TAILORED SOLID-LIQUID COMPOSITE FOR ENHANCED COMFORT IN ORTHOTIC INSOLES

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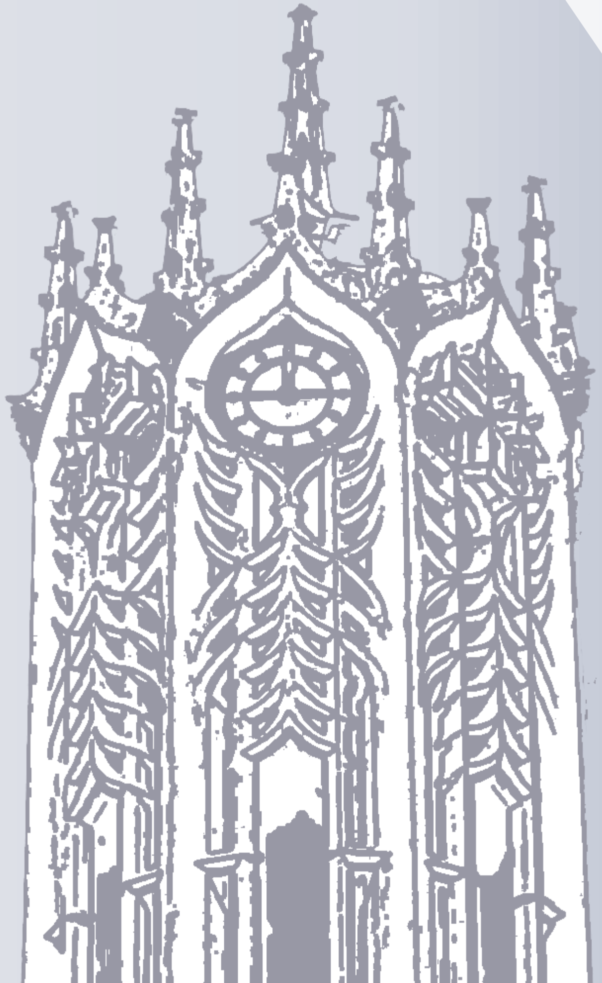


SCIENCE FOR TECHNOLOGICAL INNOVATION
Kia kotahi mai – Te Ao Pūtaiao me Te Ao Hangarau
National SCIENCE Challenges

UNIVERSITY OF AUCKLAND
Waipapa Taumata Rau
NEW ZEALAND

CENTRE FOR ADVANCED MATERIALS MANUFACTURING & DESIGN

Insoles for Comfort and Injury Prevention

Introduction to Orthotic Insoles

Peak pressure points and the plantar pressure distribution have a strong correlation with discomfort and likely regions for injury.

58% of lower-limb amputations in New Zealand are performed on patients with diabetes. Typically, amputations in these patients are proceeded with a foot ulcer.

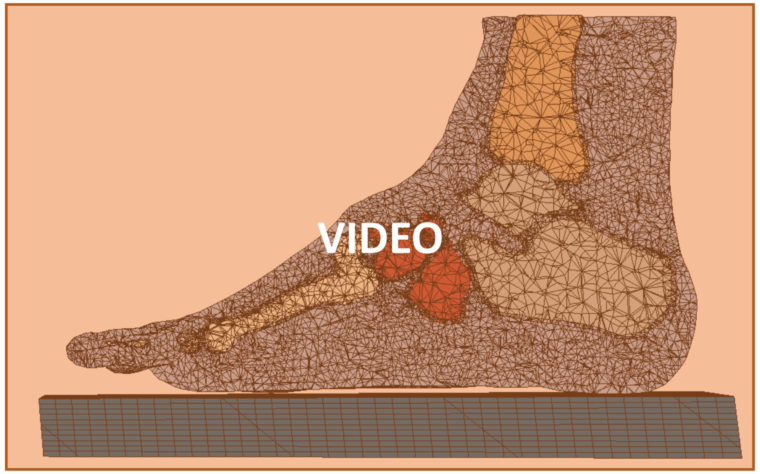
Orthotic insoles aim to even out the plantar pressure distribution to lower the peak pressure points.

Static behavior

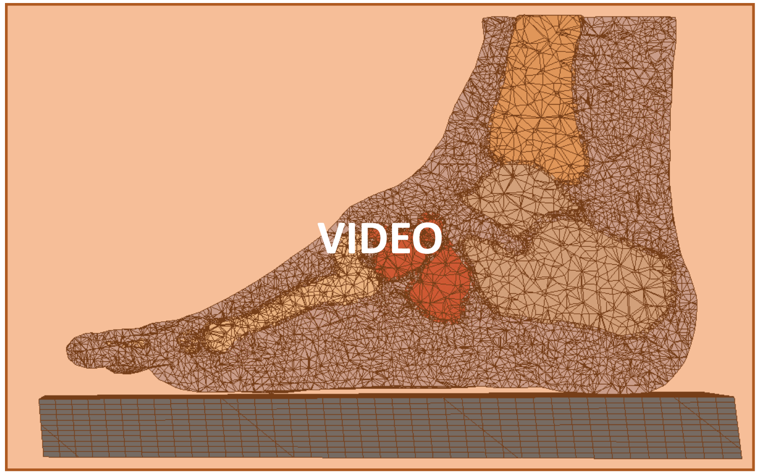
- Aim for an even distribution of pressure to lower peak plantar stresses.
- Achieved through custom orthotics with total plantar contact.

Dynamic behavior

- Optimize shock absorption and dynamically redistribute pressure.



