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Coulombic Metamaterial

PRESENTED BY

Anthony Garland

Sandia National Labs, USA

Center for Integrated Nanotechnologies — CINT — Discovery · Performance · Education · Integration · Sandia · Los Alamos

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Overview

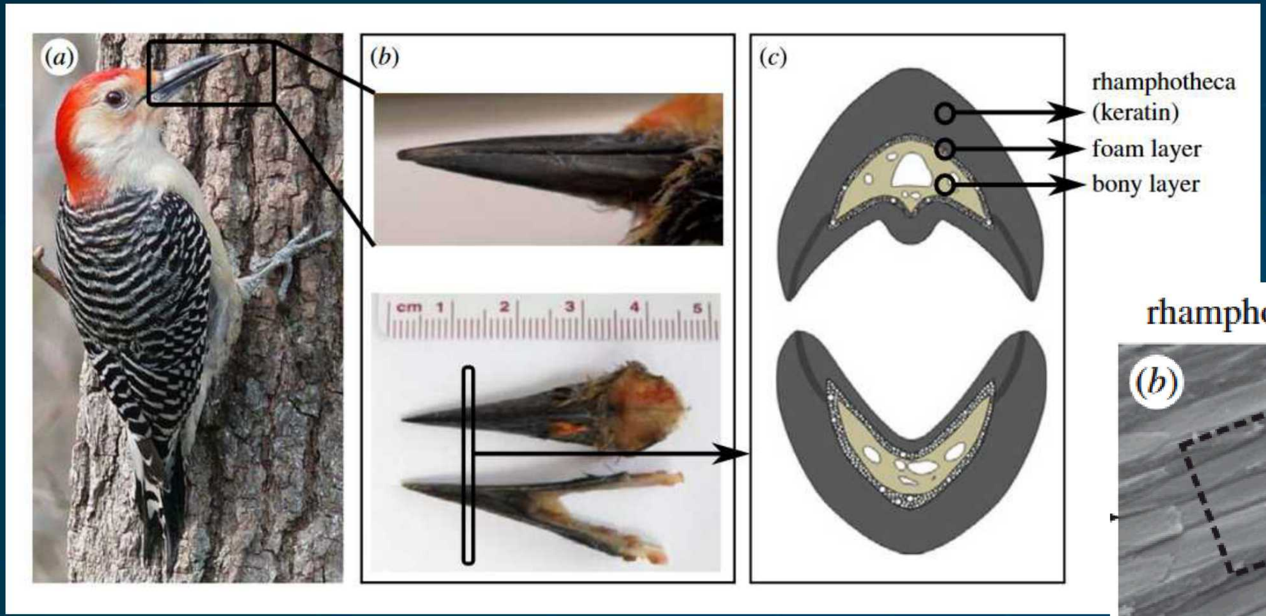
Motivation

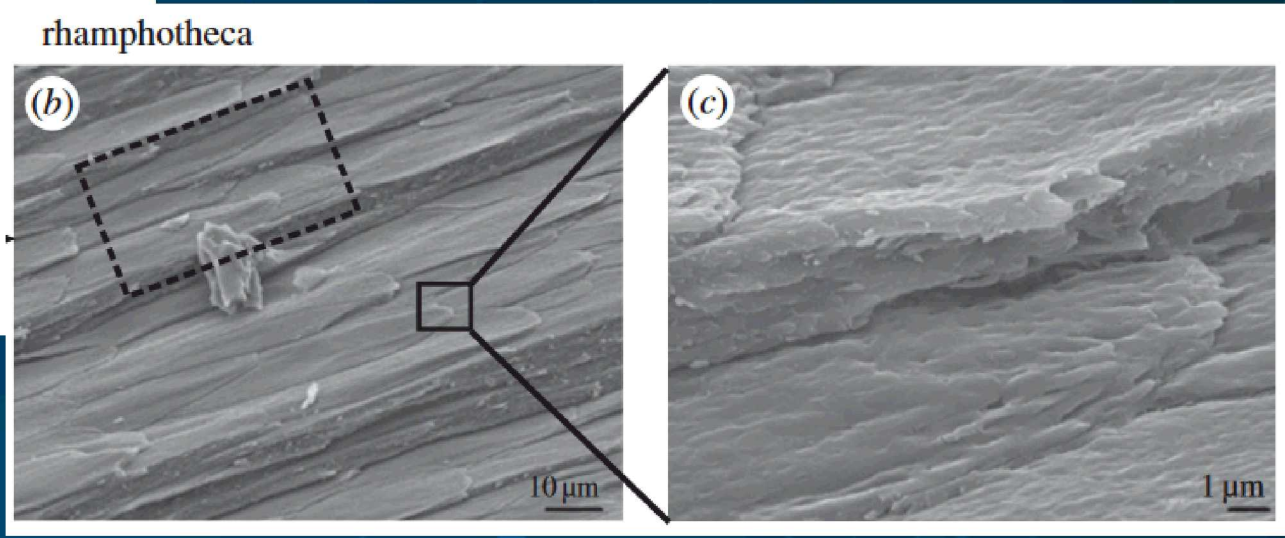
Design and Testing

Results and Interpretation

Extension to other designs and Conclusion

Motivation





Lee, N., et al., *Hierarchical multiscale structure-property relationships of the red-bellied woodpecker (Melanerpes carolinus) beak*. 2014. **11**(96): p. 20140274.

Goals

Objective

Create a metamaterial that can dissipate repeated mechanical energy input.

Questions to answer

What is the effect of adding a friction element into a metamaterial?

How does the constitutive material affect energy dissipation?

Do scaling laws exists?

