School of Engineering and Material Sciences

Queen Mary University of London

Data-driven topology optimisation for energy-absorbing structures

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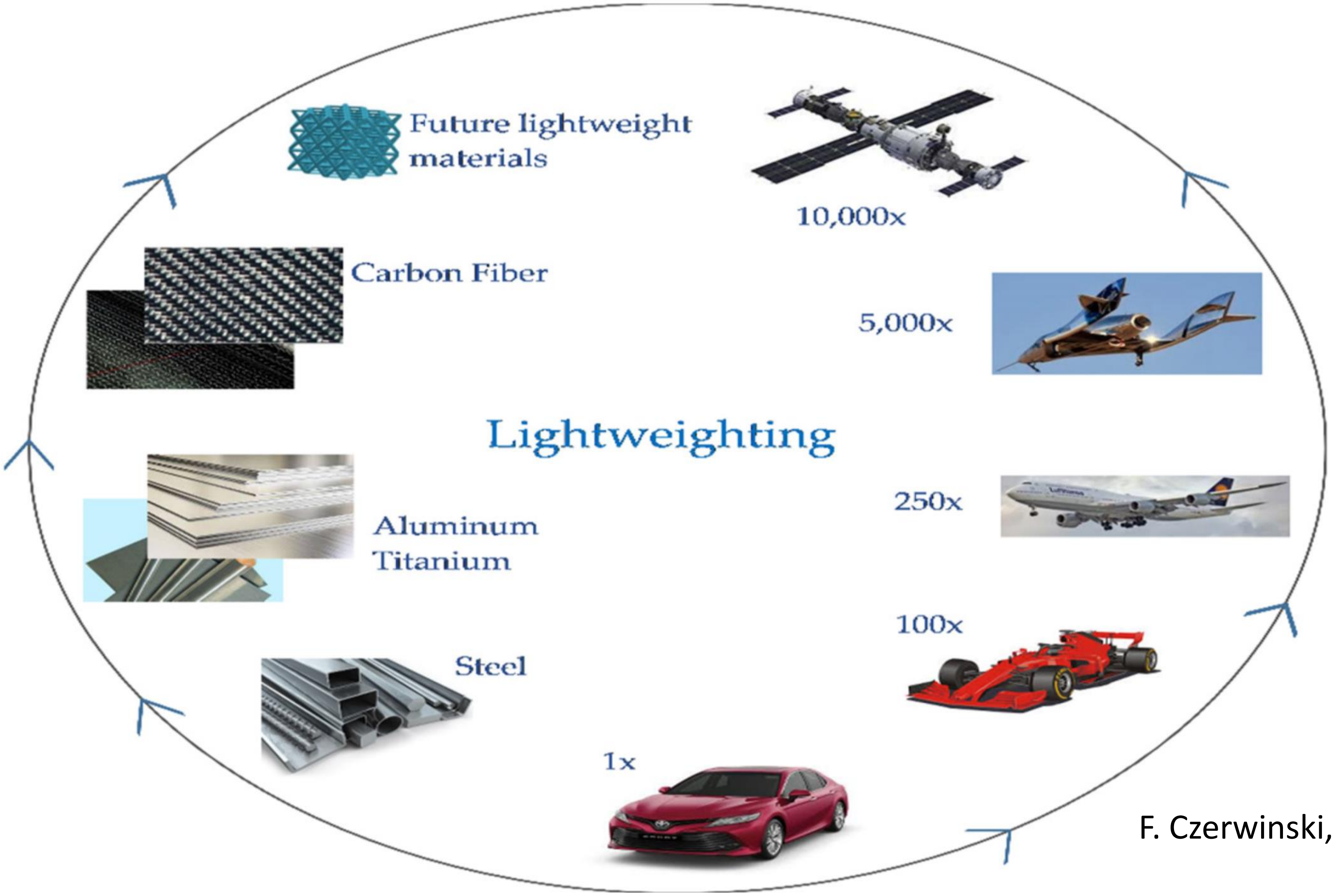
Motivation of using lightweight materials