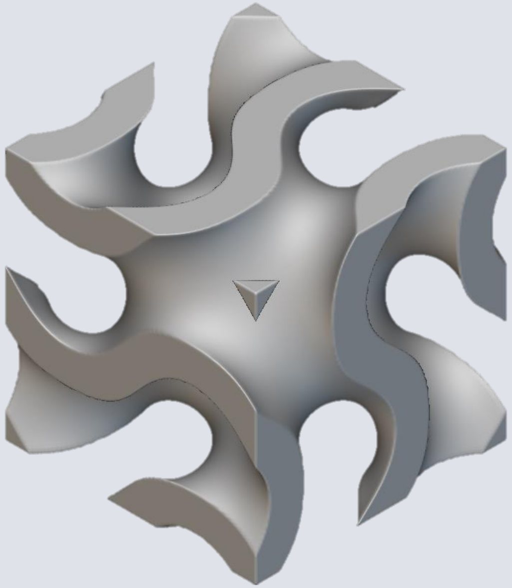
Standard Foam Orthotic Insole



SLC Orthotic Insole

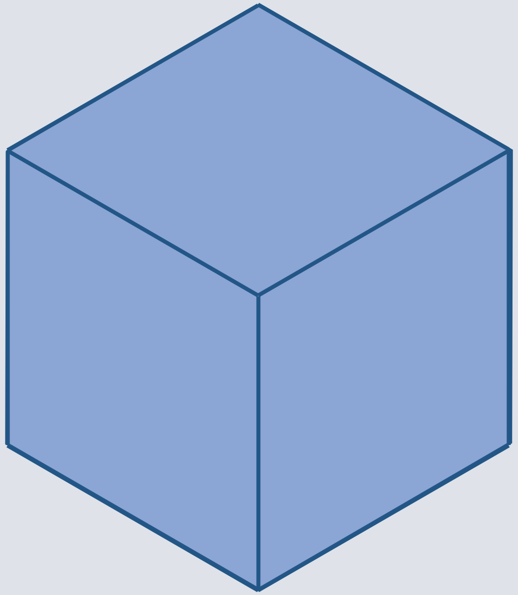
Solid Liquid Composite

Overview of Strucutre



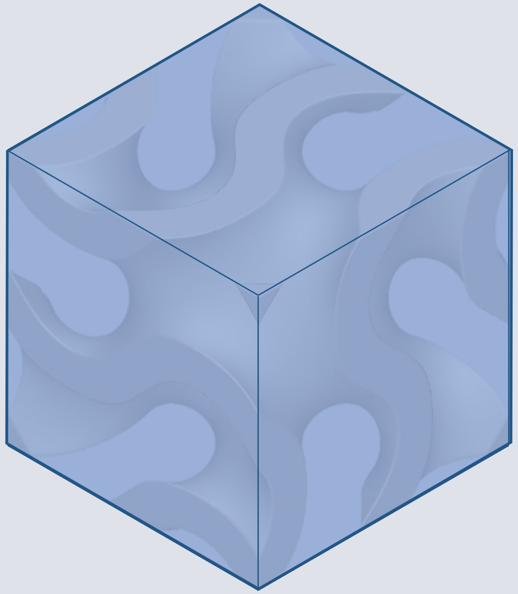
Solid
Gyroid lattice structure

+



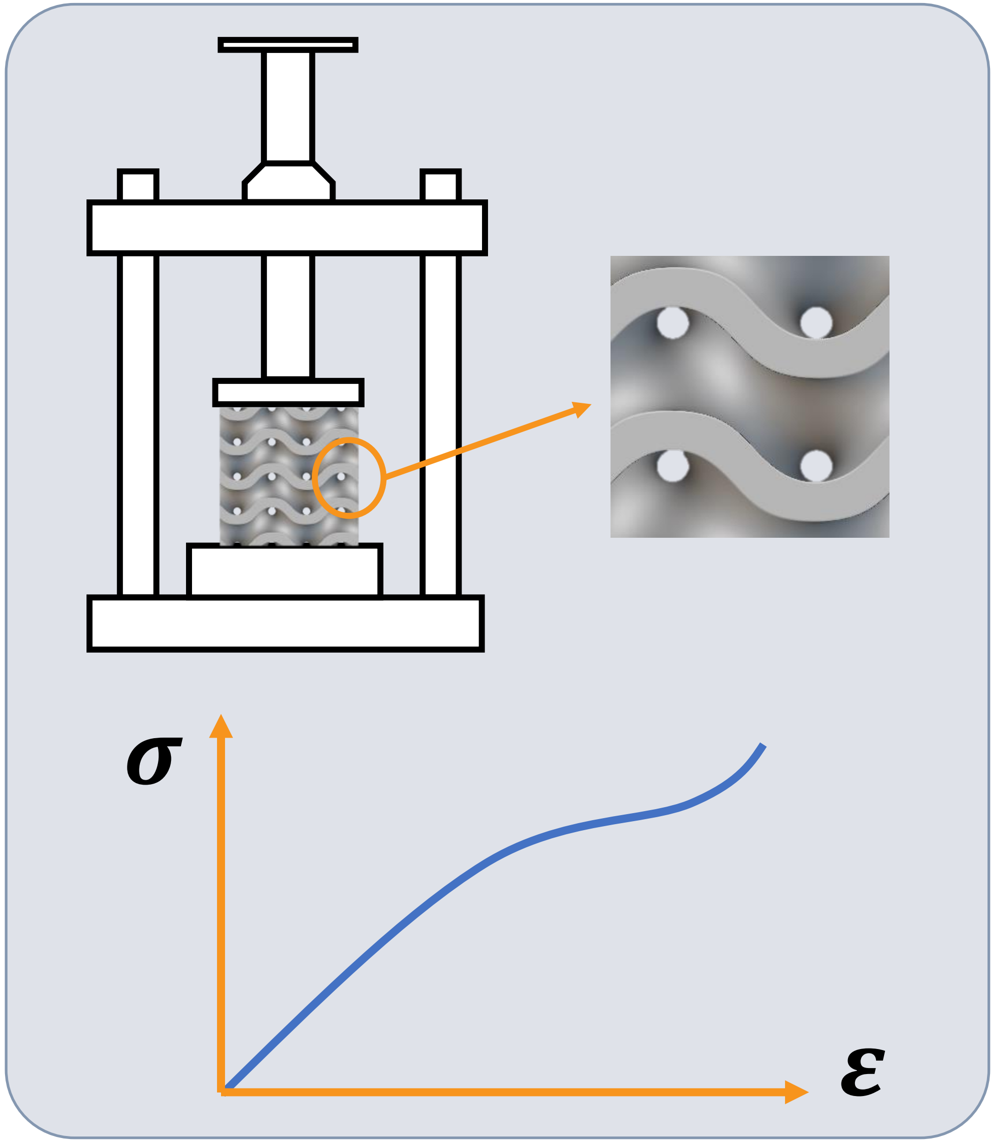
Fluid
Viscous liquid

=



SLC
Gyroid voids filled with liquid

A SLC allows us to adjust the rate dependent and rate independent response of the structure.



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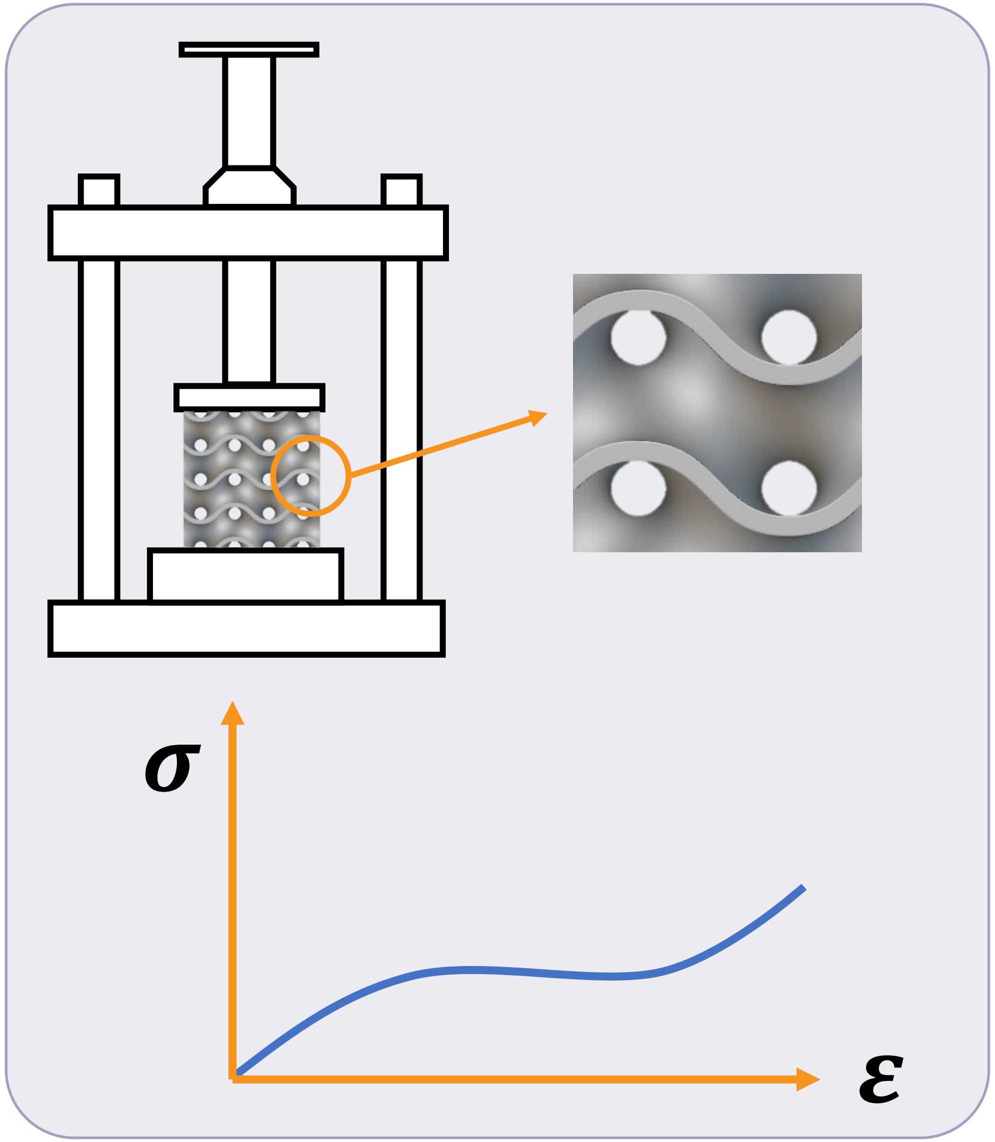

