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3D Printing of Liquid Crystal Elastomer Foams for Enhanced Energy Dissipation

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1. Introduction

Polymer foams: lightweight materials to protect valuable assets from mechanical insult.

❑ **Advantages:**

- Excellent energy dissipation
- Low density
- Low cost …

❑ **Applications:**

- Automotive
- Biomedical
- Aerospace
- Safety equipment …

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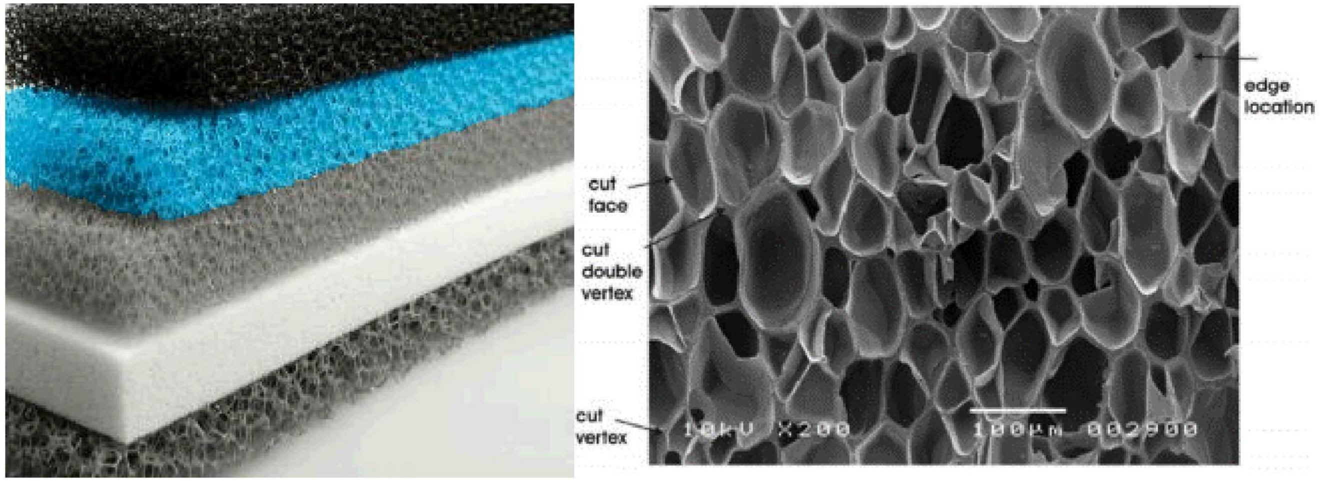
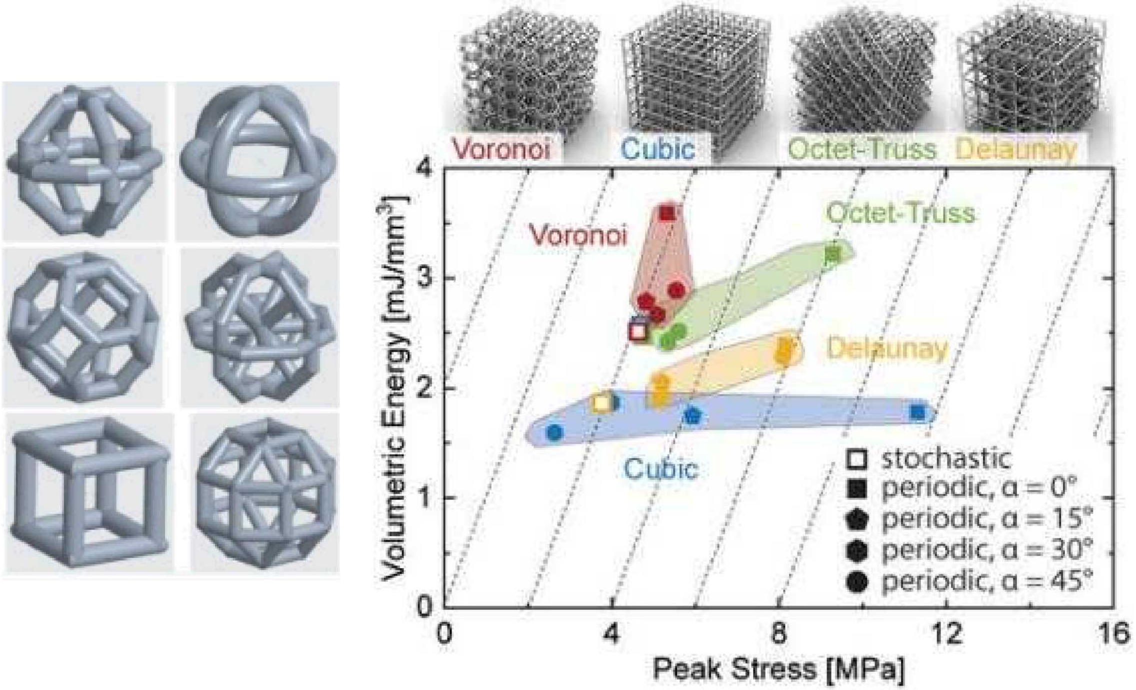
1. Introduction

- ❑ **Conventional foams with random microstructure**
- ❑ Foam density as the primary design parameter



N.J.Mills et al., Composite Science and Technology, 2003

- ❑ **Foams with periodic lattice structure**
- ❑ Unit cell geometry offer additional design freedom



F.N. Habib et al., Materials & Design, 2018
J. Mueller et al., Advanced Theory and Simulations, 2019

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2. Motivation and Goals

- Two features of the polymer foams to enhance energy absorption characteristics:
  - Foam micro (or meso) structure
  - Matrix material mechanical behaviors
- Aided with 3D printing techniques, existing works show the enhanced energy dissipation of foams by designing the geometry of periodic unit cell.
- However, they mainly focus on the energy dissipation through structural deformation.
- It remains unexplored how the intrinsic properties of a material, when combined with the lattice geometry design, can be leveraged to promote the energy dissipation capabilities.