F. Czerwinski, Materials, 2021.

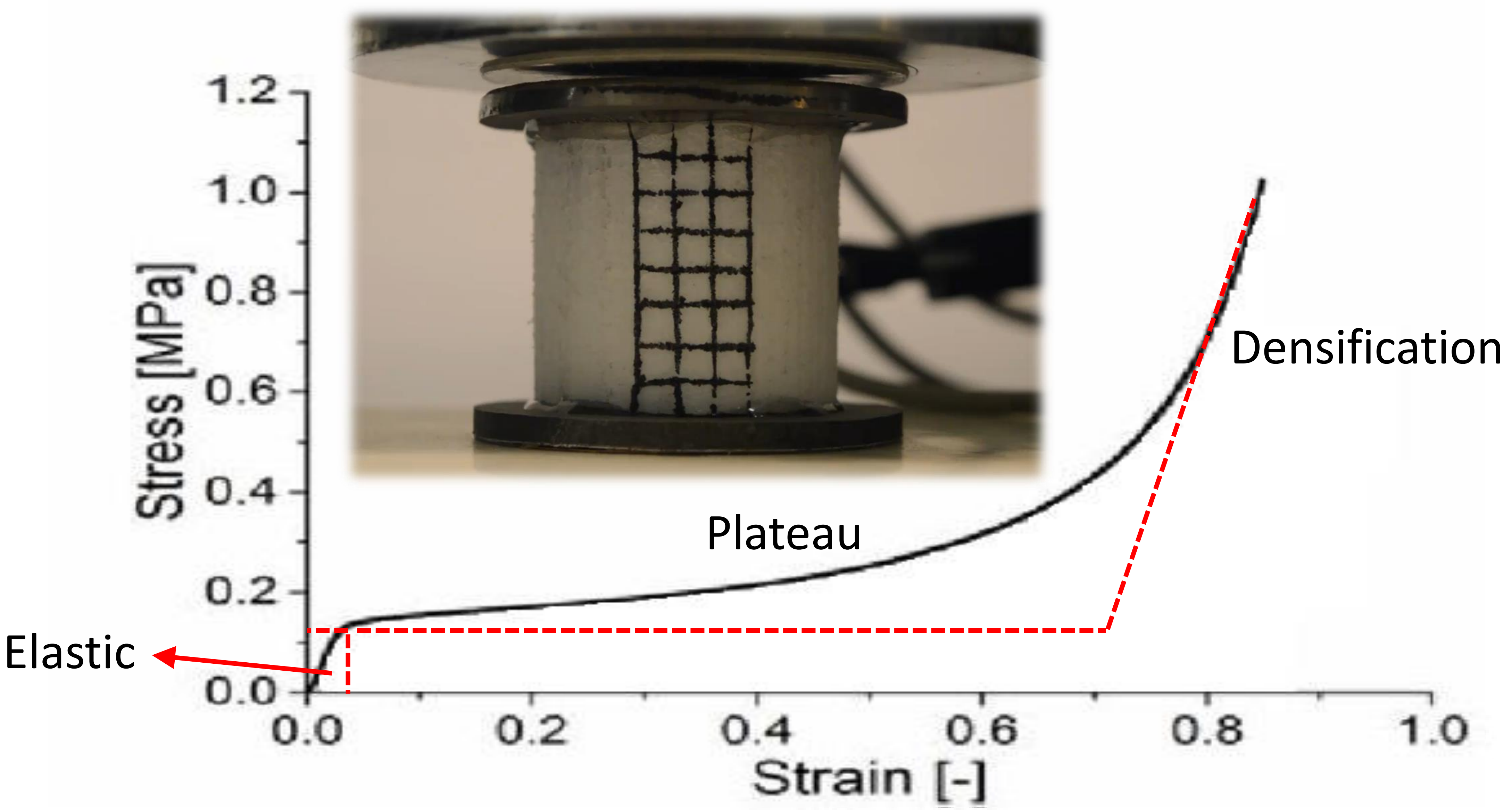
What are Impact Energy absorbers?!