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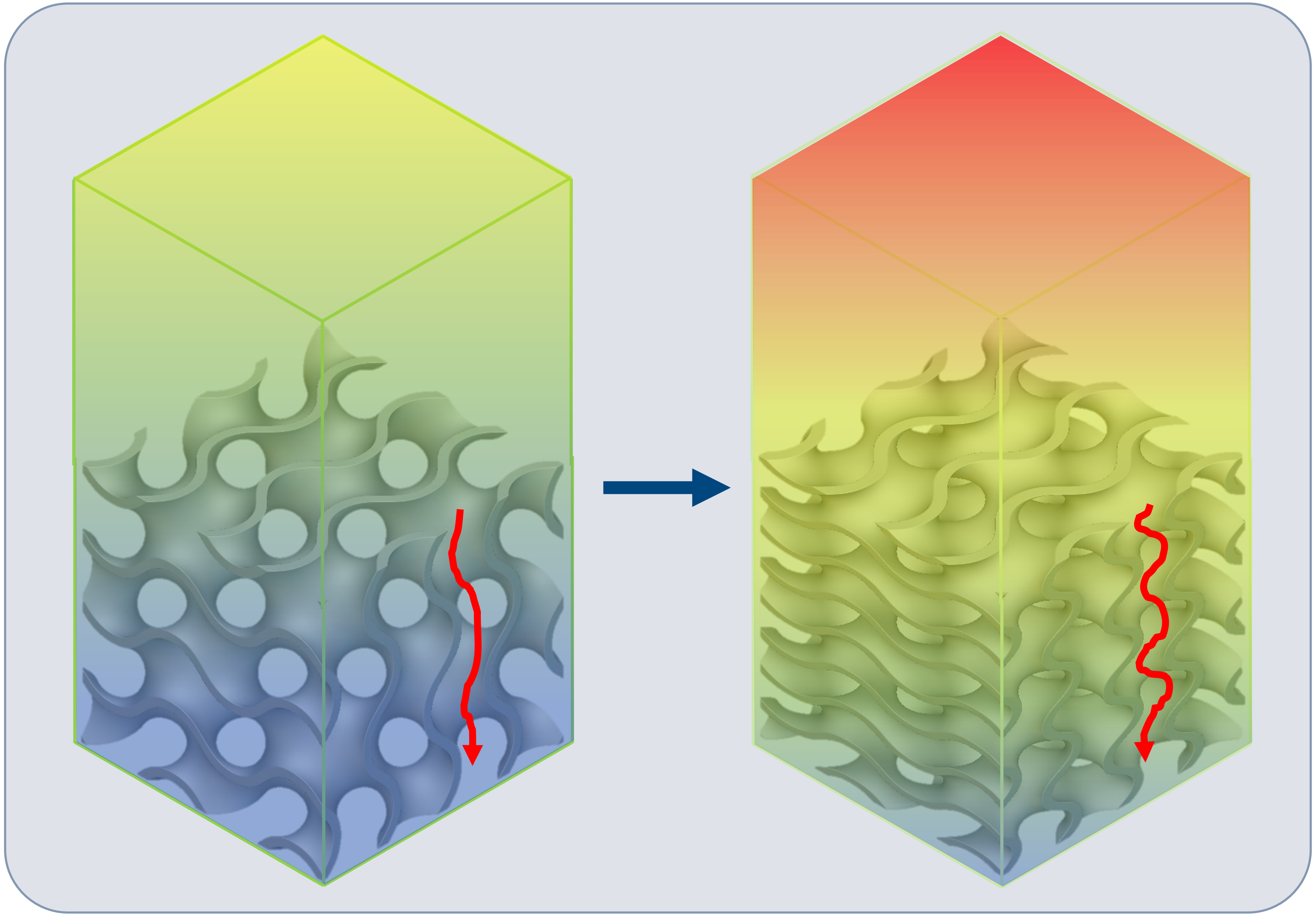
Solid Liquid Composite

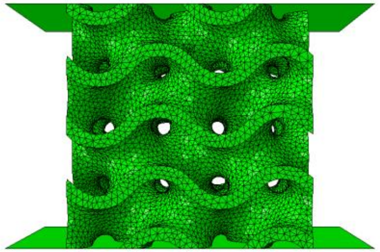
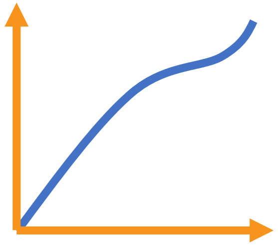
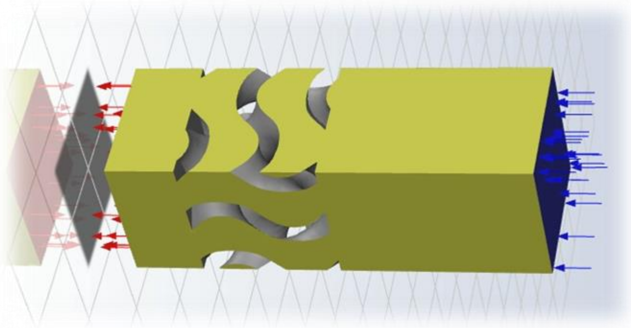
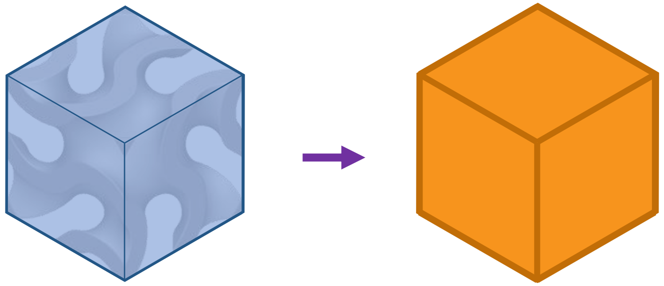
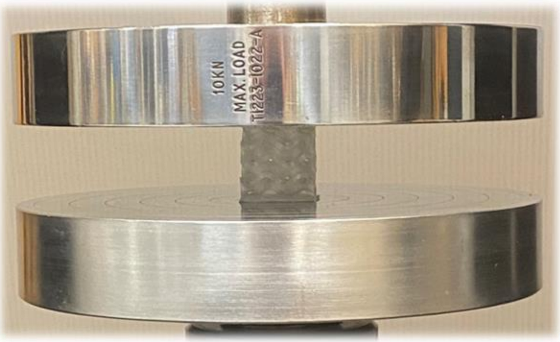
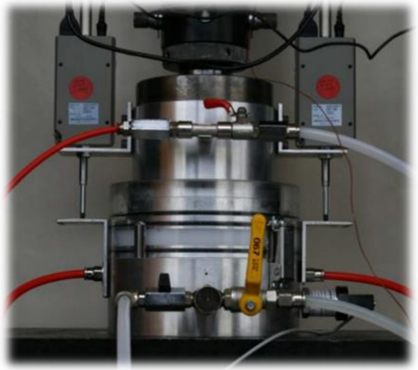
Fluid Response



- Adjusting the aspect ratio of the unit cell effects the tortuosity.
- Tortuosity has a direct relationship with the permeability of a gyroid, where the more tortuous the structure, the lower the permeability.

