Thermally actuated composite helical lattices

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Overview of Presentation

Discussion Outline

1. Background and Motivation.
2. Helical Lattice.
3. Coupled Lattice Systems - Pseudo-ductility/non-linear tuning.
4. Thermally dependent behaviour.
5. Ongoing work/prototype.

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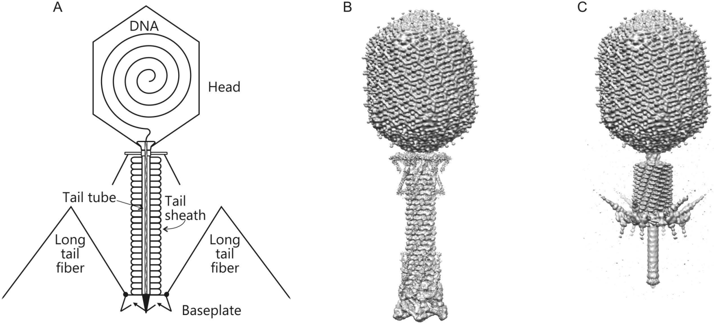
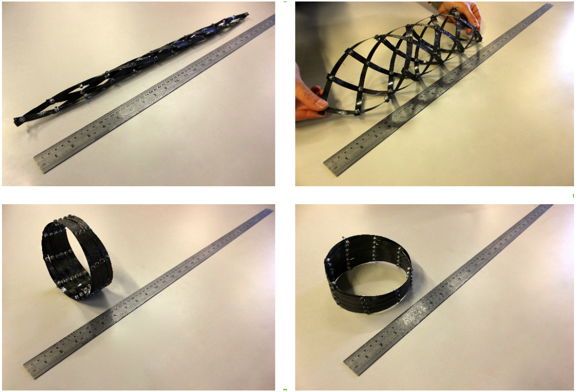
Biological Inspiration

Inspiration came from the study of Bacteriophage T4 virus.



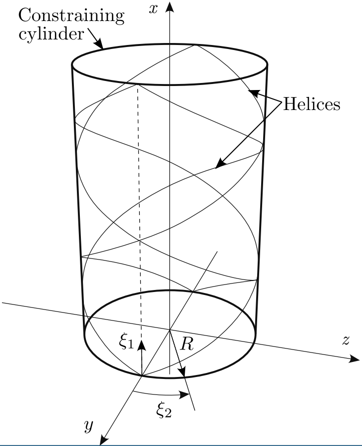
(a) Schematic representation and model of Bacteriophage T4 prior to (b) and upon (c) host cell attachment. [Leiman *et. al*. (2010)]

A Helical Lattice



A helical lattice balancing effects of pre-stress, material properties and geometry, was constructed [Pirrera *et. al.* (2013)]

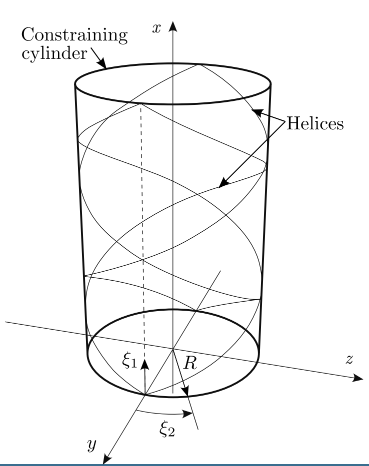
Kinematics and Elasticity

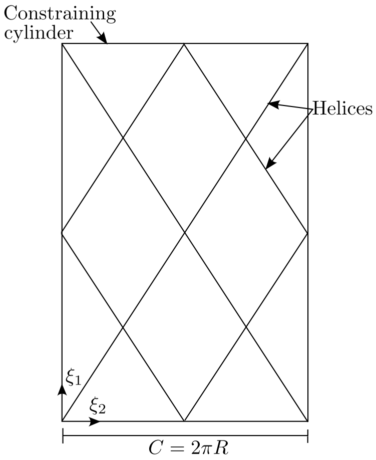


Assumptions

- Lattice lies on the surface of a cylinder - height and radius can change.
- Lattice strips assumed in-extensional.
- Hinged at points of intersection - point at which they overlap does not change, but they can translate/rotate together.