We aim to investigate a novel approach to enhance the energy dissipation of polymer foams through controlling the geometry of unit cell and mechanical properties of matrix materials.

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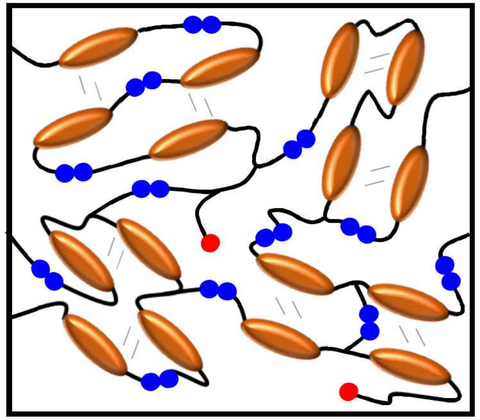
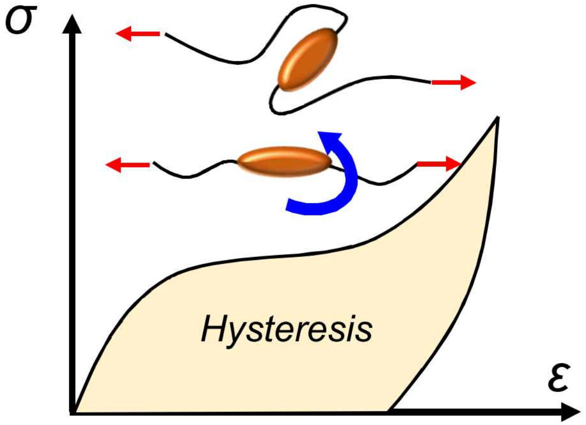
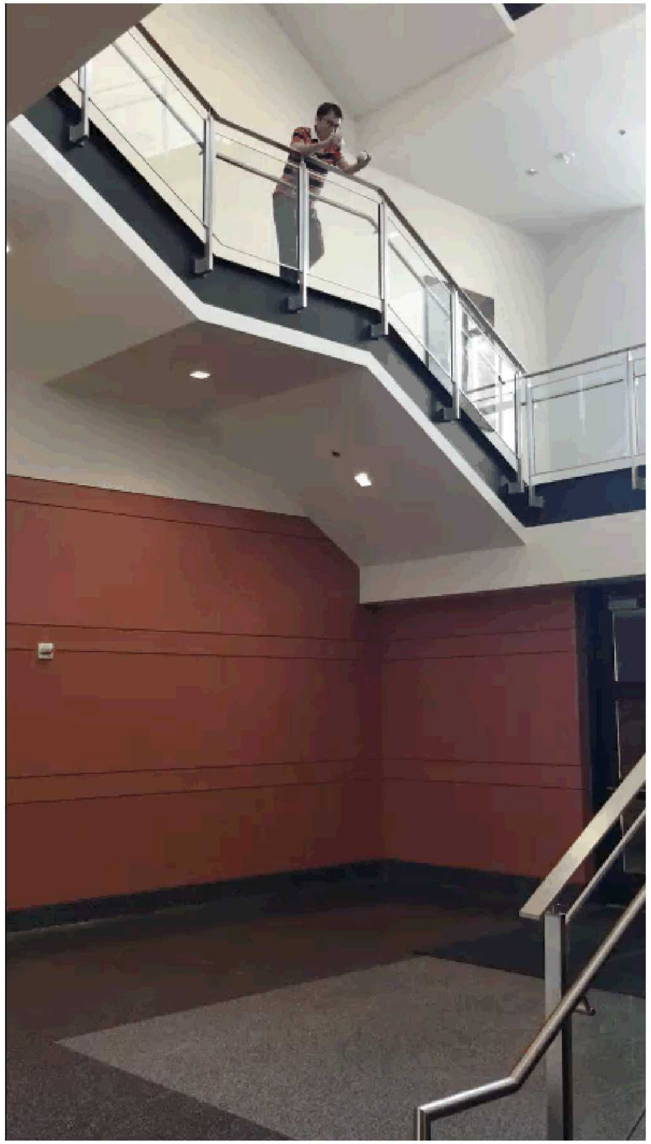
3.1 Matrix Material: LCEs with enhanced energy dissipation