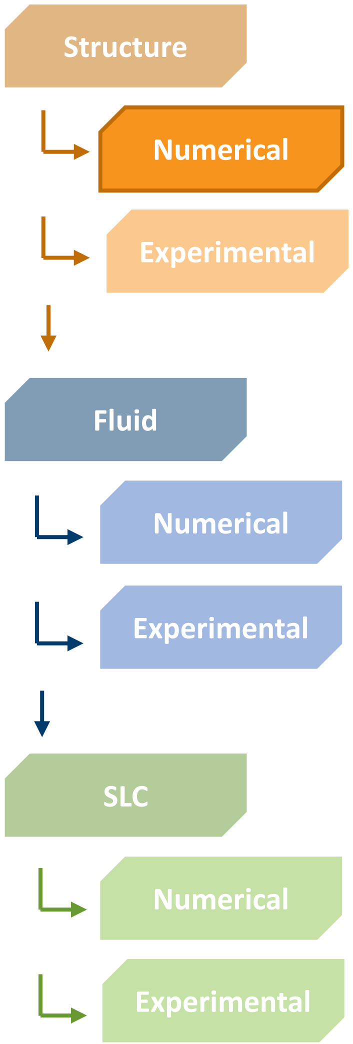
Overview

Sub-System and Full-System Analysis

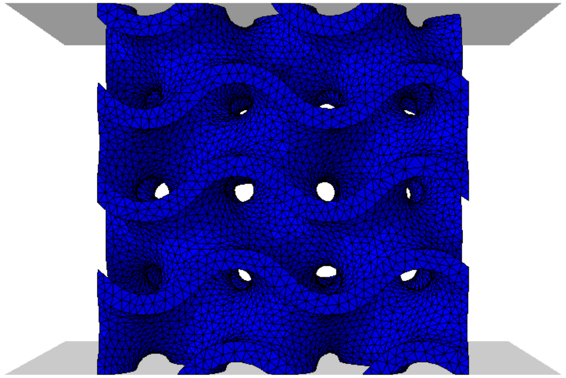
	Structural Response	Fluid Response	SLC Response
Numerical Approach	FEA: Compressive response between flat, rigid platens.  	CFD: Unidirectional flow through a unit cell. 	Homogenisation of the SLC. 
Experimental Approach	Uniaxial compression testing. 	Through-thickness permeability testing. 	Impact testing. 

Structural Response – Numerical Modelling

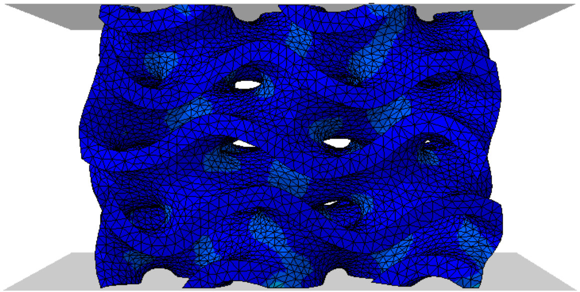
FEA



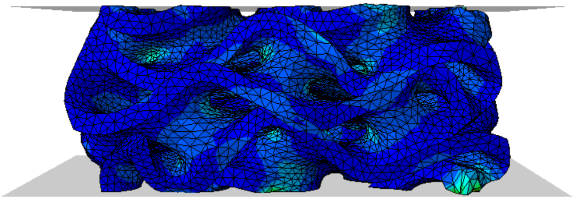
- FEA was carried out on ABAQUS.
- The gyroid geometry was compressed between two rigid platens.
- The numerical study made it feasible to do an extensive parameter sweep on the gyroid's geometric properties
- The key output from this study was the force-displacement response.