Kinematics and Elasticity

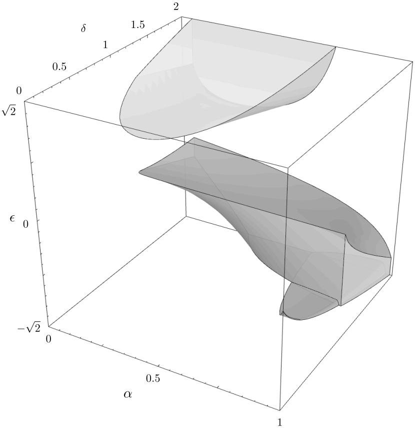




Kinematics and Elasticity

What was observed?

- Robust multi-stability.
- Neutral stability.
- Tailorable non-linear elastic responses.



How can we exploit this behaviour?

Micro-braided lattices?

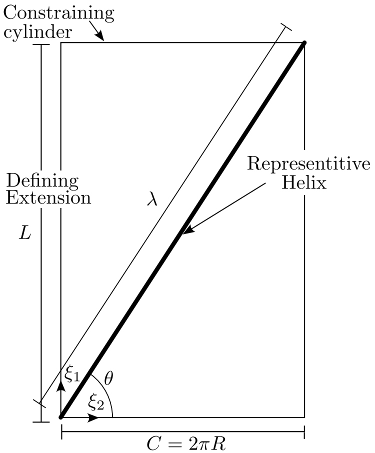
"**Can tailored non-linearity of hierarchical structures inform future material development?"** [O'Donnell *et. al.* (2016)]

- What happens if we couple the lattice with elastic restraints?
- Could we capture behaviour at different length scales?
- Can we get the system to do something new/"useful"?

Back to the unit cell

Simplest Representation

- Common lattice pitch angle.
- Mirror symmetric stiffness.
- Axial and circumferential springs.



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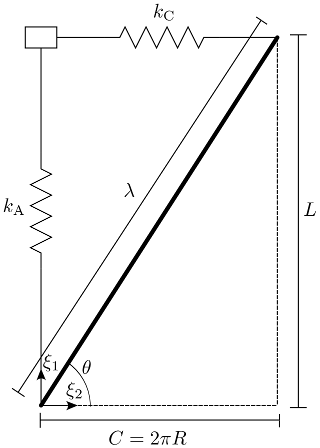
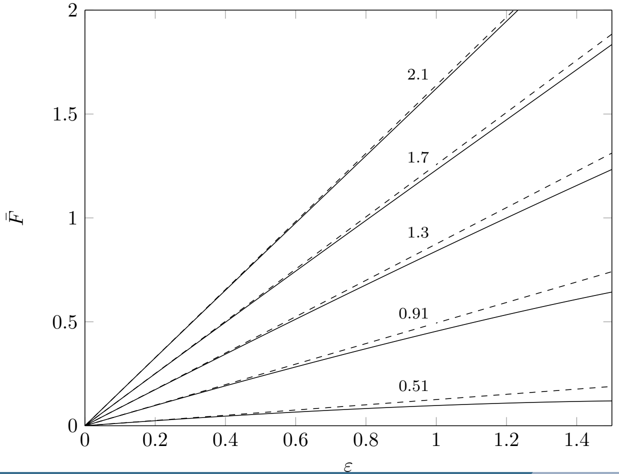