The picture is adopted from www.bikebandit.com/

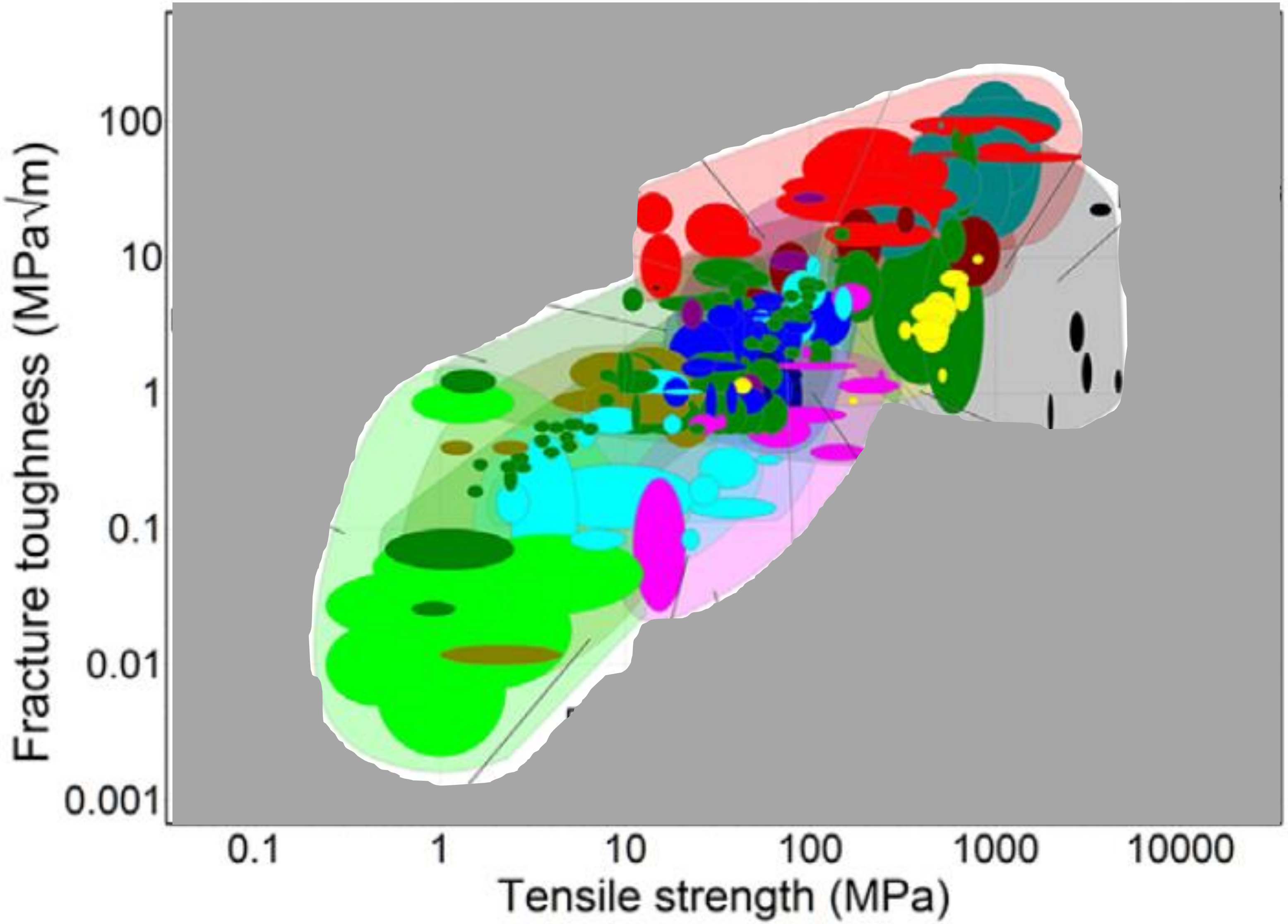
Cellular structures/materials

The video is adopted from http://www.betaty.pe.