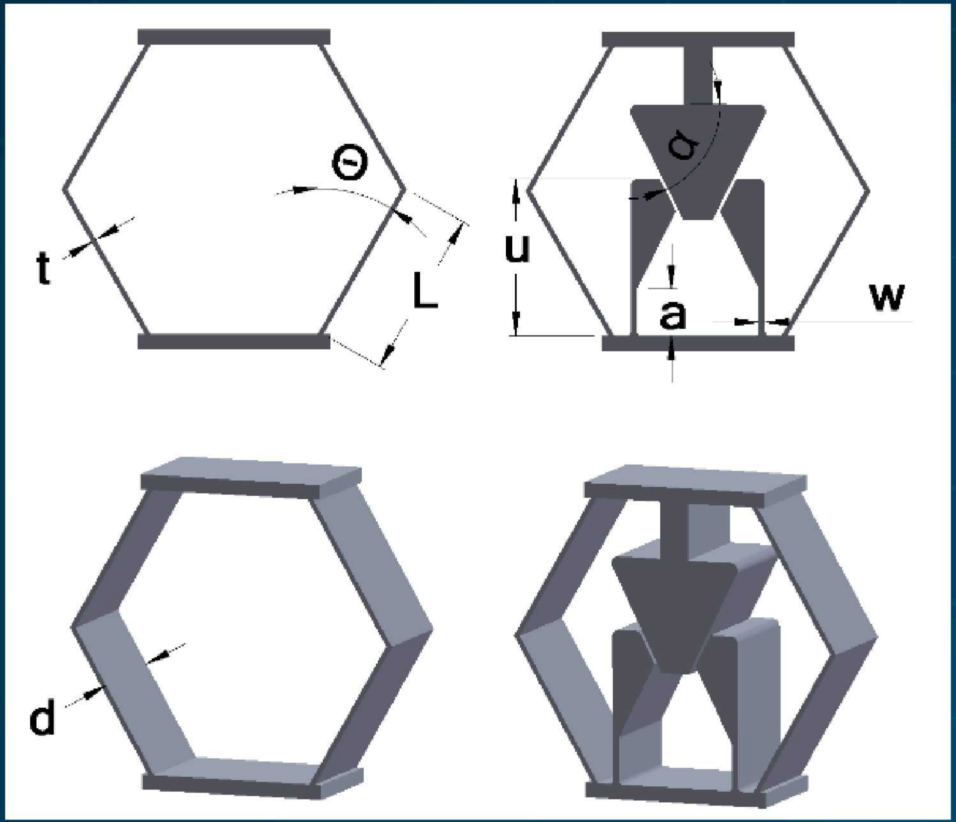
Measures of success

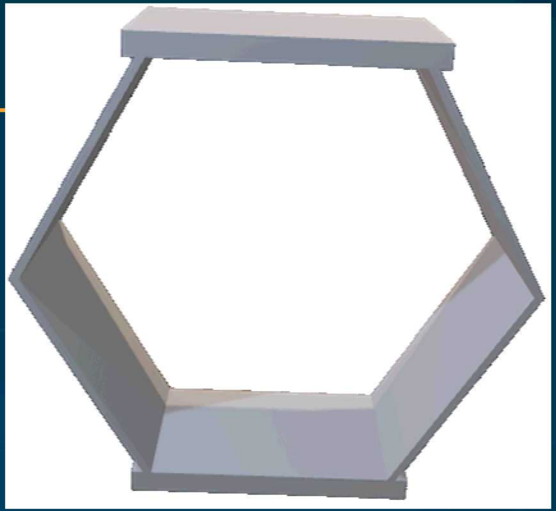
High energy dissipation to volume ratios are preferred

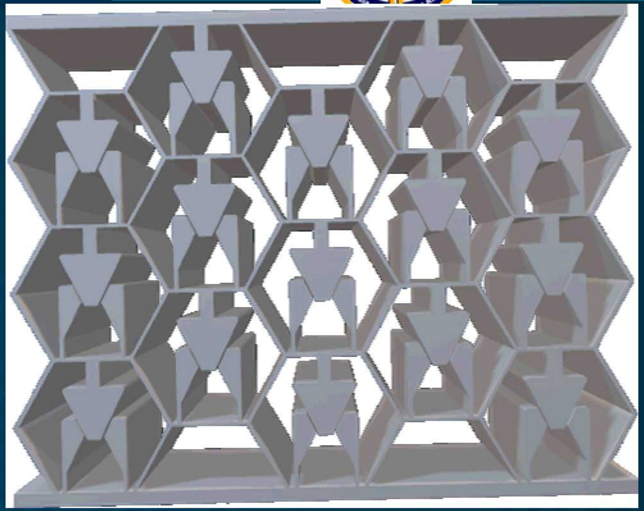
Minimize non-repeatable effects during loading (eg. Plastic deformation)

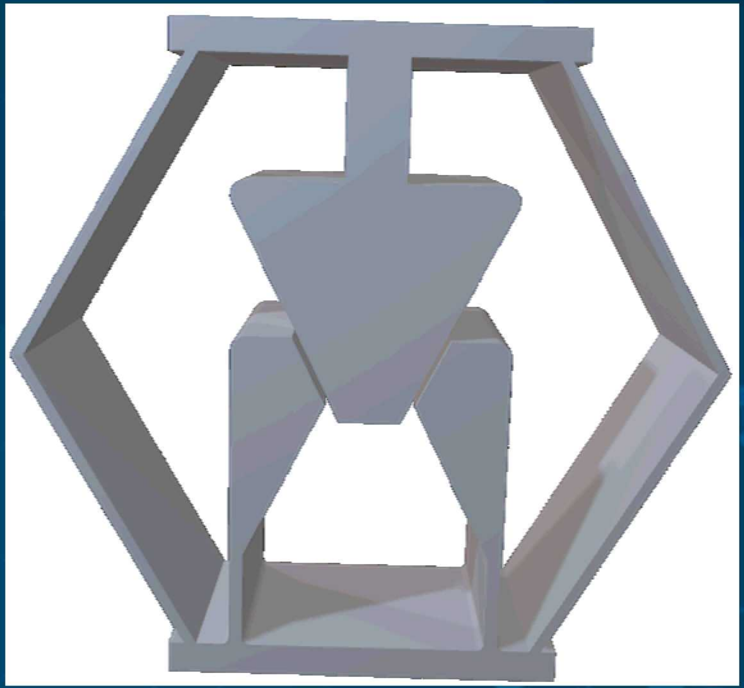
Maximize energy dissipation per unit of elastic energy storage during loading

Design





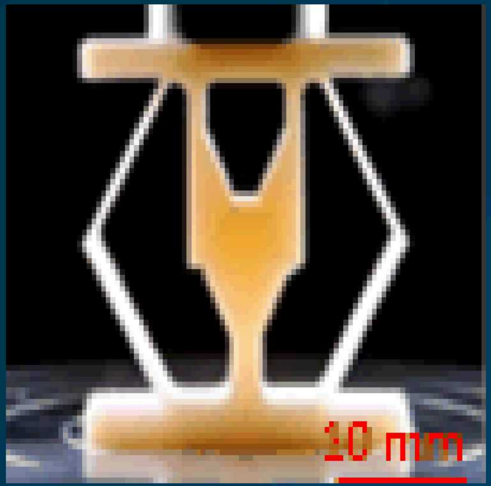




Fabrication

Fabricated unit cells in 3 different materials.