Pseudo-Ductility



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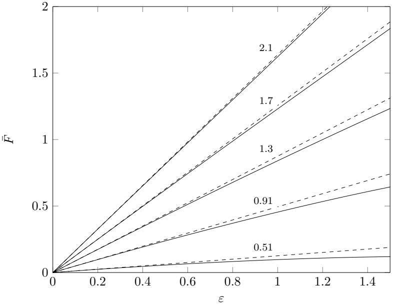
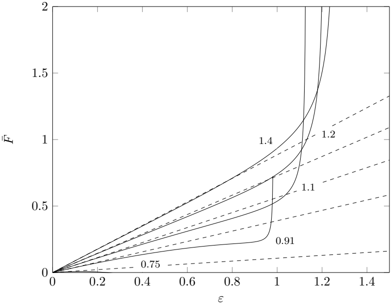
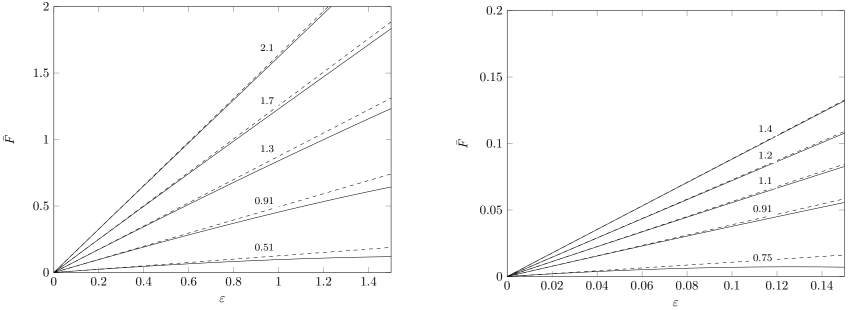




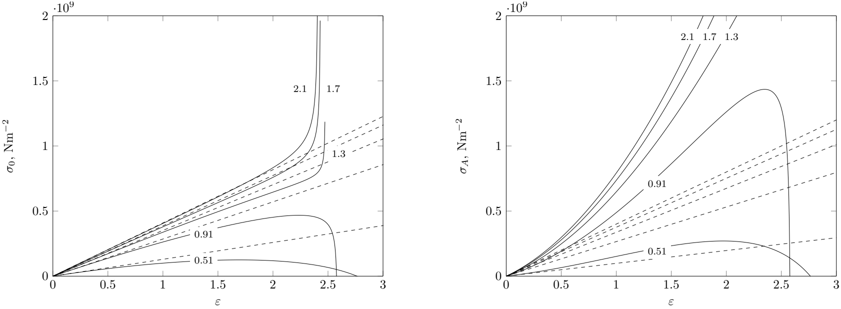
The ratio of the springs to lattice stiffness governs behaviour.

Pseudo-Ductility



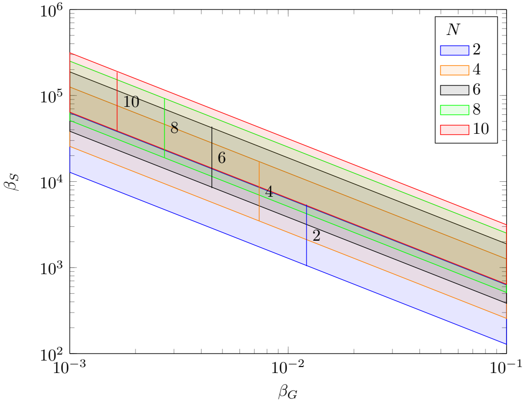
The ratio of the springs to lattice stiffness governs behaviour.

Stress-Strain



Effective area definition is important.

Robustness



Pseudo-Ductility is observed over for a range of configurations.

General behaviour

For non-rotating lattices, the non-dimensional energy may be written as a function of axial extension $\bar{h}$,

$$\Pi = a_0 + a_1\bar{h} + a_2\bar{h}^2 + b_1\sqrt{1-\bar{h}^2} + b_2\bar{h}\sqrt{1-\bar{h}^2} \qquad (1)$$

where the coefficients, $a_{1,2,3}$ and $b_{1,2}$ can be tuned to obtain desirable responses.