Mechanical behaviour of cellular materials

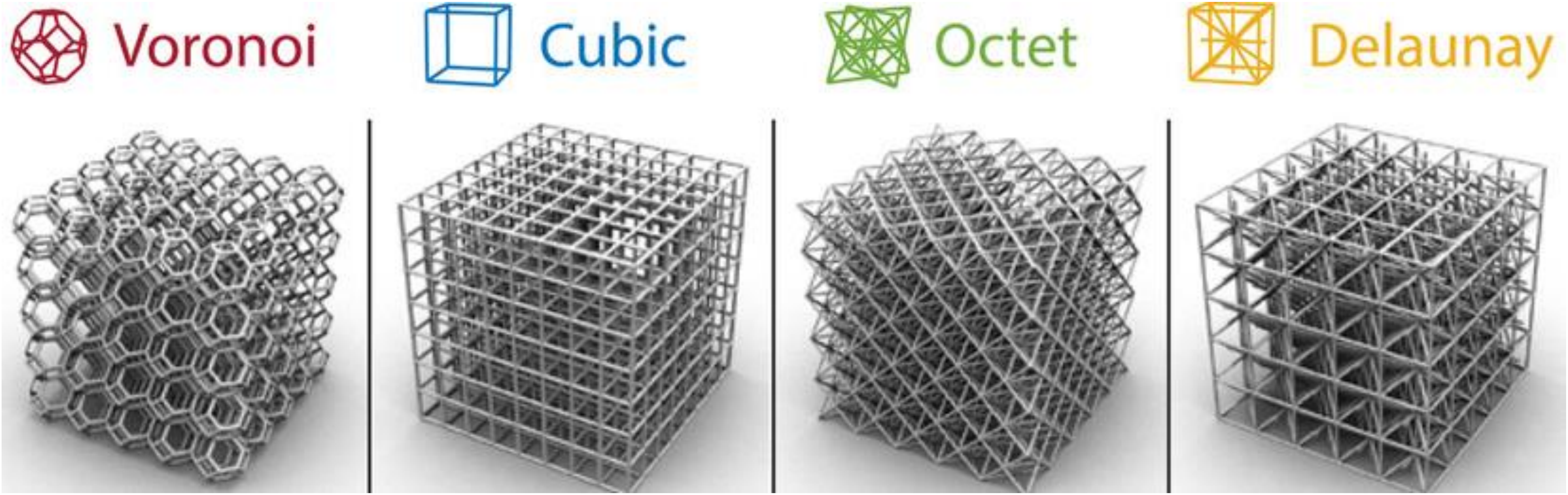


Ashby chart



Flavia Libonati & Markus J. Buehler, Advanced Engineering Materials, 2017.