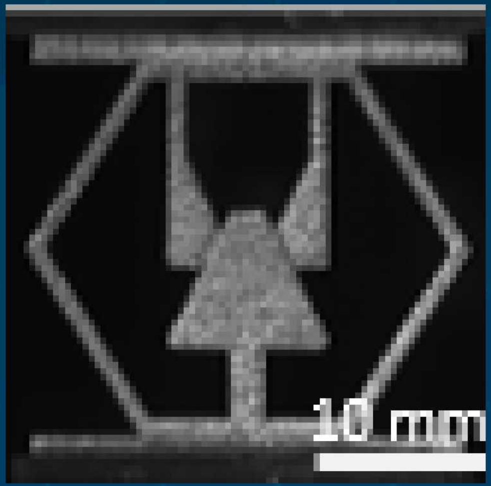
2 Different scales



Polymer

Material Jetting

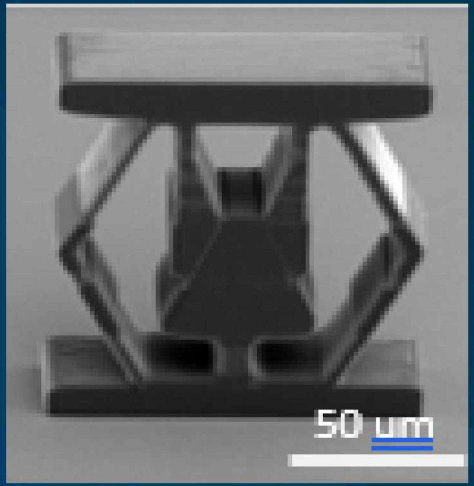
VeraWhite on an Objet 3d Printer



316L

Powder Bed Fusion

3D Systems ProX 200



Polymer

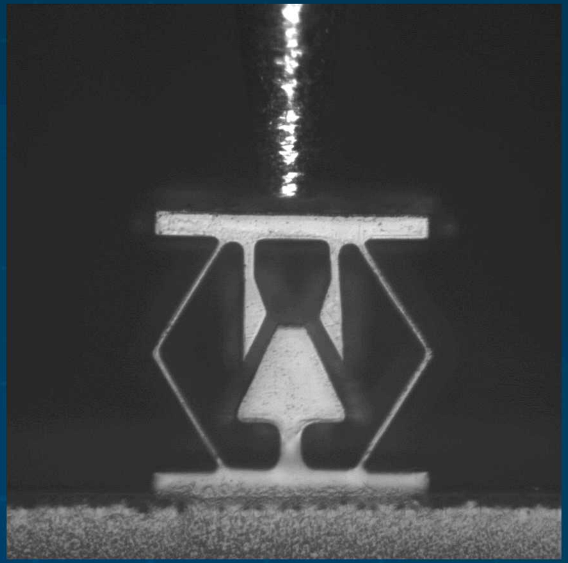
Two photon lithography

Nanoscribe Photonic Professional GT

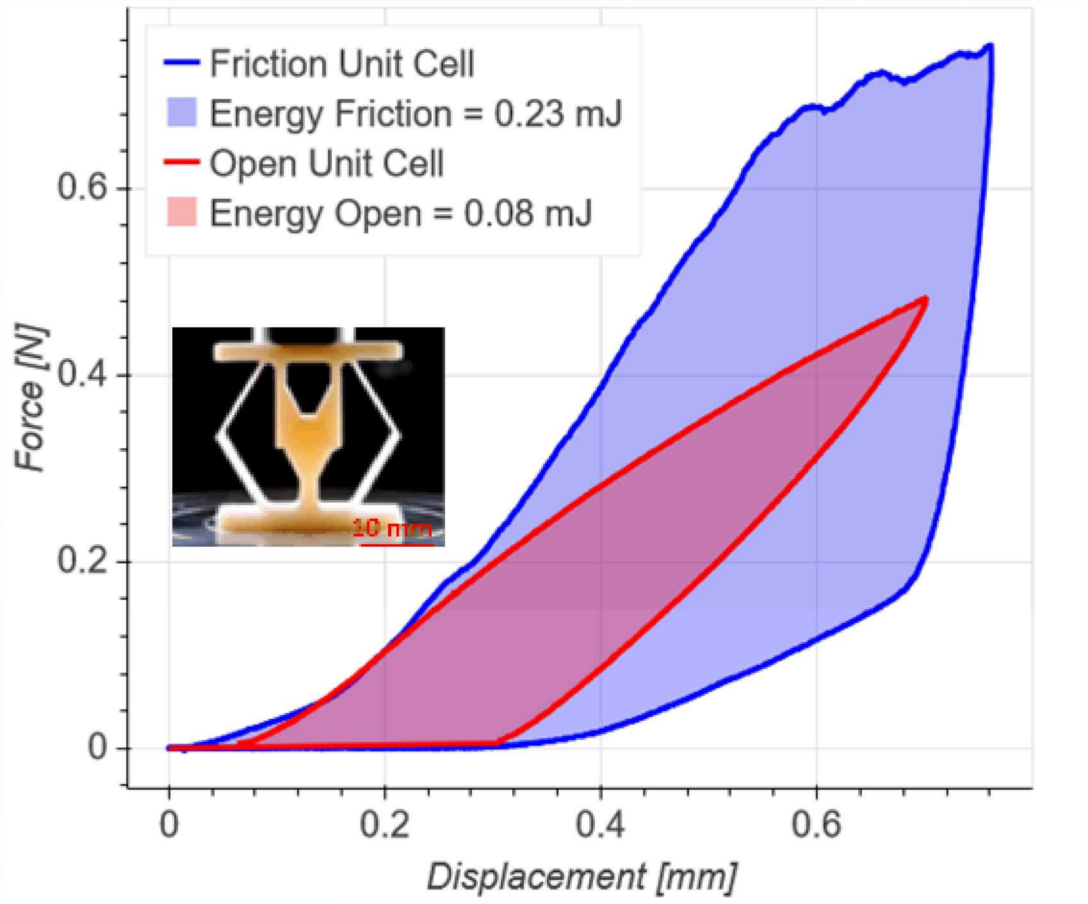
Testing

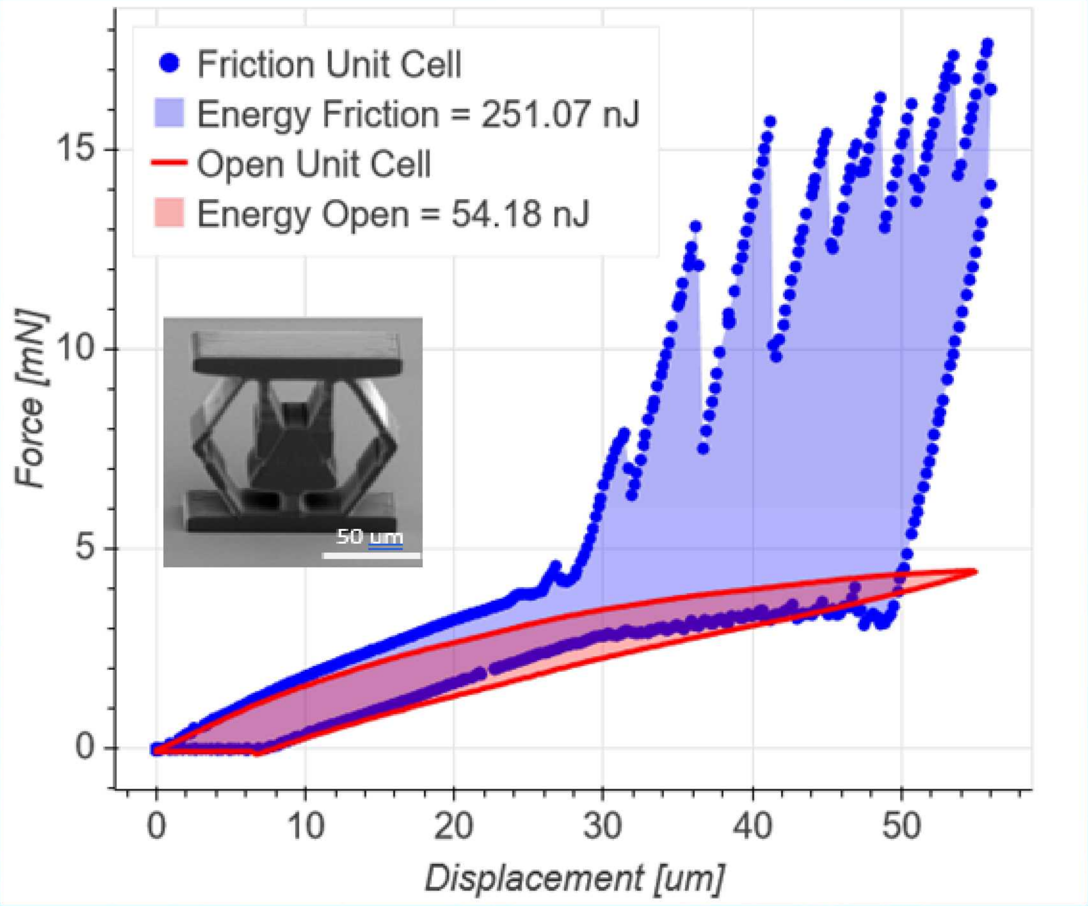
- Challenges
  - Preventing the gap between the surfaces from fusing during printing
  - Straining the unit cell sufficiently to engage the surfaces but not damage the cell.