In particular, coefficients a_0, a_1, and b_1 are functions of curvature. This can be exploited to permit thermal actuation.

Thermal curvatures

Mismatch in the coefficients of expansion causes a laminate to warp during heating/cooling. These curvature can be predicted using Classical Laminate Theory [Mansfield (2005)]

$$\boldsymbol{\kappa}^{\mathsf{Th}}(T) = \Delta T \mathbf{d}^{-1} \left(\mathbf{M}^{\mathsf{Th}} - \mathbf{B}\mathbf{A}^{-1}\mathbf{N}^{\mathsf{Th}} \right) \tag{2}$$

with $\mathbf{A}$, $\mathbf{B}$, and $\mathbf{d}$ taking their usual definitions.

A thermally dependent strip pre-stress can be defined as.

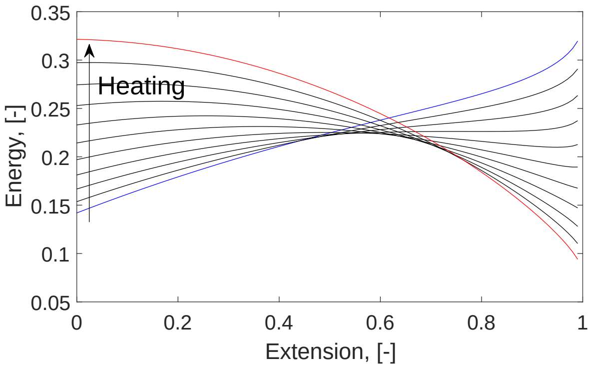
$$\boldsymbol{\chi} = \boldsymbol{\kappa}^{\mathsf{Th}}(T) + \boldsymbol{\kappa}_0 \tag{3}$$

with $\boldsymbol{\kappa}_0$ the mechanical (tooling) pre-curvature.

Desirable Responses

The system can be tuned to snap through at a critical temperature

Heating the lattice from cold state



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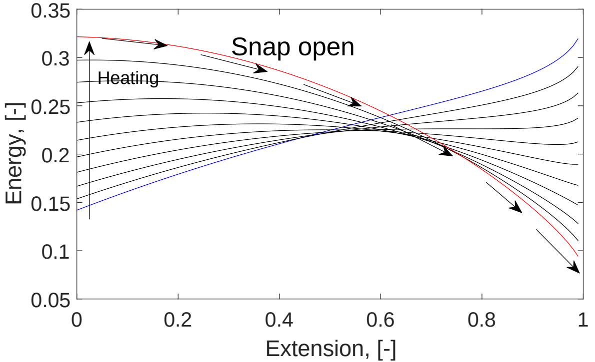
Snap open at critical temperature



Desirable Responses

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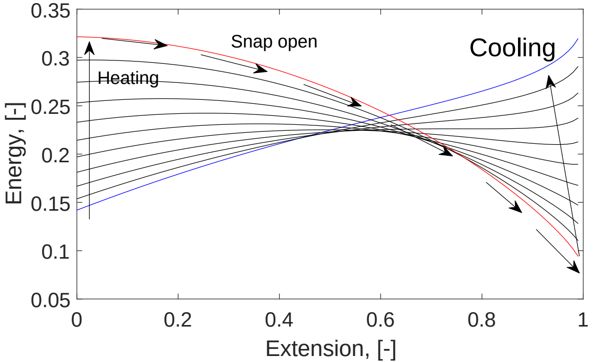
Cooling lattice from hot state