Mesogen rotation provides an additional mechanism for energy dissipation



LCE vs Rubber Ball

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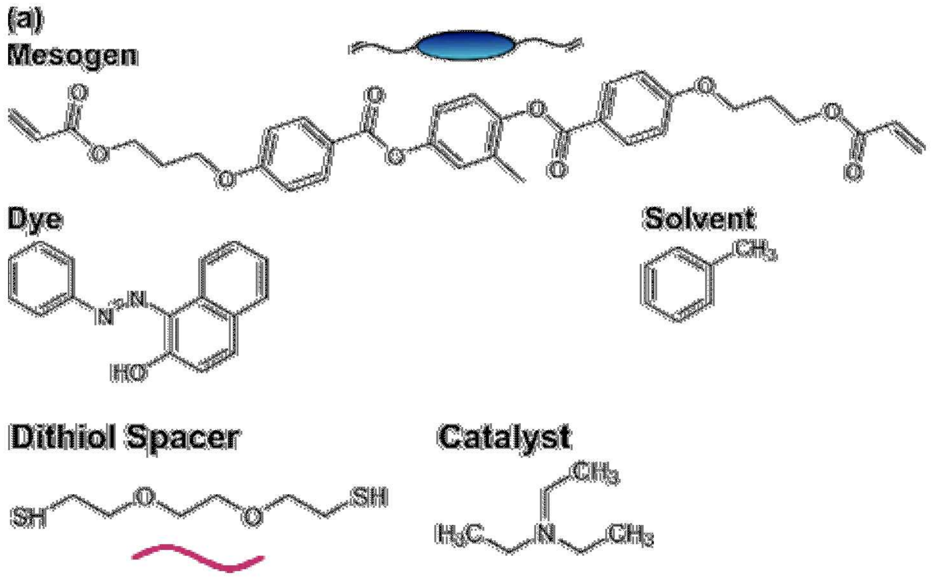
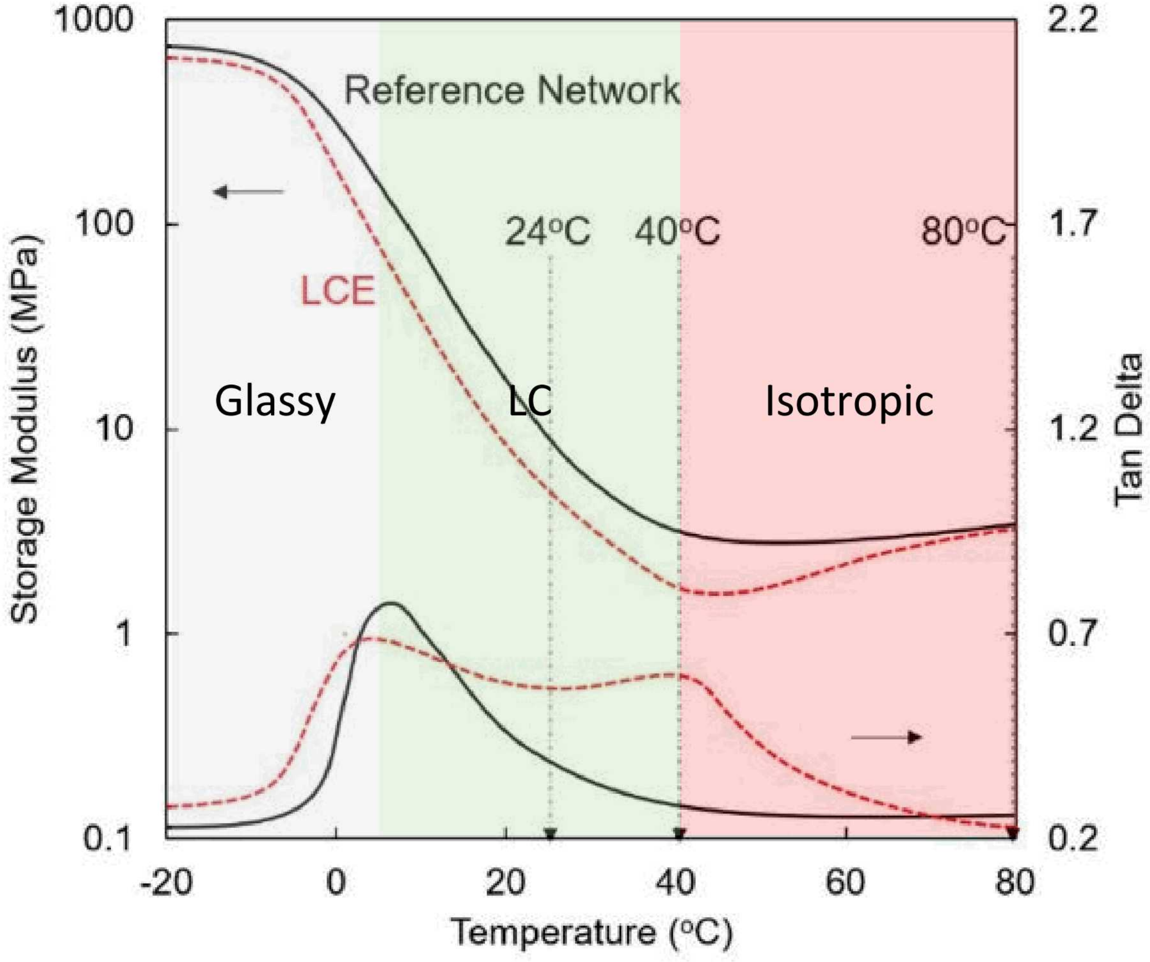
3.1 Matrix Material: LCEs v.s. reference non-LCE elastomer

- **LCE**





- **Reference non-LCE network**

  Acrylate-based network with monomers purchased from Stratasys

- **Three characterization temperatures**

  24°C: room temperature

  80°C: both networks reach a rubbery state.

