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Thermally actuated composite helical lattices

<u>Matthew P. O'Donnell</u>, Tom Watts, Nikolay Pilashev, Alberto Pirrera

7th July 2017 - MECHCOMP 3, Bolgona, Italy

www.bris.ac.uk/composites



Discussion Aims Motivation Background

Overview of Presentation

Discussion Outline

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- Background and Motivation.
- 2 Helical Lattice.
- Oupled Lattice Systems Pseudo-ductility/non-linear tuning.
- Thermally dependent behaviour.
- Ongoing work/prototype.



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Discussion Aims Motivation Background

Biological Inspiration

Multiple Contract Contra

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)]



Introduction

Coupled System Thermal Lattice Response Concluding Remarks Discussion Aim Motivation Background

A Helical Lattice

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



Discussion Aims Motivation Background

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.

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Introduction

Coupled System Thermal Lattice Response Concluding Remarks Discussion Aim Motivation Background

Kinematics and Elasticity



Introduction

Coupled System Thermal Lattice Response Concluding Remarks Discussion Aim Motivation Background

Kinematics and Elasticity

What was observed?

- Robust multi-stability.
- Neutral stability.

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• Tailorable non-linear elastic responses.



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How can we exploit this behaviour?

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Embedded Lattice Energetic Framework New Behaviour

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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"?



Embedded Lattice Energetic Framework New Behaviour

Back to the unit cell



Embedded Lattice Energetic Framework New Behaviour

Back to the unit cell

Simplest Representation

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







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Embedded Lattice Energetic Framework New Behaviour

Pseudo-Ductility



Embedded Lattice Energetic Framework New Behaviour

Pseudo-Ductility

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The ratio of the springs to lattice stiffness governs behaviour.

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Embedded Lattice Energetic Framework New Behaviour

Pseudo-Ductility

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The ratio of the springs to lattice stiffness governs behaviour.

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Embedded Lattice Energetic Framework New Behaviour

Stress-Strain



Effective area definition is important.

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Embedded Lattice Energetic Framework New Behaviour

Robustness

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

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Lattice Energy Thermal Behaviour Making a prototype

General behaviour

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

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

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where the coefficients, $a_{1,2,3} \mbox{ and } b_{1,2}$ 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.

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Lattice Energy Thermal Behaviour Making a prototype

Thermal curvatures

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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)]

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

with $\mathbf{A},\,\mathbf{B},\,\text{and}\;\mathbf{d}$ 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 κ_0 the mechanical (tooling) pre-curvature.

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Lattice Energy Thermal Behaviour Making a prototype

Desirable Responses

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

Heating the lattice from cold state



Lattice Energy Thermal Behaviour Making a prototype

Desirable Responses

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

Snap open at critical temperature



Lattice Energy Thermal Behaviour Making a prototype

Desirable Responses

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

Cooling lattice from hot state



Lattice Energy Thermal Behaviour Making a prototype

Desirable Responses

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

Snap shut at critical temperature



Lattice Energy Thermal Behaviour Making a prototype

Desirable Responses

Or produce a non-linear variation in equilibrium position





Lattice Energy Thermal Behaviour Making a prototype

Can we make one?





Manufacturing in ACCIS Lab - Tom Watts.



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Lattice Energy Thermal Behaviour Making a prototype

Can we make one?





Observed expected bi-stability at room temp.



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Lattice Energy Thermal Behaviour Making a prototype

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



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Comments Questions

Conclusions

Final Remarks

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



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Comments Questions

Thank you

I would like to thank University of Bristol and the EPSRC for financial support of undergraduate research projects.

Any questions?



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