Desirable Responses

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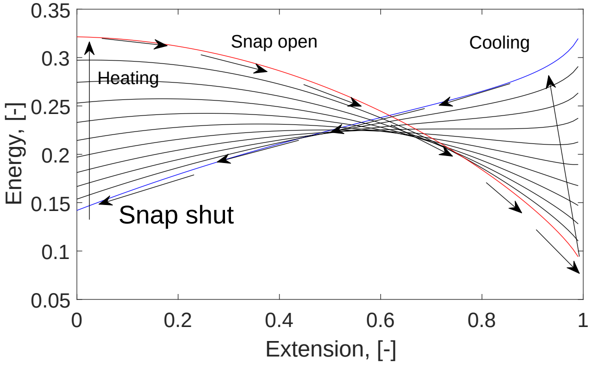
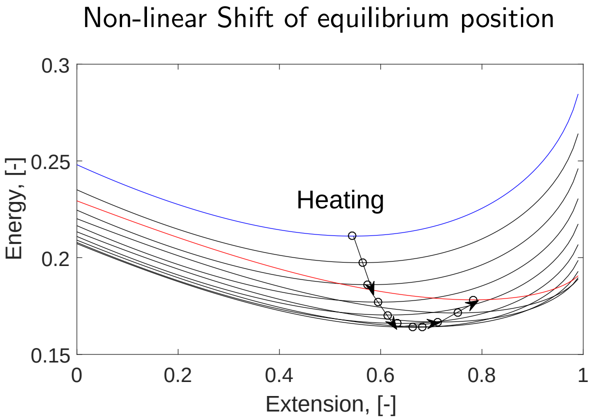
Snap shut at critical temperature

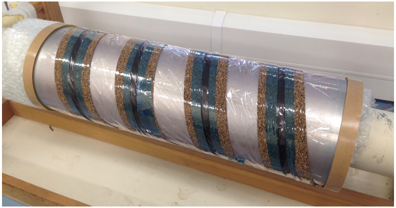


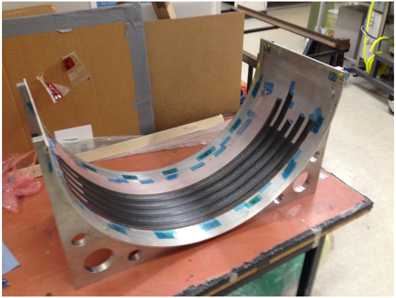
Desirable Responses

Or produce a non-linear variation in equilibrium position



Can we make one?





Manufacturing in ACCIS Lab - Tom Watts.

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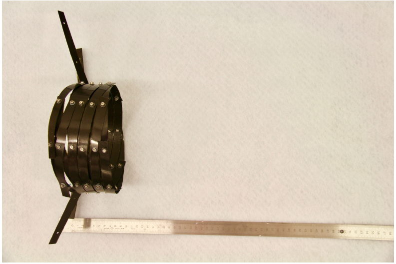
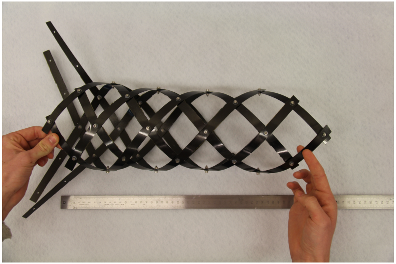
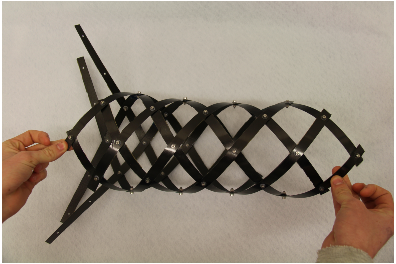


Observed expected bi-stability at room temp.

Can we make one?





Self locking end constraints and friction causing problems.
Snap open actuation, if helped with some initial extension.
Summer intern Nikolay Pilashev building V2.0

Conclusions

Final Remarks

1. Lattice structures offer a robust non-linear design space.
2. Thermal mismatch can be used to modify effective pre-stress.
3. Snap–through and smooth actuation response characteristics can be designed.
4. Promising prototype, but some manufacturing issues to be addressed.

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