Testing
  - Load and Unload single unit cell (both friction and open)
  - Cycle loaded the metal unit cell



Results Polymers

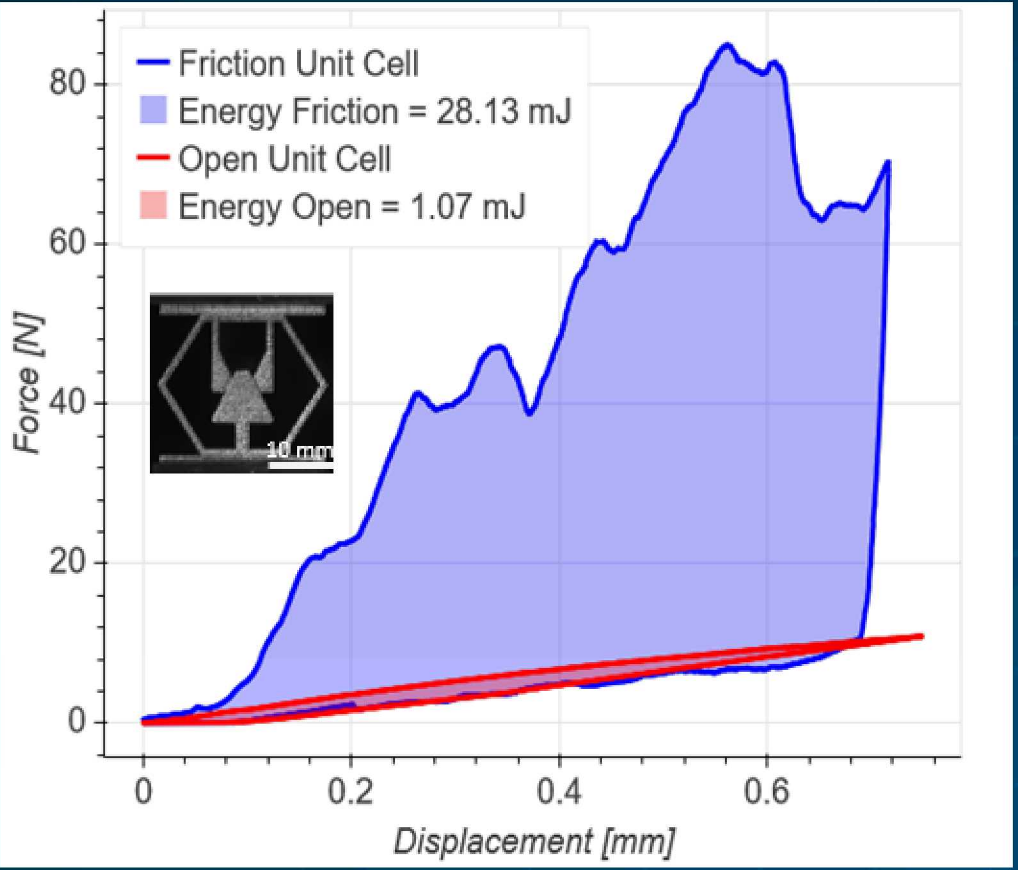


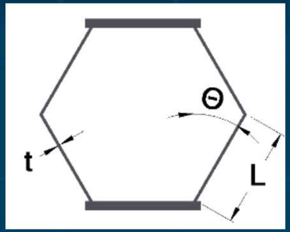


Metal

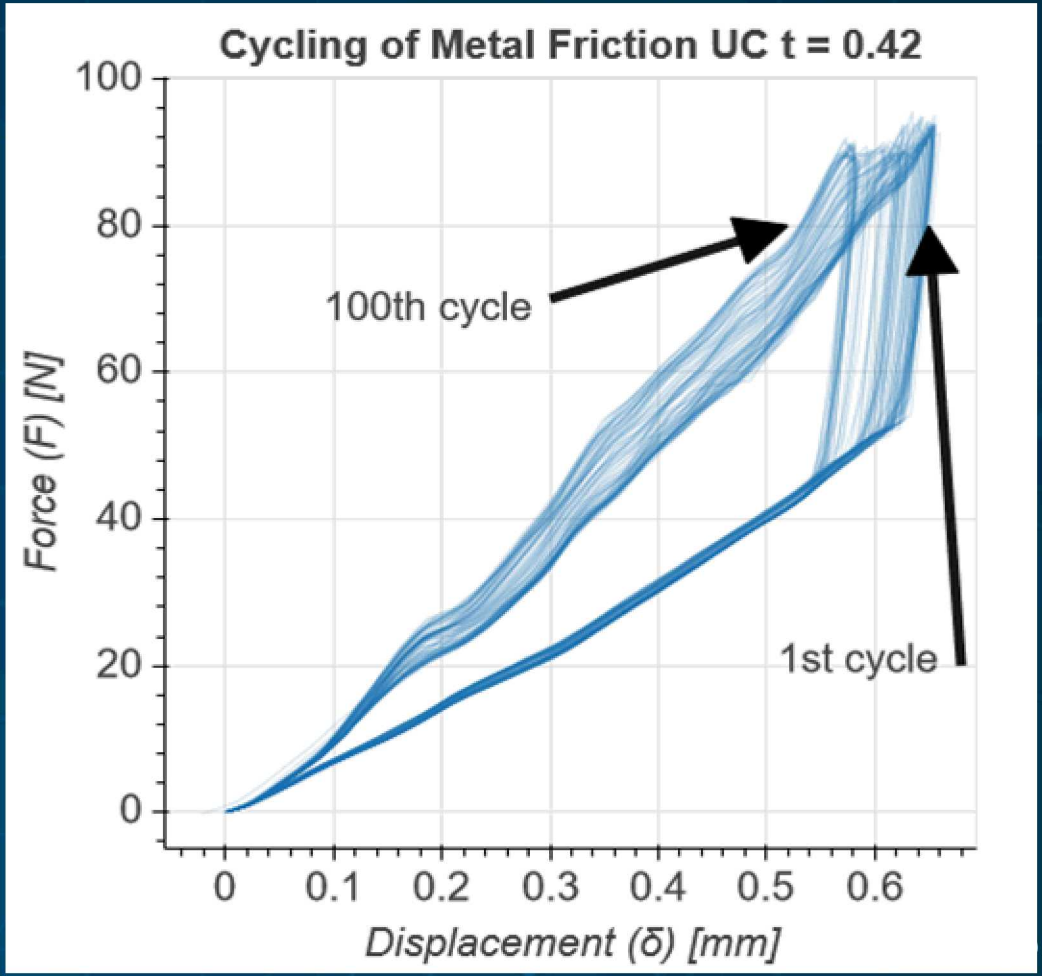
Single Cycle

$t = 0.35$

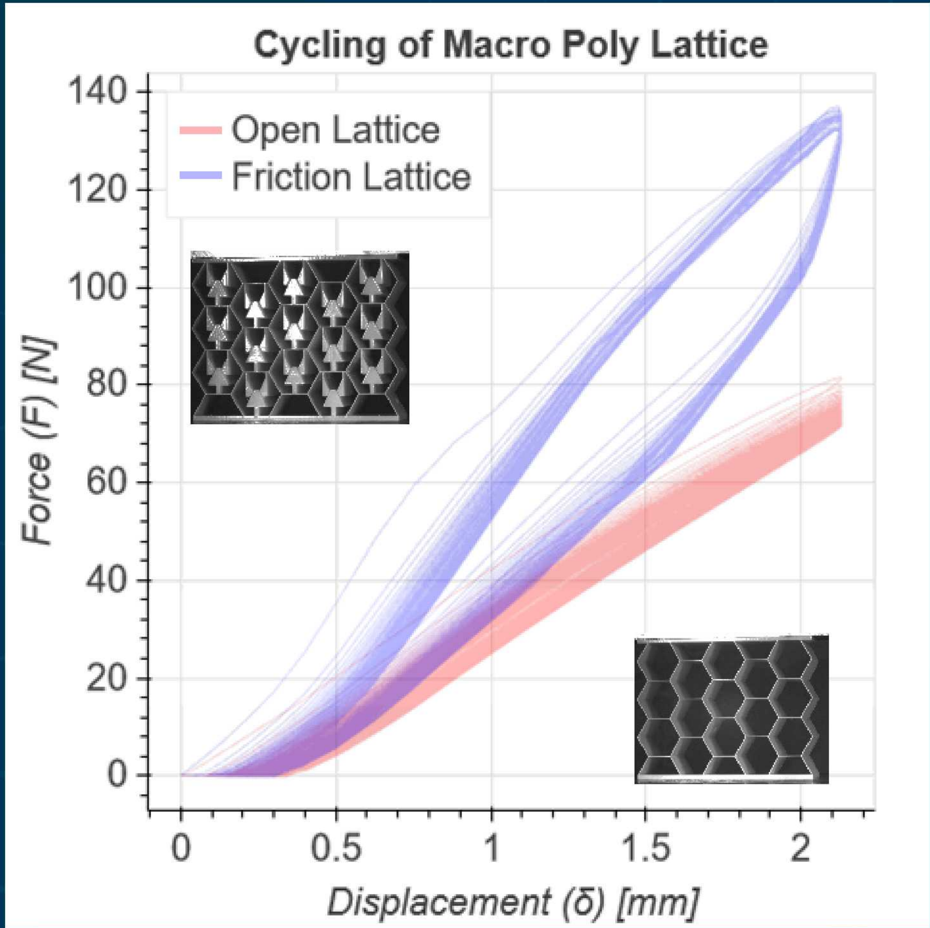