40°C: LCE at the nematic-isotropic phase transition

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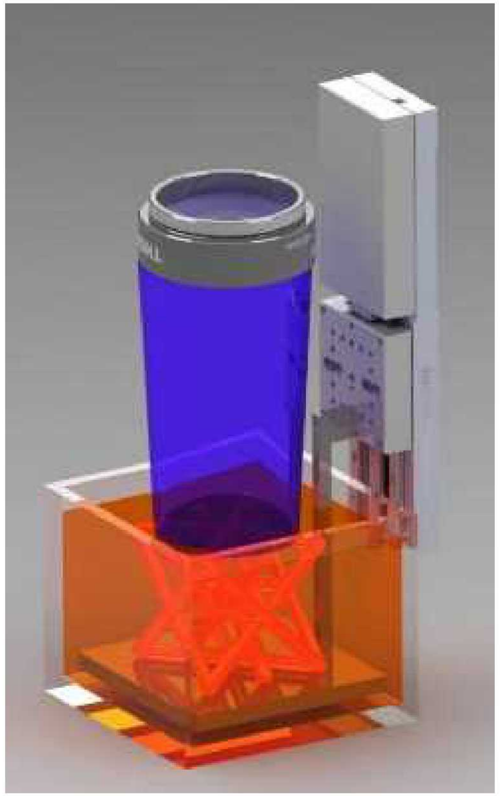
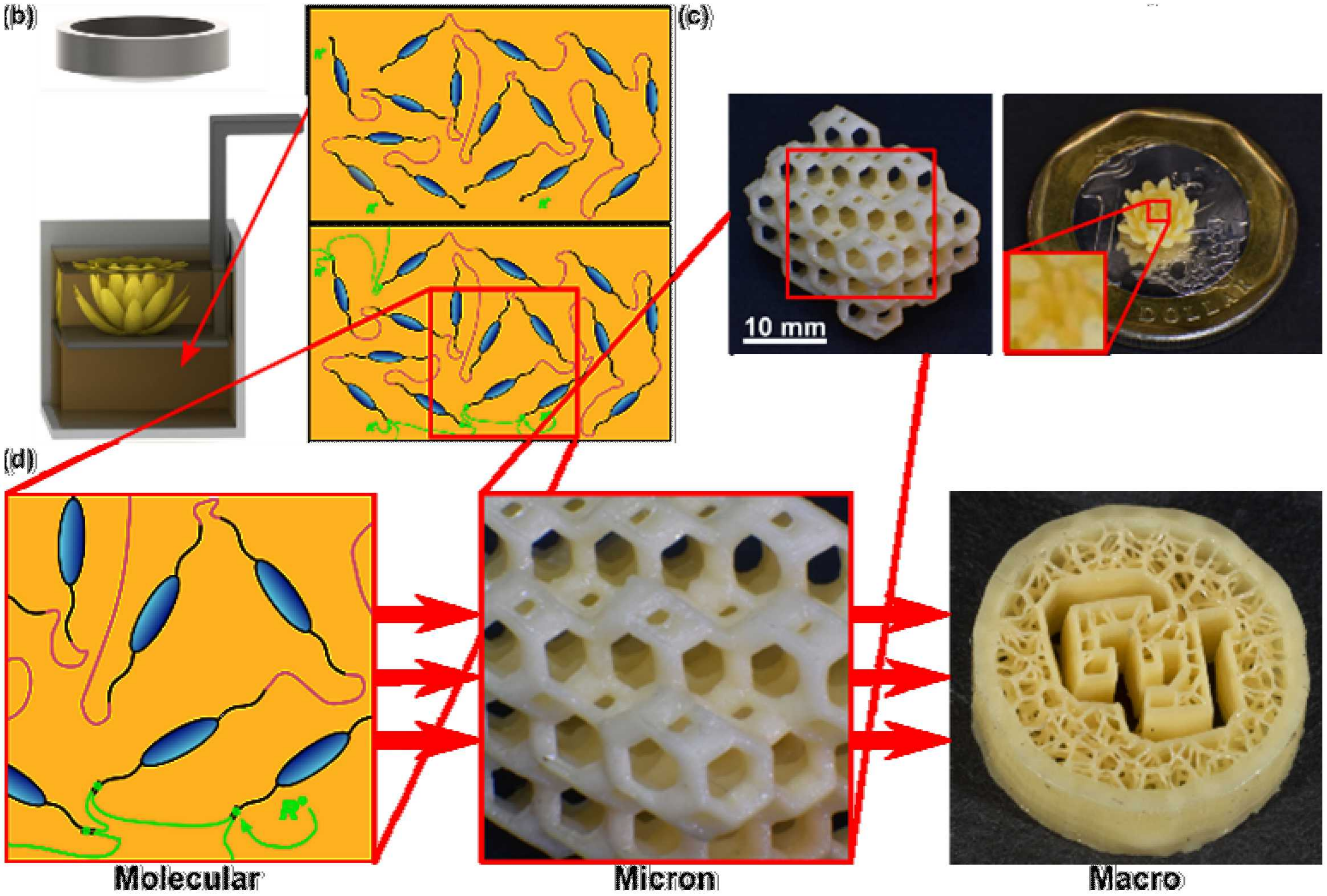
3.2 Digital light process (DLP) printing



Customized DLP printer with 50um × 50um in plane printing resolution



NA Traugutt et al., Advanced Materials, 2020.