0% Compression



25% Compression

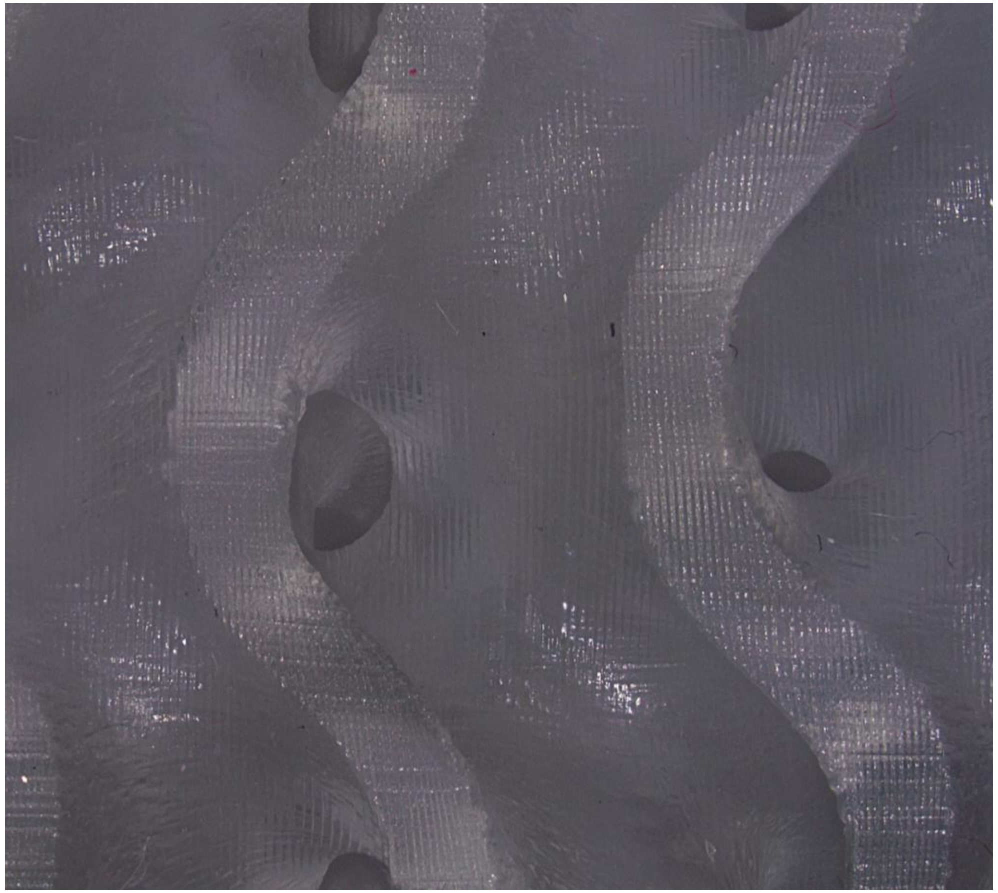


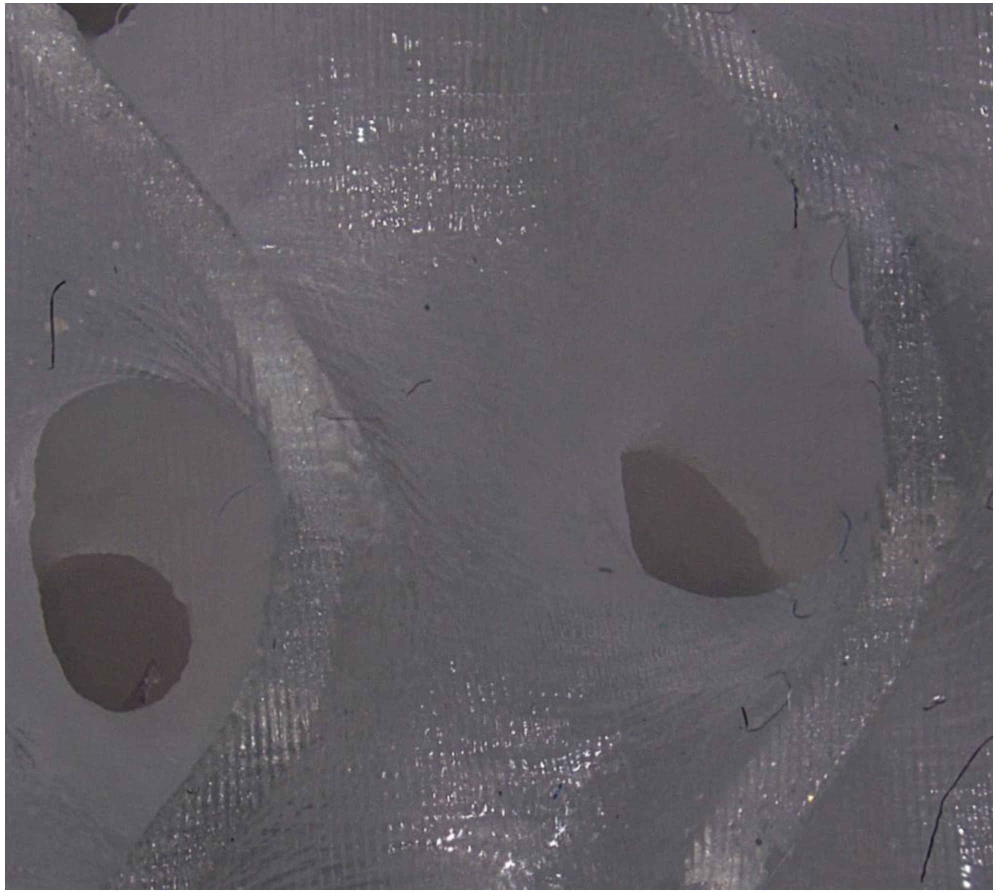
50% Compression

- Structure
  - Numerical
  - Experimental
- Fluid
  - Numerical
  - Experimental
- SLC
  - Numerical
  - Experimental

Selective Laser Sintering

- Formlabs 3 Form Printer – Elastic 50A Resin

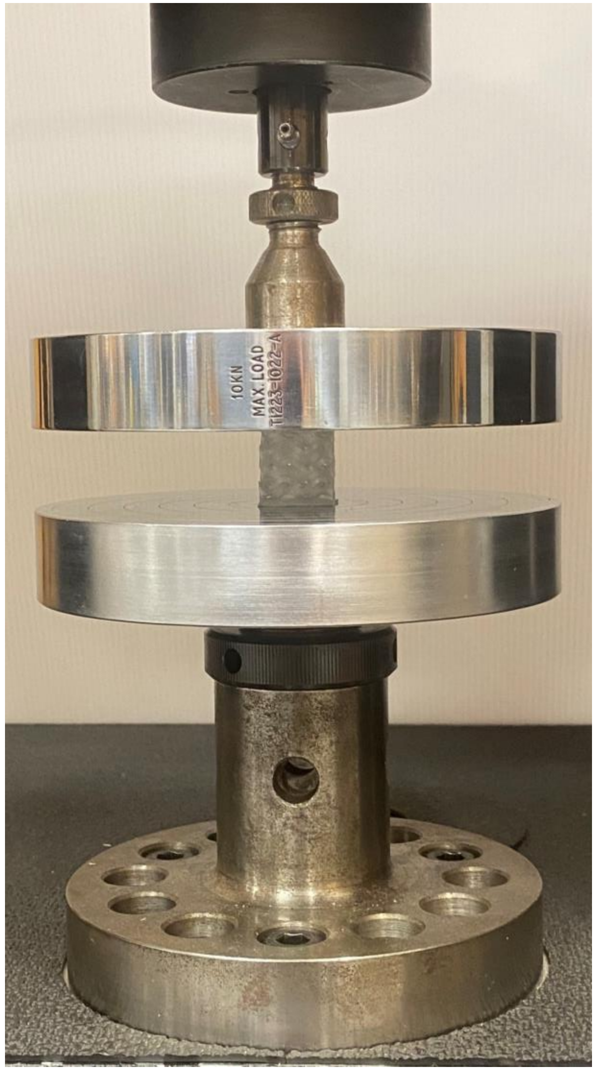


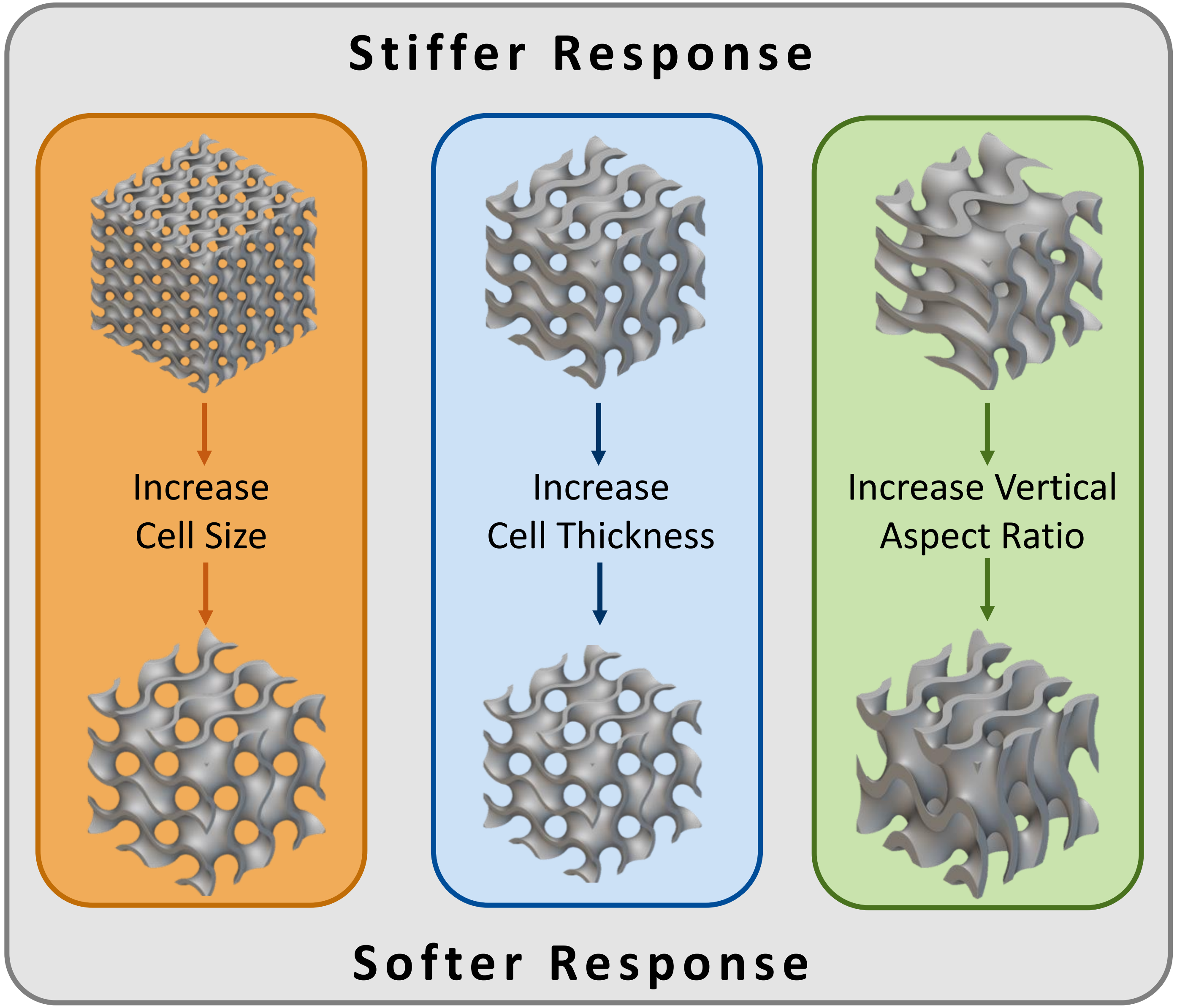


Structural Response

Compressive Testing

- Structure
  - Numerical
  - **Experimental**
- Fluid
  - Numerical
  - Experimental
- SLC
  - Numerical
  - Experimental

