Programmable soft material bends, bounces and absorbs energy on demand

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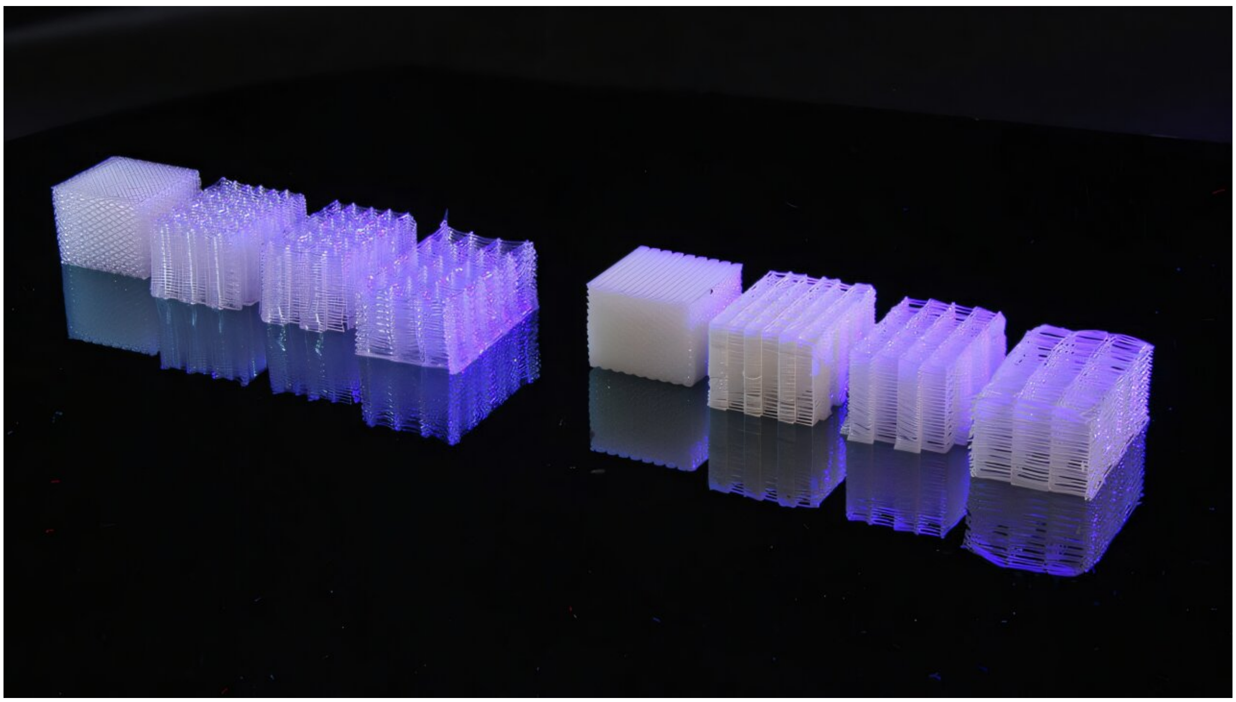

Credit: Julie Mancini

Scientists at Lawrence Livermore National Laboratory (LLNL) and their collaborators have created a new class of programmable soft materials that can absorb impacts like never before, while also changing shape when heated.

The research—which includes collaborators from Harvard University, the California Institute of Technology (Caltech), Sandia National Laboratories and Oregon State University—opens the door to smarter, lighter and more resilient materials that respond to the world around them. The research is published in the journal *Advanced Materials*.

Built from liquid crystal elastomers (LCEs)—rubbery polymers that shift in response to heat, light or stress—the team 3D-printed the materials into carefully engineered lattice structures. These lattices can be designed to absorb energy, stiffen, soften or even change shape, depending on their architecture and environmental conditions.

"What excites me most is the unprecedented level of control we now have—from the molecular scale up to the macroscopic structure—enabling us to design materials that respond and adapt to their environment," said first author and LLNL engineer Rodrigo Telles. "This opens new possibilities for engineering materials with tunable mechanical properties."

Researchers said what makes the materials unique is how they behave under stress. Unlike conventional materials like silicone or foams, which lock in their mechanical properties during manufacturing, LCEs offer what scientists call "soft elasticity." Their molecular structure reorients under stress, giving the material an unusual capacity to absorb energy and recover after deformation.

This adaptability makes LCE lattices uniquely suited for demanding environments. In tests, the structures were soft and flexible under slow compression, but when hit quickly—at very high velocities—they absorbed up to 18 times more energy than similar silicone-based lattices. And unlike conventional rubbery structures, which often cracked or shattered under repeated impacts, the LCE lattices remained intact, making them promising for applications such as protective gear, aerospace parts and shape-morphing robotic systems.

"The resilience stems from the unique behavior of LCEs under stress," explained co-author Elaine Lee, group leader of the Responsive and Active Materials and Manufacturing Group. "When the lattice experiences a high-speed impact, the liquid crystal molecules within the elastomer rapidly reorient, dissipating energy throughout the structure rather than allowing localized damage."

The researchers achieved this by carefully aligning the molecular structure of the LCEs during a special 3D printing process. Each microscopic beam within the lattice is aligned like muscle fibers during printing, thanks to a custom extrusion-based process that orients the LCE molecules as they are deposited. This built-in directionality lets researchers program shape-shifting behaviors, such as shrinking in one direction and expanding in another when heated.

The team also developed computer models to simulate how the material behaves. When the temperature rises, the lattices shrink in some directions and expand in others. And when hit hard, they can bend and rebound instead of cracking.

The researchers also found that while conventional silicone structures were often damaged or destroyed after high-speed impact, the LCE lattices stayed intact, even after multiple hits, making them ideal for repeated use in demanding environments. As the team looks ahead, they plan to explore more complex lattice designs and push further into dynamic applications, such as body armor that responds to impact in real time to biomedical devices that flex and move with the body.

More information: Rodrigo Telles et al, Architected Liquid Crystal Elastomer Lattices with Programmable Energy Absorption, *Advanced Materials* (2025). DOI: 10.1002/adma.202420048

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