new material is not yet widely available, its adoption by industry might take some time.

"Traditional manufacturing processes are not practical for the fabrication of these intricate metal metamaterials, and not everyone has a laser powder bed fusion machine in their warehouse," he said.

"However, as the technology develops, it will become more accessible, and the printing process will become much faster, enabling a larger audience to implement our high-strength multi-topology metamaterials in their components. Importantly, metal 3D printing allows easy net shape fabrication for real applications."

Technical Director of RMIT's Advanced Manufacturing Precinct, Distinguished Professor Milan Brandt, said the team welcomed companies wanting to collaborate on the many potential applications.

"Our approach is to identify challenges and create opportunities through collaborative design, knowledge exchange, work-based learning, critical problem-solving, and translation of research," he said.

More information: Jordan Noronha et al, Titanium Multi-Topology Metamaterials with Exceptional Strength, *Advanced Materials* (2023). DOI: 10.1002/adma.202308715

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