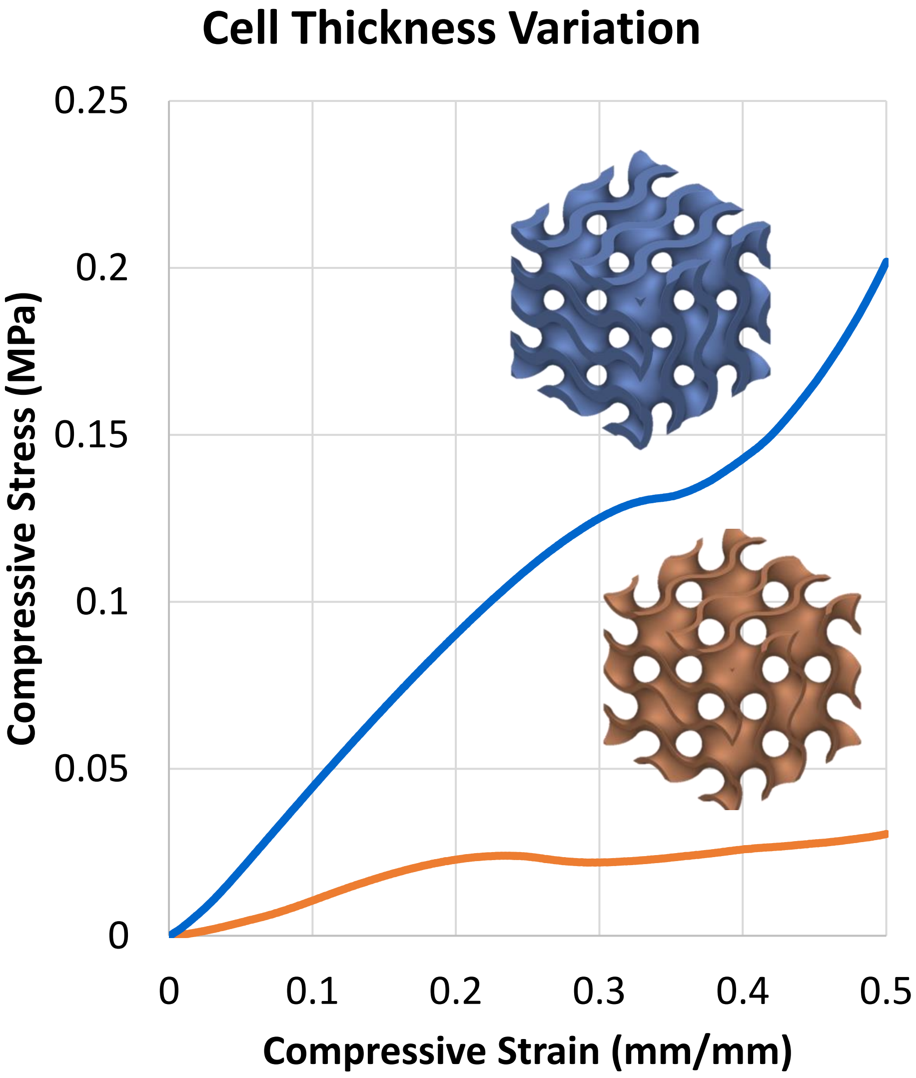


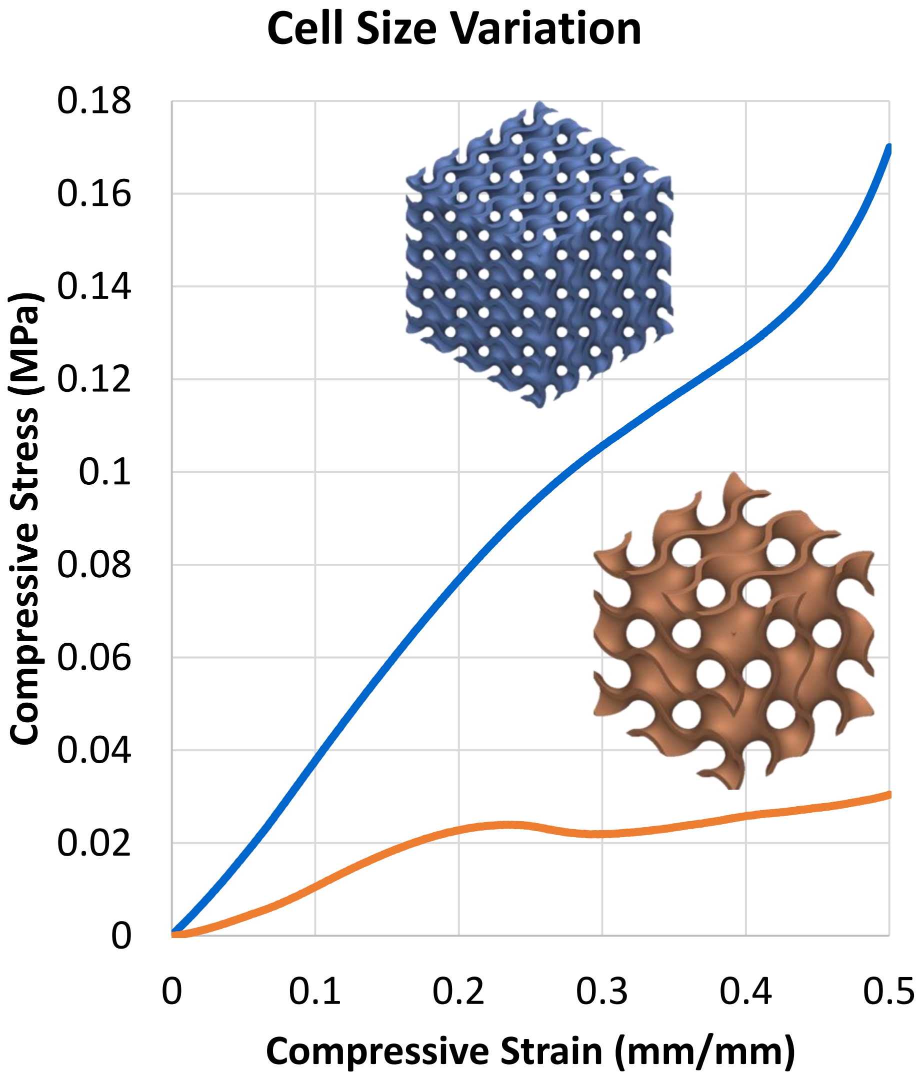


Structural Response

Validation

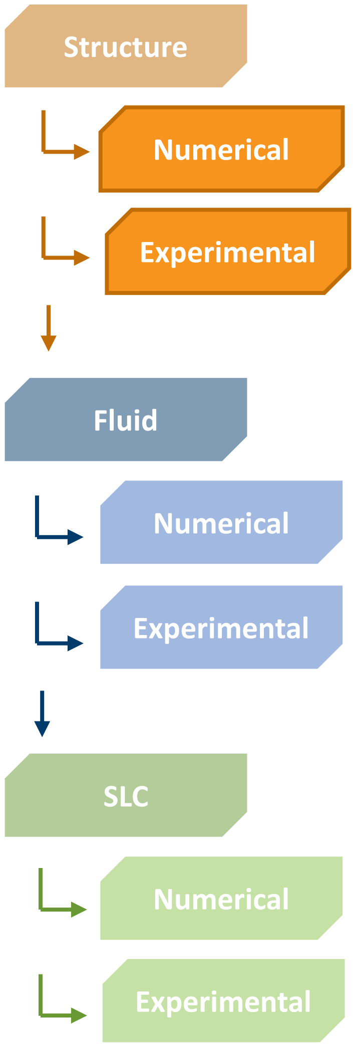
- Structure
  - Numerical
  - Experimental
- Fluid
  - Numerical
  - Experimental
- SLC
  - Numerical
  - Experimental