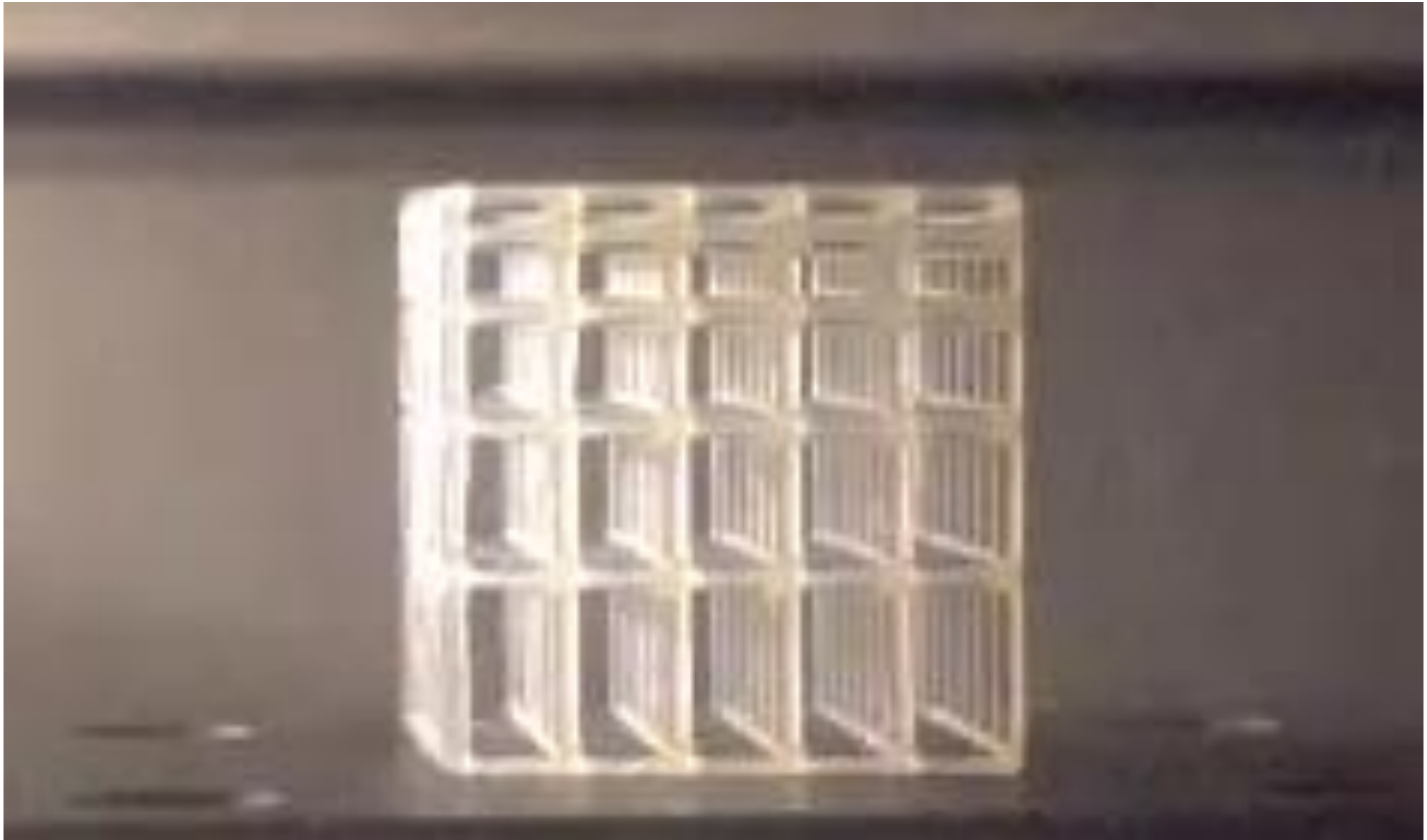
Development of new structures/materials



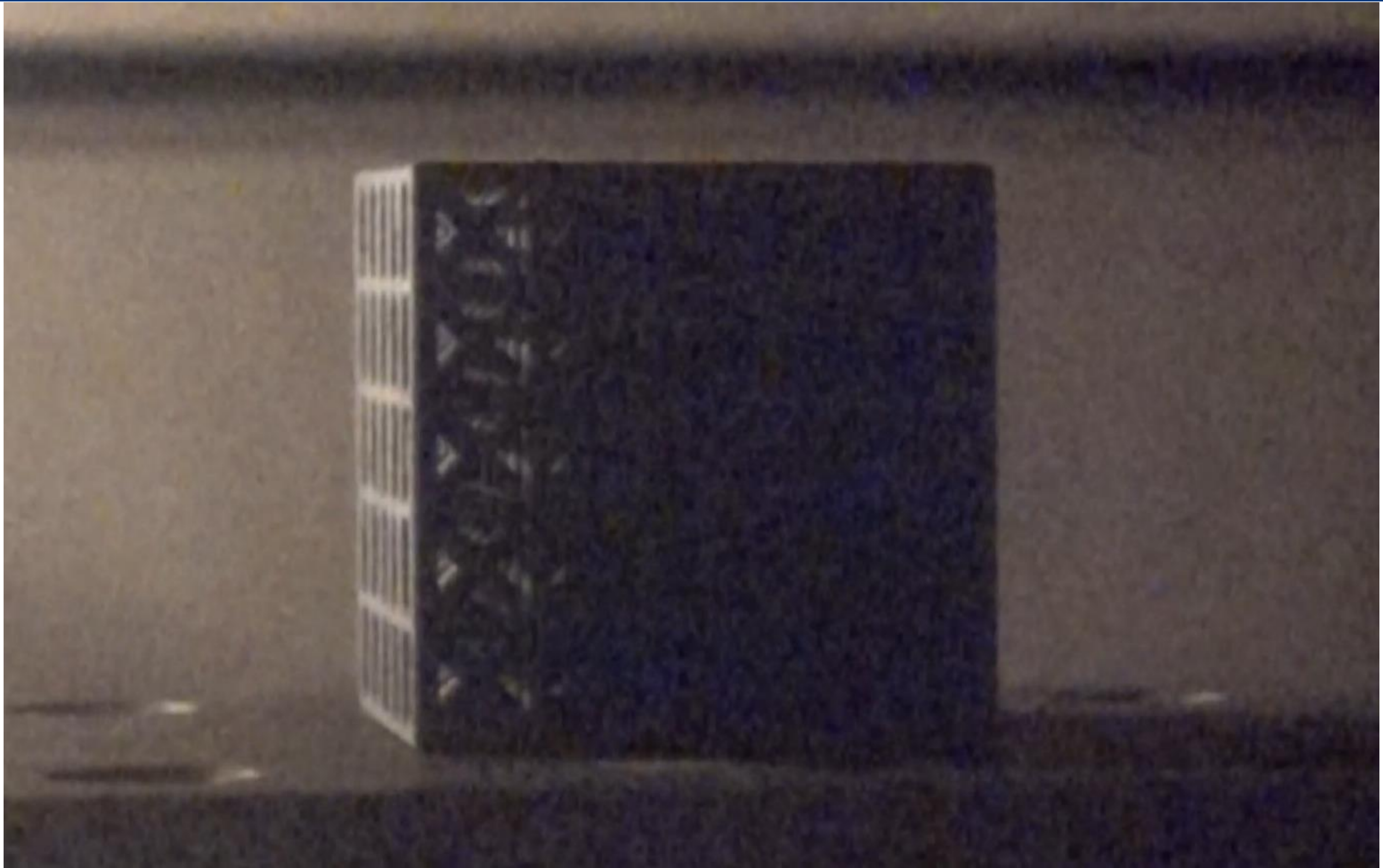
Jochen Mueller et al, Advanced Theory and Simulations, 2019.

