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MECHANICAL METAMATERIALS

The strength awakens

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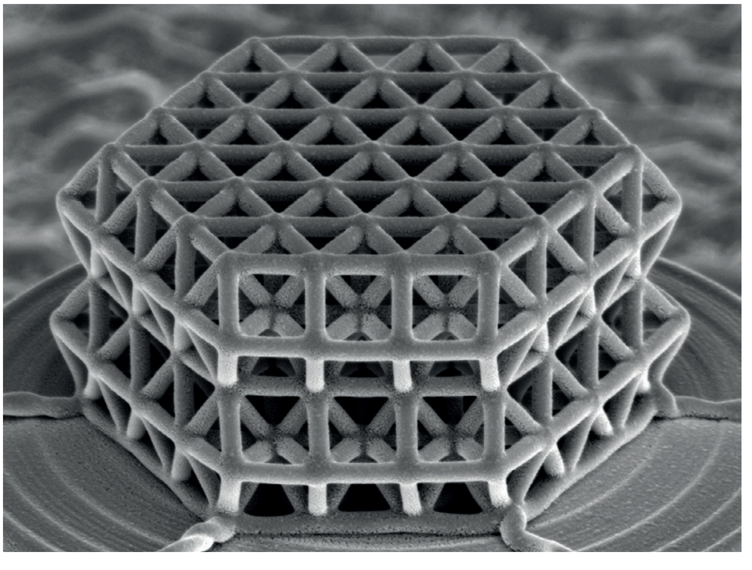
Strong, lightweight and durable materials are needed for numerous advanced applications from more efficient cars to higher-performance sports equipment. Now, glassy carbon nanolattices with unprecedented strength and very low density — beaten only by diamond in terms of strength-to-density ratio — are reported in *Nature Materials* by Jens Bauer, Oliver Kraft and colleagues at the Karlsruhe Institute of Technology.

Glassy carbon is a disordered carbon allotrope with low density and remarkable properties, ranging from high mechanical hardness to low electrical resistance, making it a good candidate for use in metamaterial-based applications. In structured materials, however, the properties are determined not only by the composition and architecture of the material but also by the size of its components. Examples of this are most apparent in nature, as Bauer explains: "Biological materials such as bone and enamel have optimized architectures and hierarchical structures consisting of nanometre-sized building blocks. Owing to material-strengthening size effects, they are remarkably strong even though their basic material components are originally weak."

However, taking advantage of these size-dependent strengthening effects in man-made materials is far from straightforward. "The challenge we faced was to reduce the length scale of our samples to create new lightweight materials," says Bauer. Until now, the miniaturization of microlattice materials to the nanoscale has been hindered by the resolution of 3D manufacturing technologies, which is limited to hundreds of nanometres, and by the poor mechanical properties of the polymers that are compatible with these fabrication techniques. The research team used pyrolysis — a treatment in which samples are heated, in vacuum, to a temperature of 900 °C — to transform 3D-printed polymeric microlattices into glassy carbon structures that are only 20% of the size of the original samples. "3D lithography and pyrolysis are established techniques, but we were the first to combine them to produce miniaturized ultra-strong nanolattice materials," says Kraft.



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The resulting 3D lattices are the smallest of this kind produced so far, with struts that are less than 1 μm in length and 200 nm in diameter: these features are about five times smaller than those obtained with 3D manufacturing processes. Owing to their very small size, these lattices are extremely strong, reaching the fundamental strength limit determined by the strength of the atomic bonds. "The entire structure is as strong as high-strength metals but has only half the density of water," remarks Bauer, "diamond is the only bulk material with a notably higher strength-to-density ratio." Coating the nanolattices with a very thin alumina film further increases their strength and stiffness.

The challenge now is to realize the transition from laboratory- to large-scale fabrication, which will open up the possibility of using glassy carbon nanolattices for practical purposes. In addition to the exceptional mechanical properties of these structures, their glassy carbon nature is expected to give them excellent electrical properties, very good thermal and chemical stability, and biocompatibility, making them appealing for use in optics, electronics and biomedical applications.

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