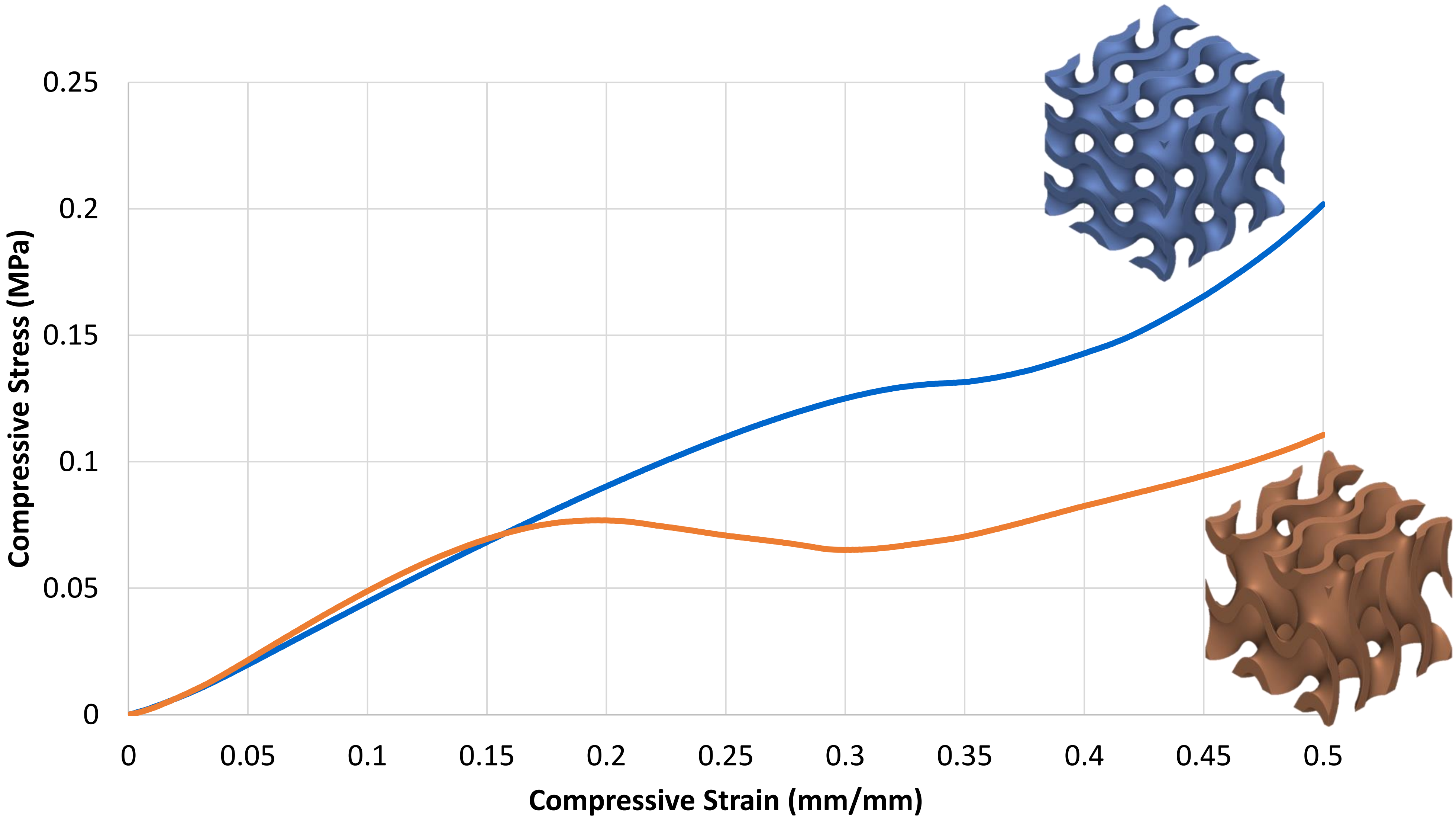




Structural Response

Validation

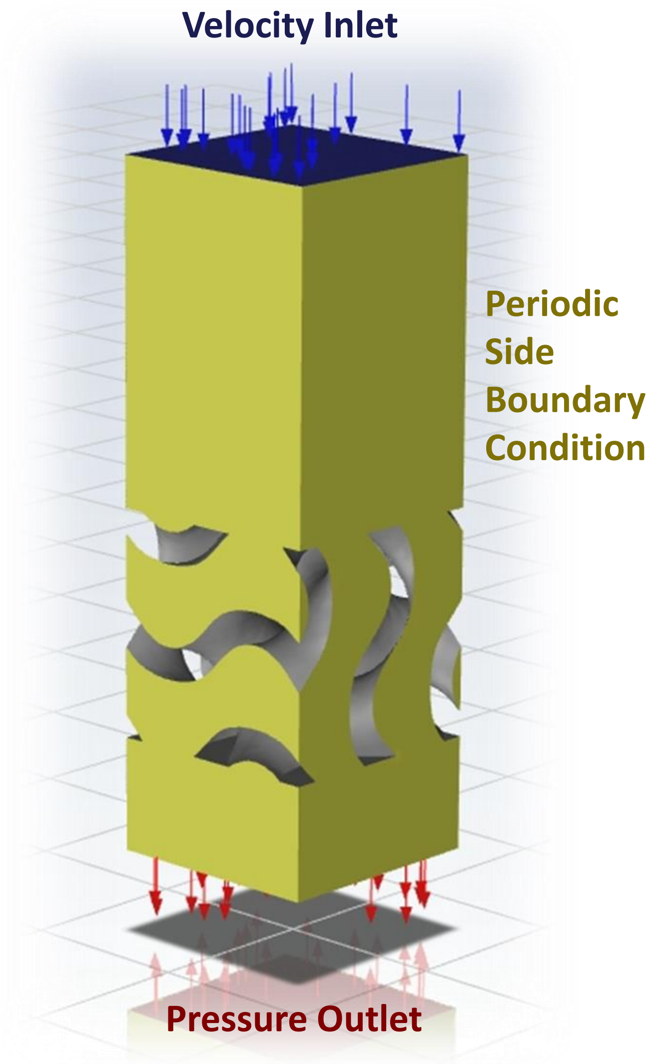




Fluid Response

Numerical Approach

- Structure
  - Numerical
  - Experimental
- Fluid
  - **Numerical**
  - Experimental
- SLC
  - Numerical
  - Experimental



Darcy's Law

$$q = -\frac{k}{\mu} \nabla p$$

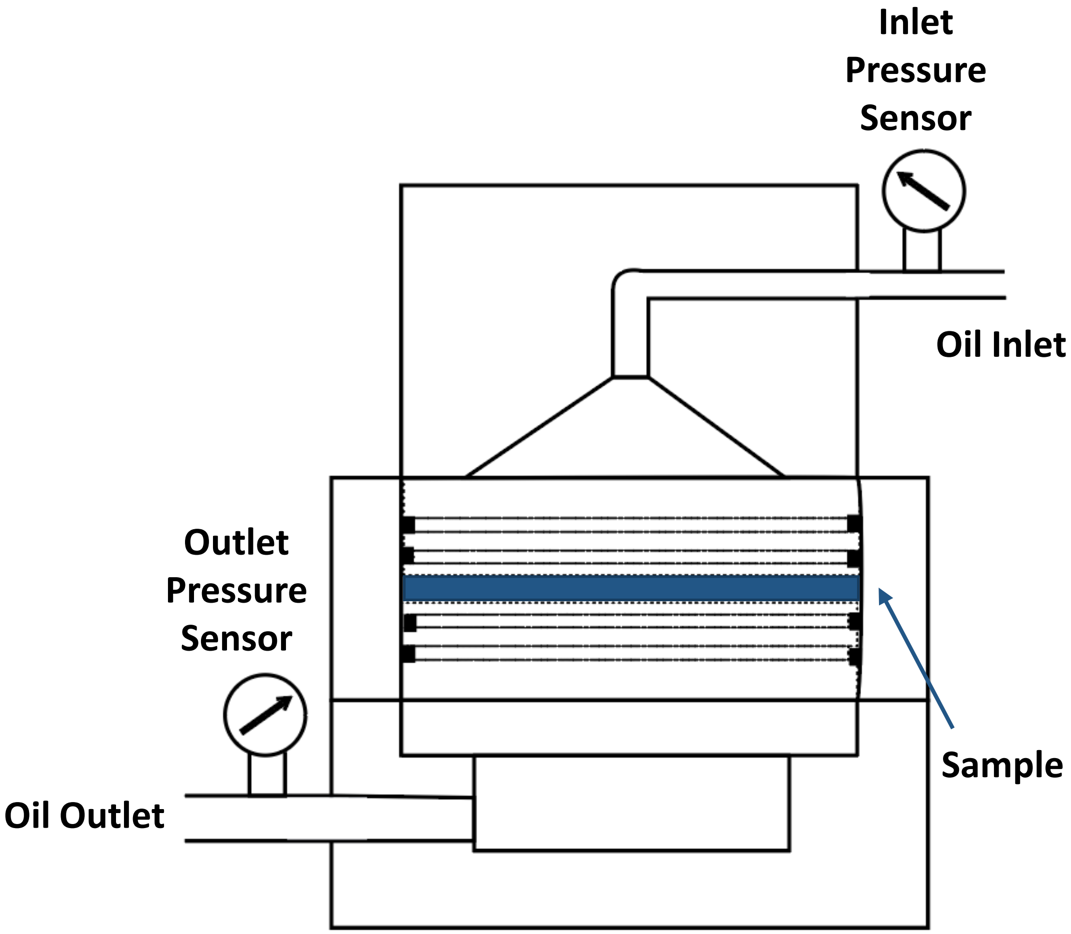
Parameters to vary included:

- Unit cell size
- Cell thickness
- Aspect ratio

Fluid Response

Experimental Approach

- Structure
  - Numerical
  - Experimental
- Fluid
  - Numerical
  - Experimental
- SLC
  - Numerical
  - Experimental



- A gyroid sample was tested in a through-thickness permeability set up.
- The permeability calculated from this experiment was used to validate the numerical models
- Results aligned with numerical results within 10% on average.

Numerical Modelling of the SLC

Homogenisation of a SLC

Structure

Numerical

Experimental

Fluid

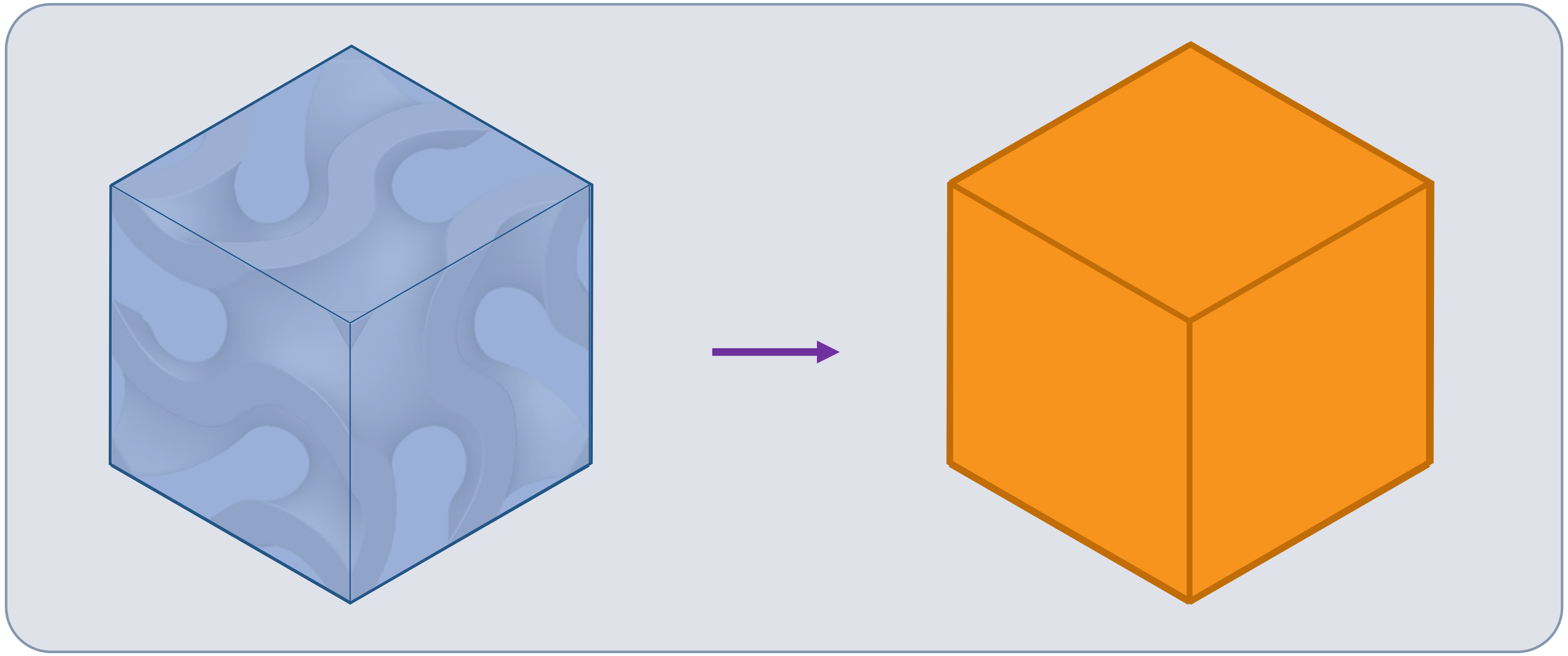
Numerical

Experimental

SLC

Numerical

Experimental



- Homogenising the SLC will make parametric studies and large scale modelling feasible.
- It must capture the rate dependant and rate independent behaviour.

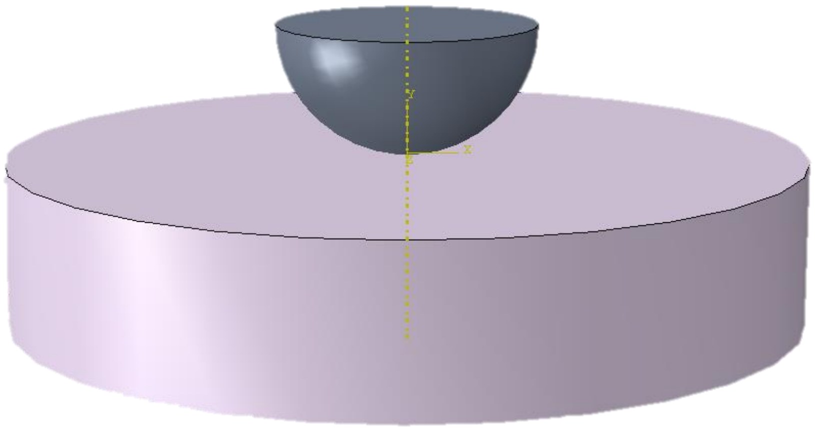
Numerical Modelling of the SLC

Parameter Study

Structure
Numerical
Experimental

Fluid
Numerical
Experimental

SLC
Numerical
Experimental



- Using ABAQUS, the material is assigned a hyperelastic model and a permeability.
- The SLC geometry is enclosed, and compressed by a hemispherical indenter.
- The main output is the force-displacement data for a variety of indentation speeds.

Experimental Analysis

Validation of the Numerical Model

- Structure
  - Numerical
  - Experimental
- Fluid
  - Numerical
  - Experimental
- SLC
  - Numerical
  - Experimental

- Fully enclosed, fluid filled disk samples were printed.
- The SLC liquid is mineral oil.

- SLC samples were tested in a replica set up of the numerical model.
- Each sample was impact tested at 3 different speeds.

Conclusions

- Modelling the SLC using the homogenisation methods described is effective for a extensive parametric study.

- Results must be checked through numerically modelling the non-homogenised geometry, then validated through experimental testing.

- The rate dependant effects of the SLC are capable of providing energy absorption properties and pressure redistribution effects.

Next Steps

SLC for Orthotic Insoles

Integrating the homogenised model into an optimisation framework to assign properties to different regions of an orthotic insole.

Implementation in a full scale orthotic insole, both numerically and experimentally, to assess its effectiveness compared to a standard foam insole.