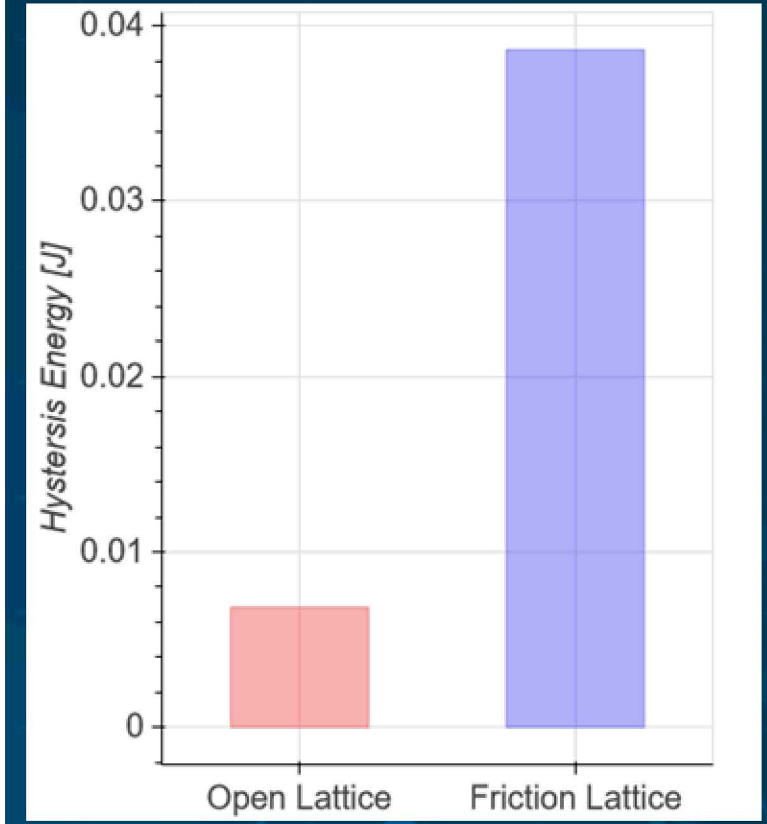


100 Cycles



Metamaterial cyclical loading





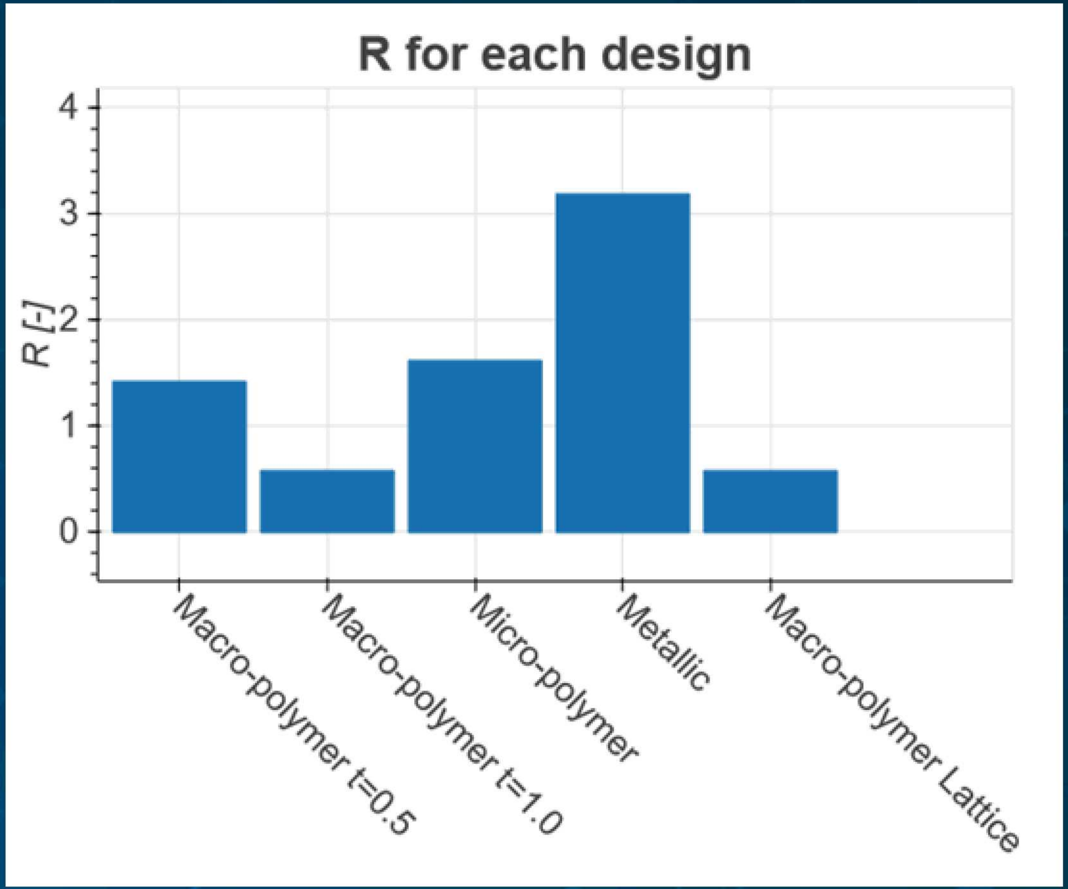
Metrics (1)

$$R = \frac{E_{FrictionCell}}{W_{OpenCell}}$$

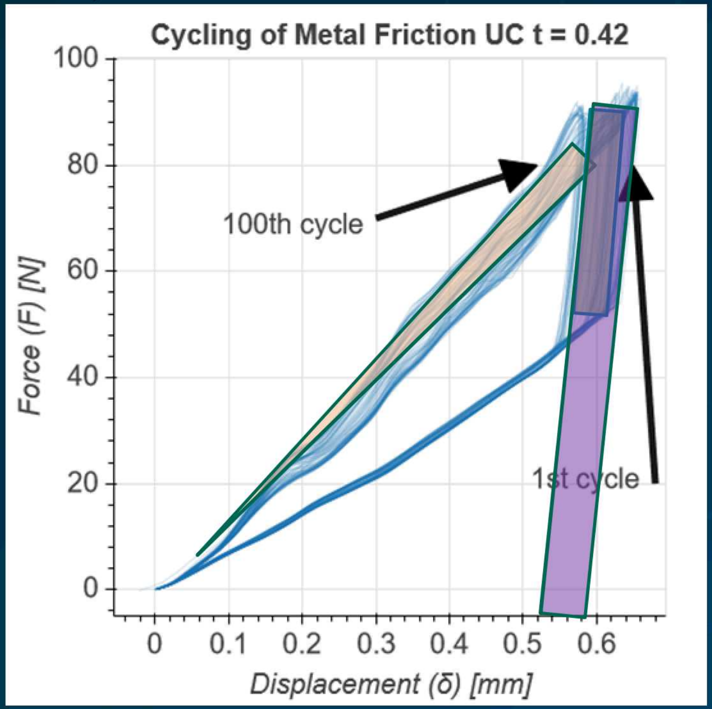
$E_{FrictionCell}$ is energy lost to friction

$W_{OpenCell}$ is the energy required to load the open cell.