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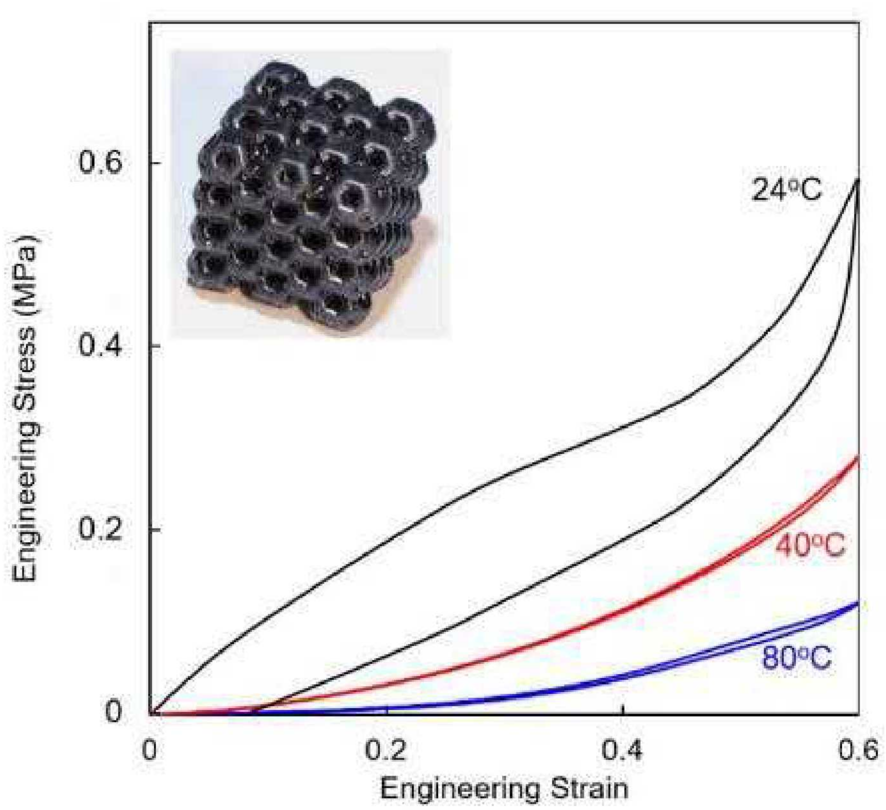
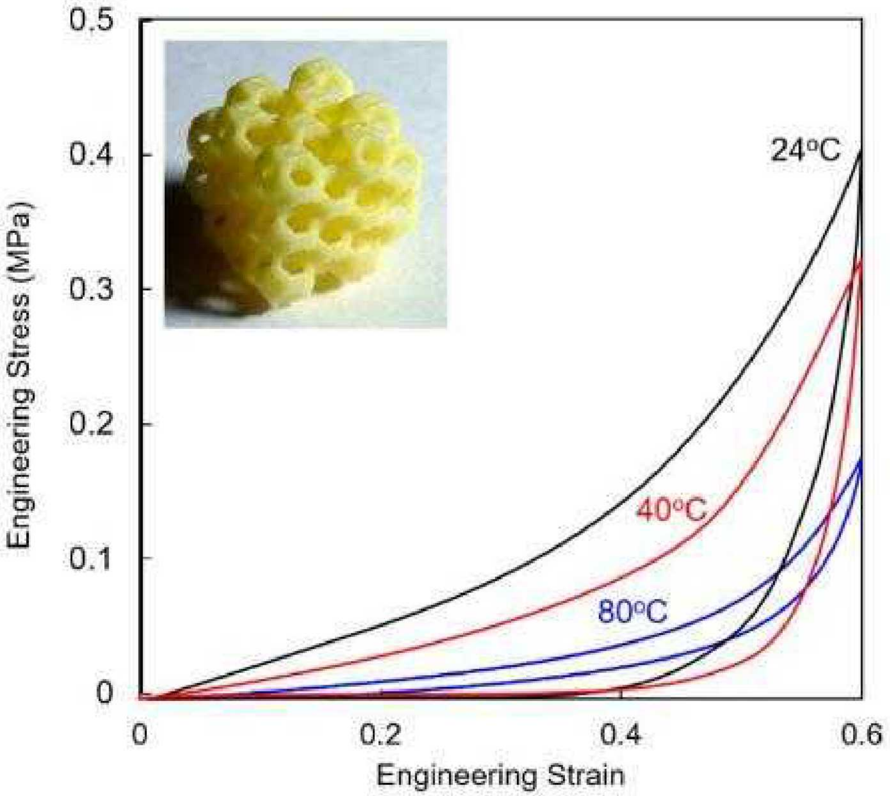
3.3 Stress-strain curves of LCE and reference non-LCE foams

Foams with Kelvin Lattice cell; Porosity=62%





- At 24°C, LCE foam exhibits more prominent hysteresis compared to the reference counterpart.
- At 40°C, the hysteresis of LCE foams is still prominent due to the mechanically induced mesogen rotation.
- At 80°C, both LCE and reference foams exhibit negligible energy dissipation.

