Growth under pressure: New metamaterial designed with counterintuitive property

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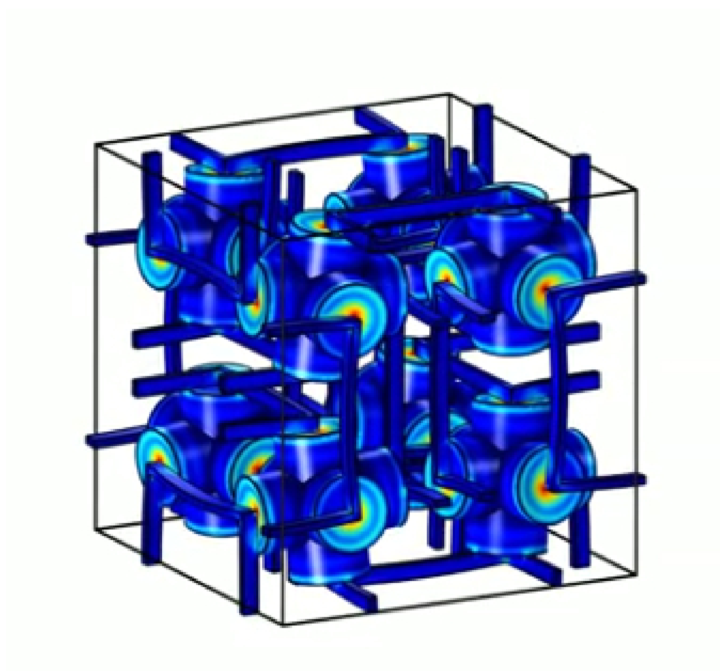

In the not-too-distant future, it may be possible to 3-D print virtually anything. Consider standard printers, which "synthesize" thousands of colors by using only three color cartridges. By analogy, future 3-D printers may be capable of synthesizing thousands of different material properties with a mere handful of material cartridges.

This concept inspired a group of researchers from the Karlsruhe Institute of Technology (KIT) in Germany and the French National Center for Scientific Research to explore such development of one mechanical property called effective static compressibility. As they now report in *Applied Physics Letters*, from AIP Publishing, by using a single cartridge it's possible to print a metamaterial which expands in size under hydrostatic pressure, even though it's made up of material which normally shrinks under hydrostatic pressure. In principle, there is no limit to the negative value this material's effective compressibility can take.

"[O]ur poroelastic three-dimensional metamaterial, a man-made composite material that exhibits properties not found in natural materials , effectively expands upon increasing the hydrostatic pressure of a surrounding gas or liquid," said Jingyuan Qu, a doctoral student and researcher at KIT's Institute of Applied Physics and Institute of Nanotechnology. "For most materials, the behavior is the exact opposite. At first sight, a negative compressibility even appears to violate fundamental laws of physics."

At the heart of the group's design for the metamaterial structure is a hollow, 3-D cross structure with circular membranes at each end of the cross.

"Akin to a drum, these membranes will warp inward if the outside pressure is larger than the pressure in the enclosed volume inside the cross," Qu said. "By properly connecting these membranes via bars, and by using eight such three-dimensional crosses within one unit cell, it's possible to obtain an isotropic effective volume increase upon increasing the pressure—a negative effective compressibility."

This is particularly intriguing work, Qu pointed out, because a negative compressibility under static and unconstrained conditions is generally forbidden by the laws of physics.

"It's unstable and violates energy conservation," Qu said. "The trick of our structure is that the volume you can see increases upon increasing the surrounding pressure, whereas the volume enclosed by the 3-D printed material—a quantity that you don't perceive directly—decreases and makes the structure both stable and physical."

One of the metamaterial structure's special properties is a zero negative effective compressibility, according to Qu. "This means that the metamaterial's effective volume simply won't change," he said.

With the success of the structure's extensive modeling, the group has already started to pursue the demanding task of demonstrating its fabrication.

"We've calculated the behavior of the material using [engineering simulation software], so the material has yet to be fabricated and measured experimentally," Qu said. "Fabrication is a demanding case for 3-D laser nanoprinting because the necessary concealed inner volumes haven't previously been achieved."

Making such a metamaterial would probably not be possible with conventional machining techniques which tend to remove material to build a structure. With an additive technique like 3-D printing, however, fabricating concealed structures and enclosed volumes becomes possible making this an ideal way to create negative compressibility metamaterials.

More information: "Poroelastic metamaterials with negative effective static compressibility," DOI: 10.1063/1.4981783

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