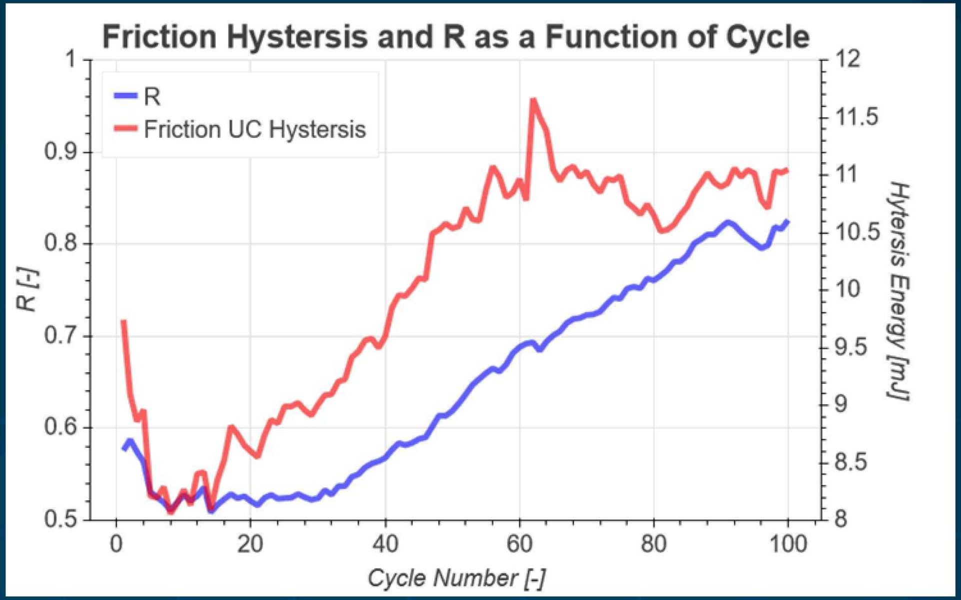
R tell us how much energy is dissipated per energy to load the unit cell.



a)



b)



$$R = \frac{E_{FrictionCell}}{W_{OpenCell}}$$

$E_{FrictionCell}$ increased

$W_{OpenCell}$ decreased

Therefore R increased

The unit cell strain hardens and becomes stiffer.

ie. Slope becomes greater

>

<

More Frictional Energy

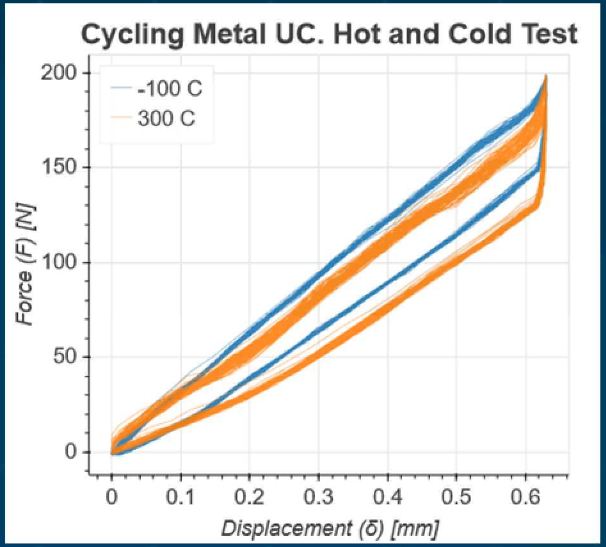
Decrease in work required to load unit cell

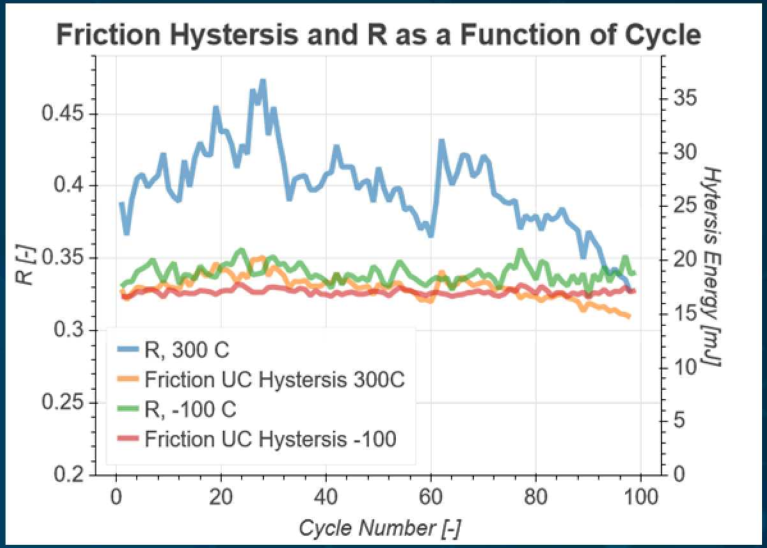
Extreme temperature Test

Other materials absorb energy as well (like rubber)

These materials are limited in their operational range.

Cycled the metal unit cell at -100C and 300C





Metrics (2)

Different materials and different strains were used. So, we need a metric which takes these into account.

$$\gamma = \frac{E_{FrictionCell} - E_{OpenCell}}{V\epsilon^2}$$

$E_{FrictionCell}$ is energy lost to friction

$E_{OpenCell}$ is the energy lost while loading of the open cell

V is volume

ϵ is strain

γ tell us how much energy is dissipated per unit volume

Analytical model of γ

Assuming linear elastic properties

Derive γ in 15 steps, you get

$$\gamma = \frac{\sqrt{3} E I_{mult} \epsilon^2 w^3 (2L\cos(\theta) + t)^2 \left(\frac{2\mu}{\sin(2\alpha)} + \frac{1}{\tan(\alpha)}\right)}{9L^2 (I_{mult} a^3 - a^3 + u^3) \tan(\alpha)}$$