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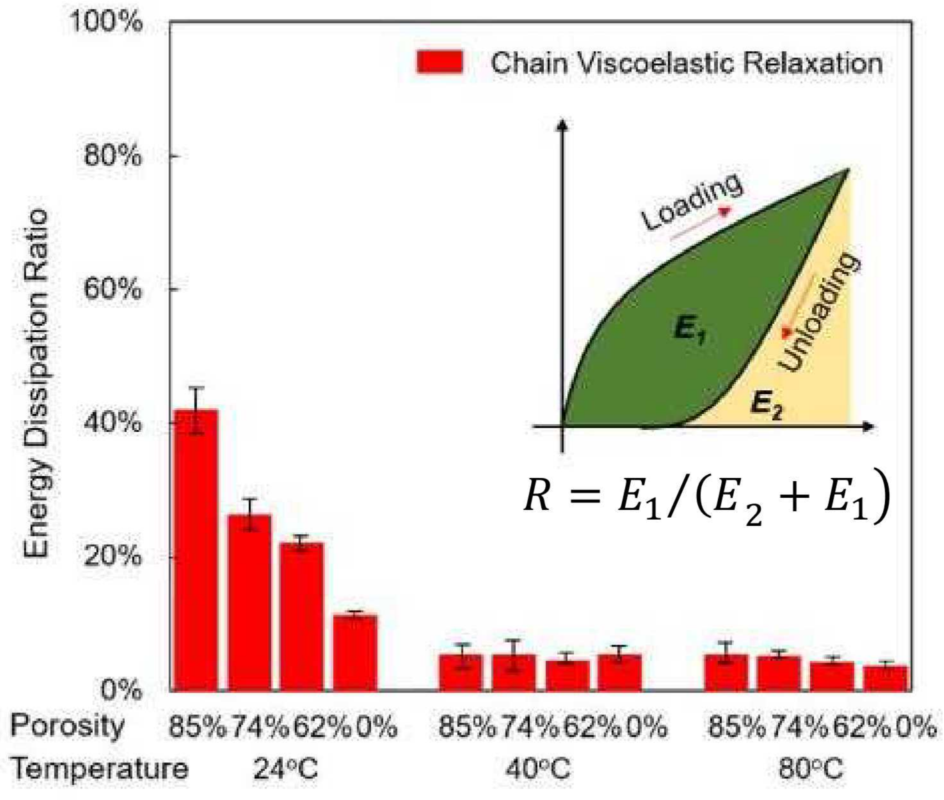
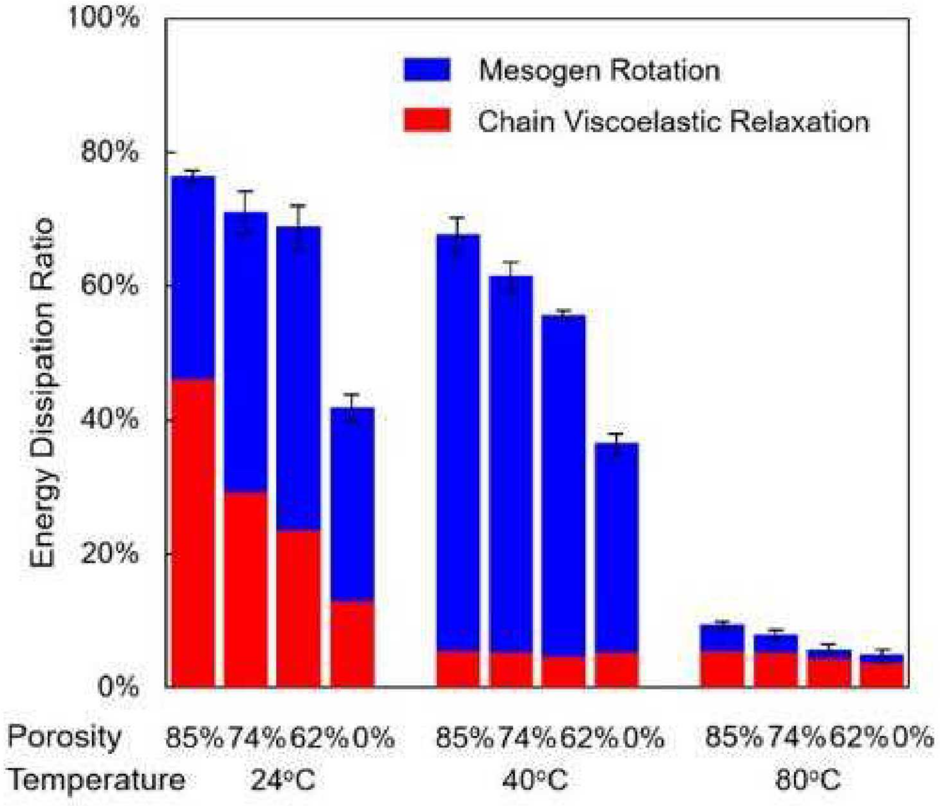
3.4 Energy dissipation ratios of LCE and non-LCE foams





- At 24°C, the higher dissipation ratios of LCE foams result from the substantial amount of energy released through mesogen rotation
- At 40°C, the increased chain mobility leads to the elimination of viscoelastic effect to the network deformation.
- However, the enhanced mesogen mobility is seen to further enhance their contribution to energy dissipation.

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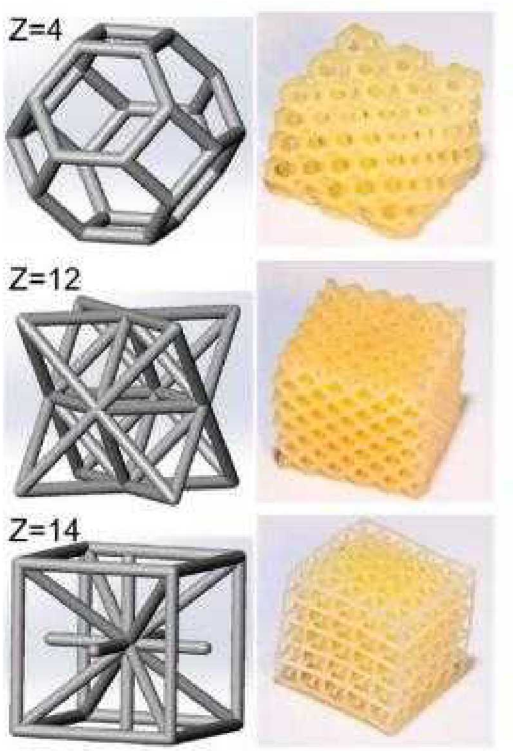
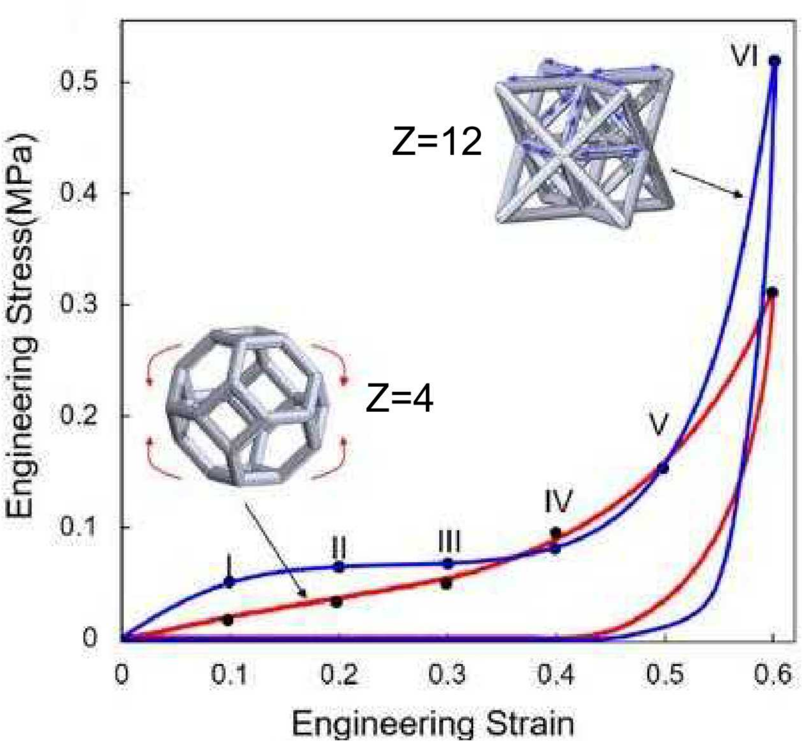
3.5 Enhanced energy dissipation by tailoring geometries of unit cell

