Origami lattices from flat sheets and patterning yield metamaterials with exotic functions

Inspired by the Japanese paper-folding art of origami, researchers have devised techniques to create complex three-dimensional (3D) lattices from predesigned flat materials. Unlike 3D printing—one route for creating lattice structures—the origami method could enable scientists to add functional features and create materials with novel properties.

Lattice-like highly porous 3D structures made of metals, polymers, and carbon have recently opened up a slew of novel applications. They can be used to make ultra-strong, ultralight car and aircraft parts; for energy storage; as tissue-generating scaffolds in regenerative medicine; and for metamaterials.

Advanced 3D printing is used to make lattice-like metamaterials. But it does not allow easy access to the inner surfaces of the structures. Accessing the inner surfaces is critical for creating nanopatterns that can stimulate tissue growth or for integrating electronic sensors inside metamaterials.

To overcome this problem, biomechanical engineers Shahram Janbaz, Amir Zadpoor, and their colleagues at the Delft University of Technology in The Netherlands turned to origami. “We can start from flat structures, use available patterning technologies to make what you want on the surface, and then fold it into the shape you want,” Zadpoor says.

Computational geometry algorithms allow flat shapes to be folded into simple polyhedra. But there are no algorithms that create polyhedral lattices, which contain polyhedral cells stacked vertically and horizontally. The researchers therefore devised a general platform for folding various types of 3D metallic lattices from flat states. They first identified three categories of polyhedra, which would be repeated to make a lattice, and came up with a folding pattern for each. Then they figured out how the lattice would need to be sliced in order to open up completely.

The first category has the simplest unit cell—a cubic lattice is a good example—and can be sliced along every row to unfold. The second category has more complex unit cells, requiring the lattice to be sliced along the tops and bottoms of rows. The last category builds on the second one, by requiring spatial rotations during the folding process.

As a demonstration, the researchers hinged together 3D printed aluminum panels using metal pins and prestretched rubber bands. The piece self-folds into a cubic lattice, the team reported in a recent issue of *Science Advances* (doi:10.1126/sciadv.aao1595). To demonstrate the technique’s usefulness for adding features to the insides of lattices, they used electron beam deposition to make tiny 3D structures a few tens of nanometers in size on the origami sheets, so that these became situated on the inside of the folded lattices. They could pack multiple types of surface patterns into the same origami lattice.

“We have demonstrated that we have a folding strategy,” Zadpoor says. “Now we want to be able to do this at the microscale.”

The advantage of this new approach for creating complex 3D structures is that it decouples structure and function, says Jesse Silverberg, a researcher at Harvard University’s Wyss Institute of Biologically Inspired Engineering. “Most of the earlier work on origami-inspired materials shows that structure is function,” he says. “Here, functionality can be arbitrarily prescribed on the 2D surface before the structure folds. Once folded, the functionality is now embedded in the 3D structure.”

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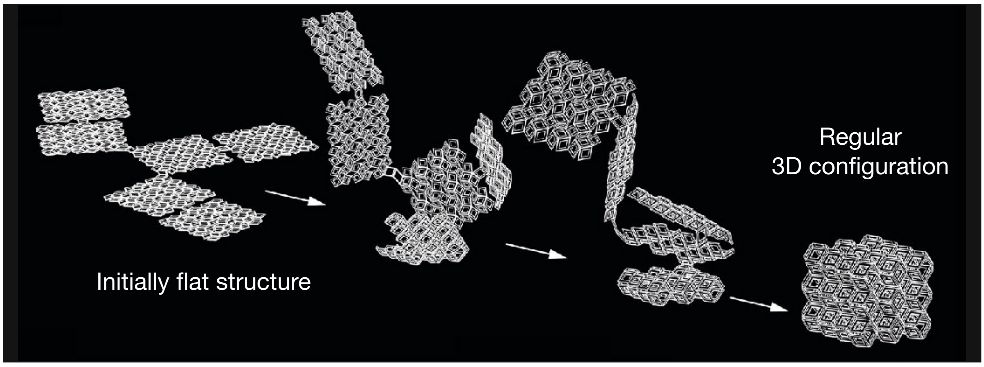

The self-folding sequences for a rhombic dodecahedron origami lattice. Credit: *Science Advances*.