Reduces to

$$\gamma = Z_c E_{mod}$$

Shape and friction coefficient

Elastic Modulus

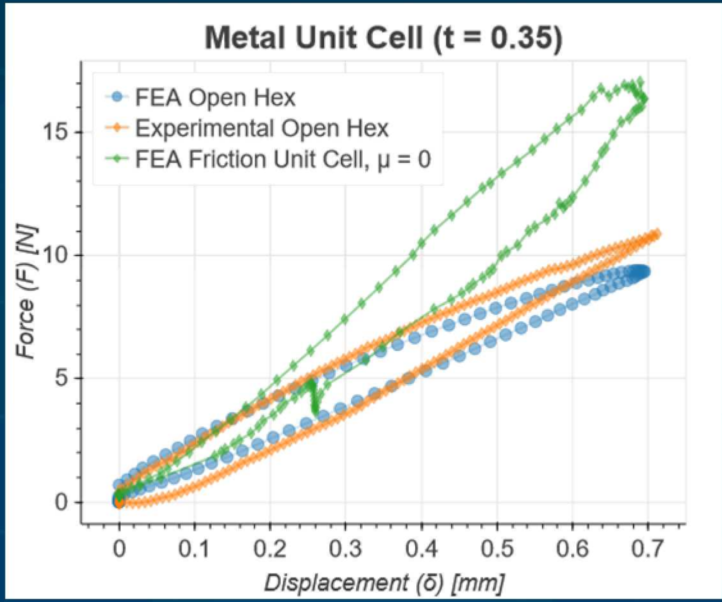
Tradeoffs in design

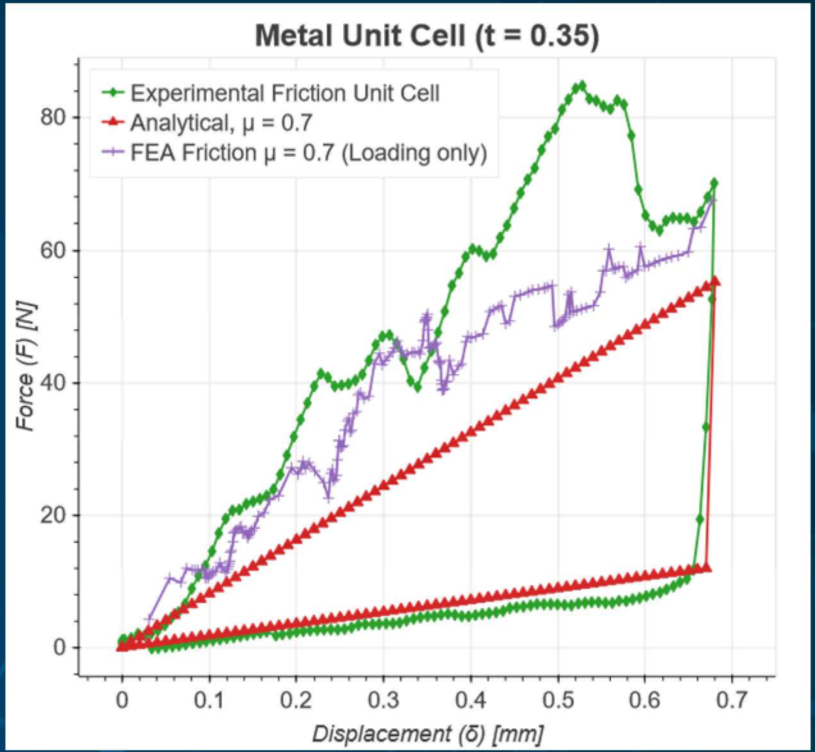
Zero plastic deformation

Minimal energy stored elastic energy

High frictional energy dissipation

FEA used to model the plastic deformation, and frictional energy.

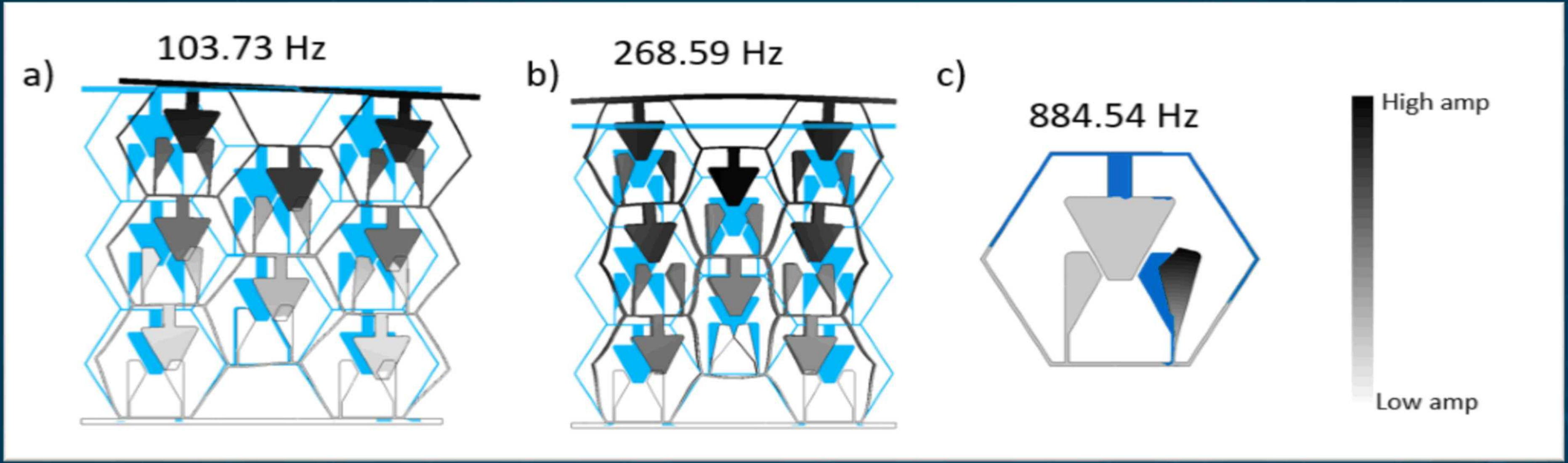




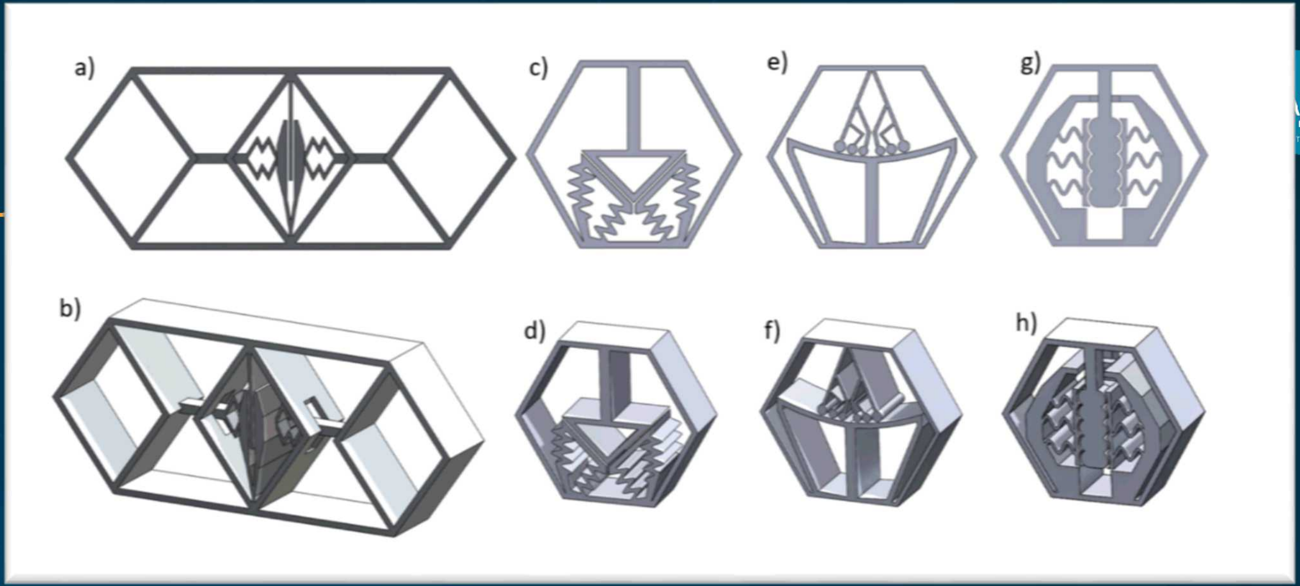
Potential Application: Vibration Absorber

Dissipating energy at the resonant frequency of some object.

Will the internal vibration modes of the legs cause them to hit the middle arrow rather than slide to dissipate energy?