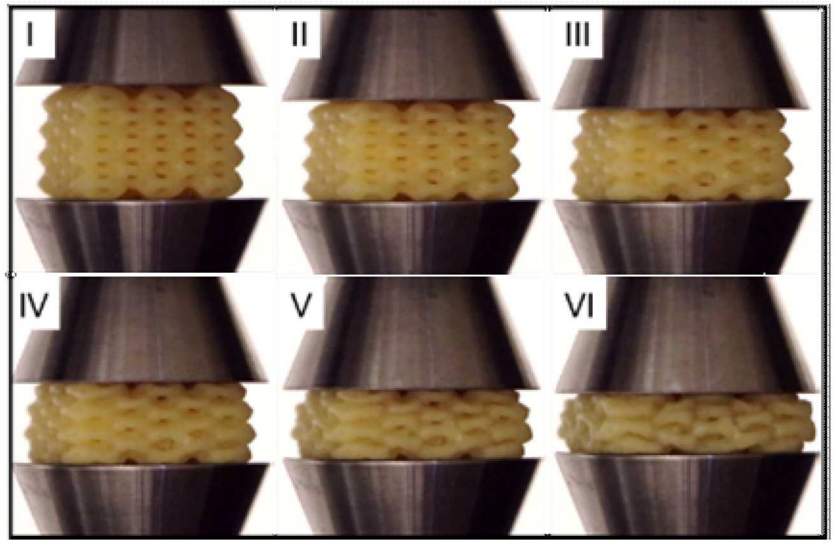
Z: Connectivity

Bending dominated

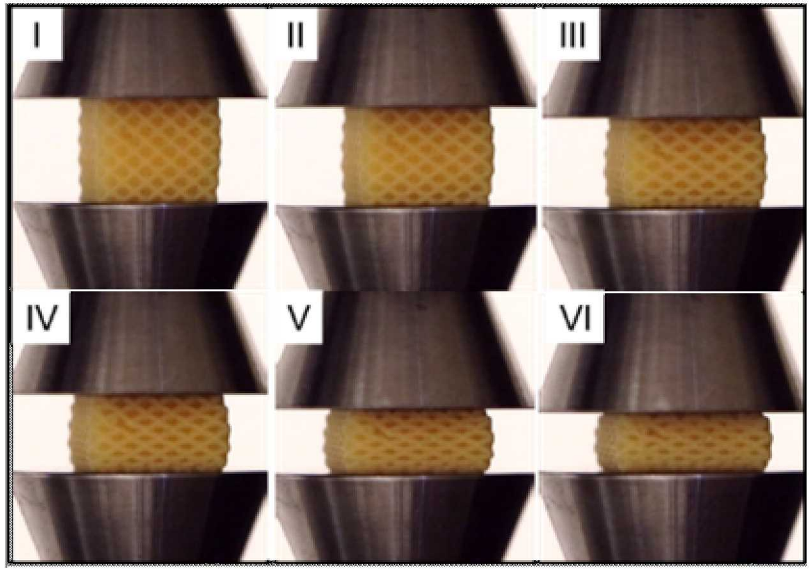
Stretching dominated







Z=4



Z=12

A stretching-dominated LCE lattice foam is more likely to develop a higher axial strain in each strut, which enhances the network phase transition and energy dissipation properties.

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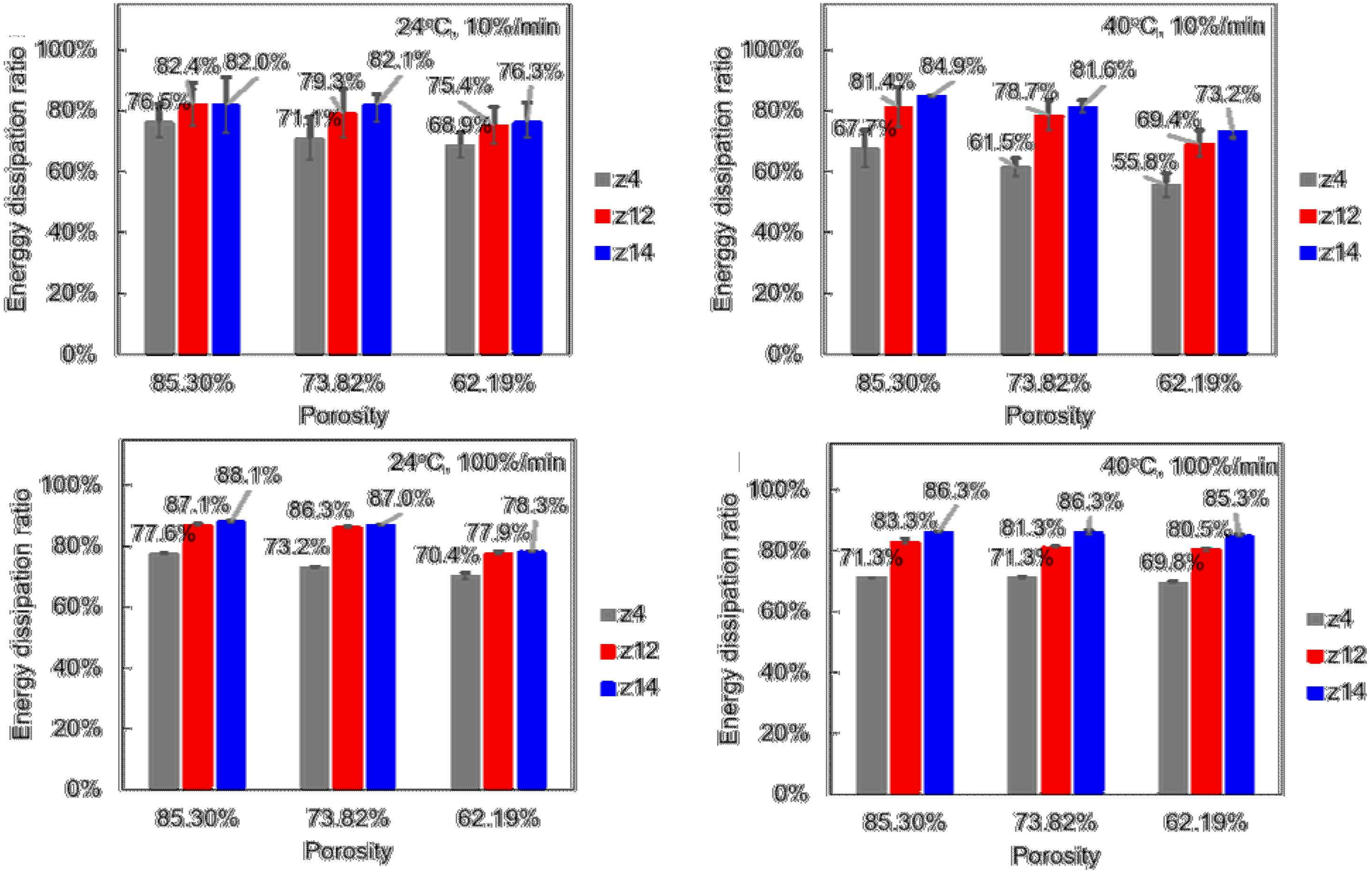
3.5 Enhanced energy dissipation by tailoring geometries of unit cell



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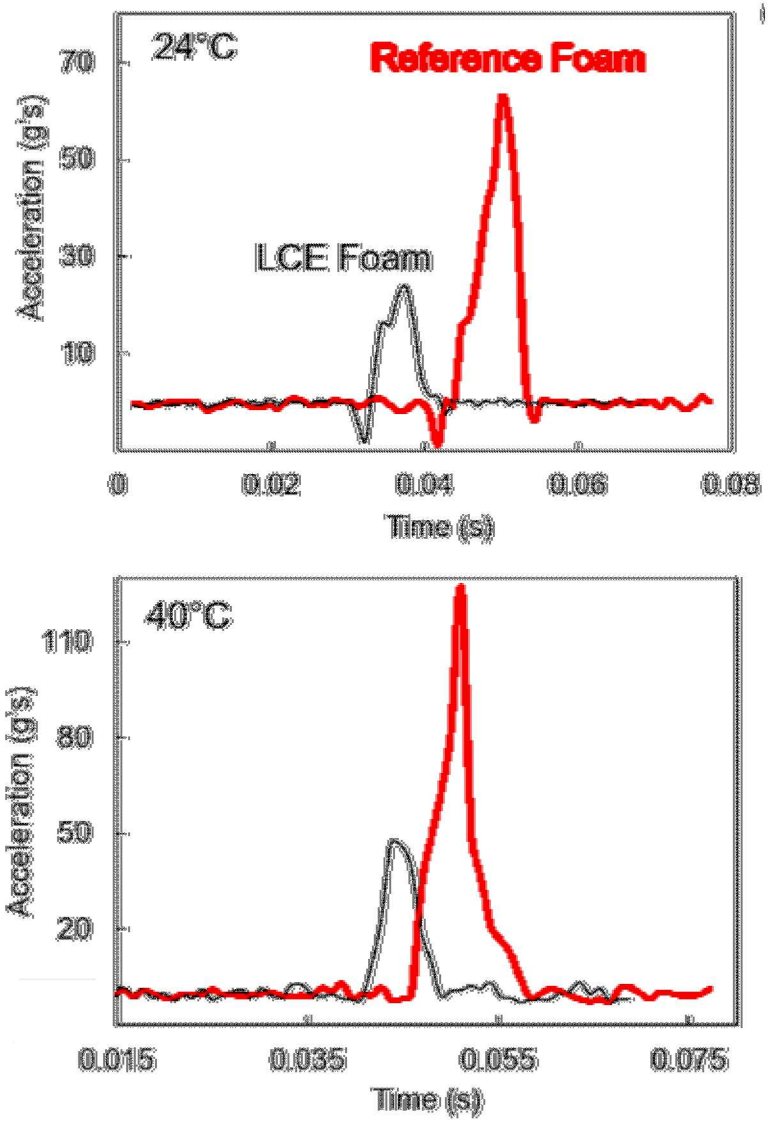
3.7 Energy dissipation of LCEs in drop tests



- An egg was dropped from a 50cm height.
- Loading rate at the initial contact is ~6260%/s

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4. Conclusion

- In this work, we investigate a novel approach to enhance the energy dissipation of polymer foams through controlling the geometry of unit cell and mechanical properties of matrix materials.
- The printed LCE foams exhibit enhanced energy dissipation ratio due to the mesogen rotation at large deformation, which provides a second dissipation mechanism in addition to the viscoelastic relaxation of polymer chains.
- Due to the same reason, the LCE foams maintain almost the same level of dissipation capability with moderate temperature changes, while their reference counterparts behave like elastic solids without notable dissipation.
- By tailoring the connectivity of unit cells to promote the local deformation of the LCE foam, the mechanically-induced phase transition and mesogen rotation of LCE is enhanced, which is shown to further increase the foam energy dissipation at different loading rates.
- The LCE foams also demonstrate a good dissipation capability during the repeated loading or at a dynamic loading condition.

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Sandia National Laboratories

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