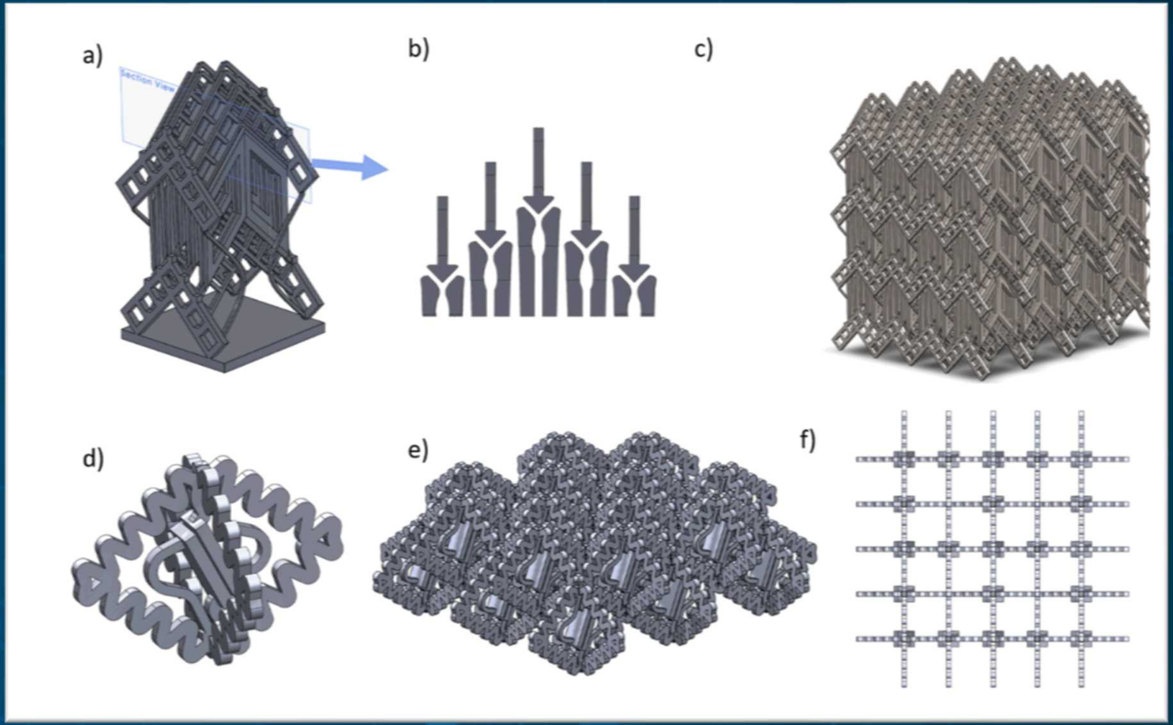
Conclusion



Columbic metamaterials show potential to dissipate mechanical energy in a wide variety of environments.

The designs can be customized for an particular application

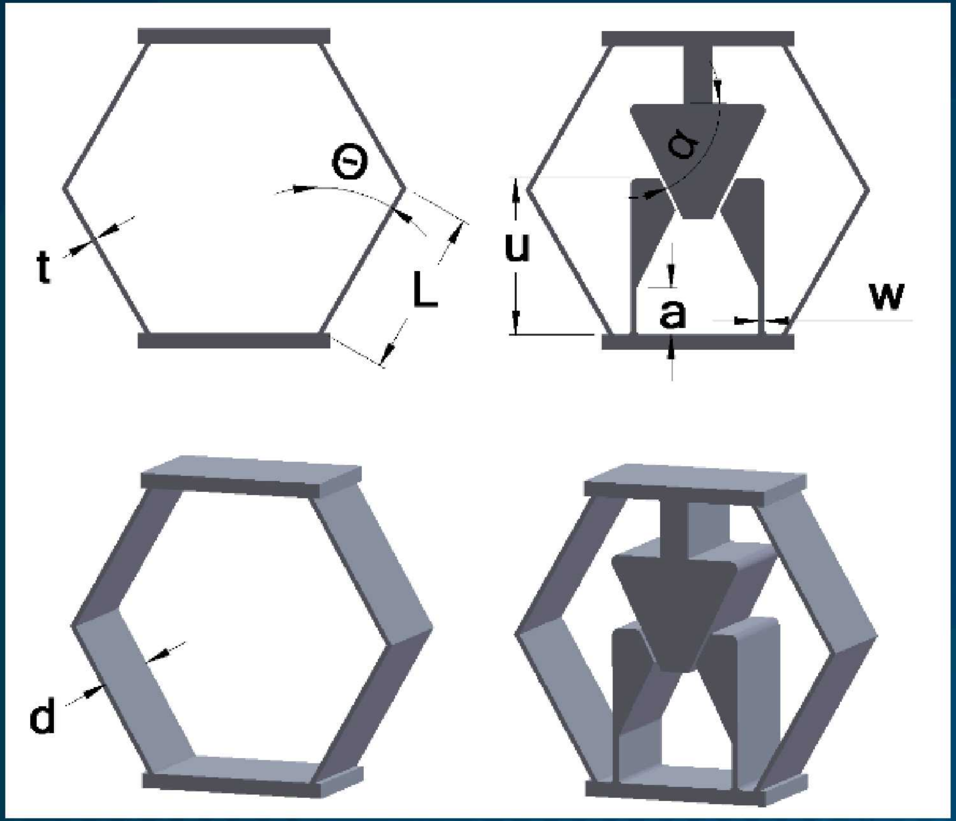
- Size
- Material
- Topology
- Shape



Questions

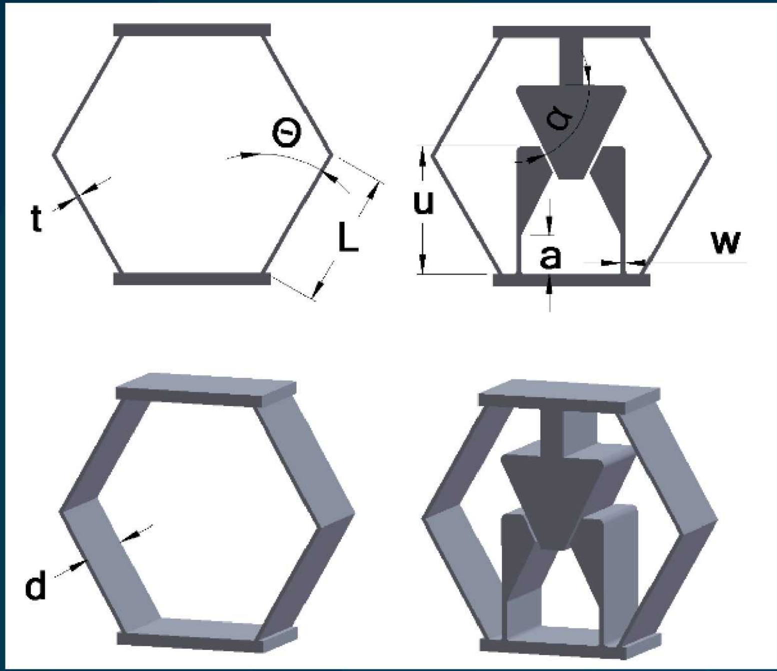
Backup slides

Table 1 (dimensions)



Material	Dimensions							
	t (mm)	L (mm)	a (mm)	Θ (degrees)	w (mm)	u (mm)	α (degrees)	d (mm)
Macro-polymer	0.5	11.55	2.92	30	0.45	10.85	63.43	8
	1	11.55	2.92	30	0.45	10.85	63.43	8
Micro-polymer	0.01	0.14	0.035	30	0.0125	0.136	63.43	0.1
Metallic	0.35	11.55	2.92	30	0.45	10.85	63.43	8
	Lattice With 15 Unit Cells							
Macro-polymer Lattice	0.5	11.55	2.92	30	0.45	10.85	63.43	8

Table 2 (Results)



Material	Side Wall Width, t (mm)	Hex Edged Length, L (mm)	Hex Depth, d (mm)	Unit Cell Volume, V (mm^3)	Energy Dissipated in Friction Unit Cell (mJ)	Dissipation Factor, R (-)	Specific Energy from Frictional Element, γ (Pa)
Macro-polymer	0.50	11.55	8	2946	0.23	1.421	4.173E+04
	1.0	11.55	8	2946	0.76	0.581	9.783E+04
Micro-polymer	0.01	0.14	0.1	0.0051	0.00025	1.619	5.150E+05
Metallic	0.35	11.55	8	2946	14.2	3.189	5.157E+06
15-Cell Macro-polymer Lattice[a]							
Macro-polymer Lattice	0.50	11.55	32	11784	2.57[a]	0.580[a]	2.998E+06[a]