Graded lattice structures

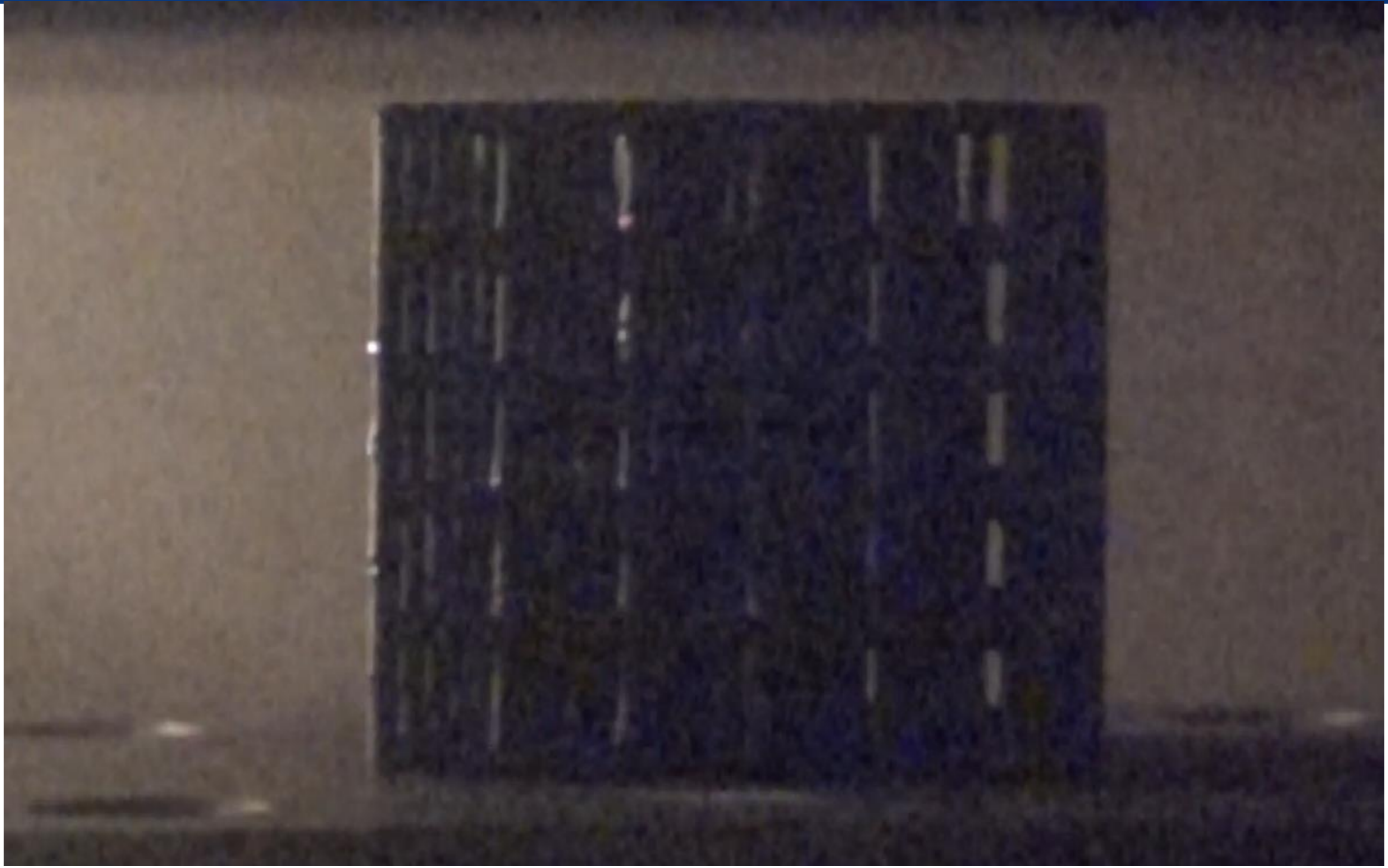
Graded lattice structures



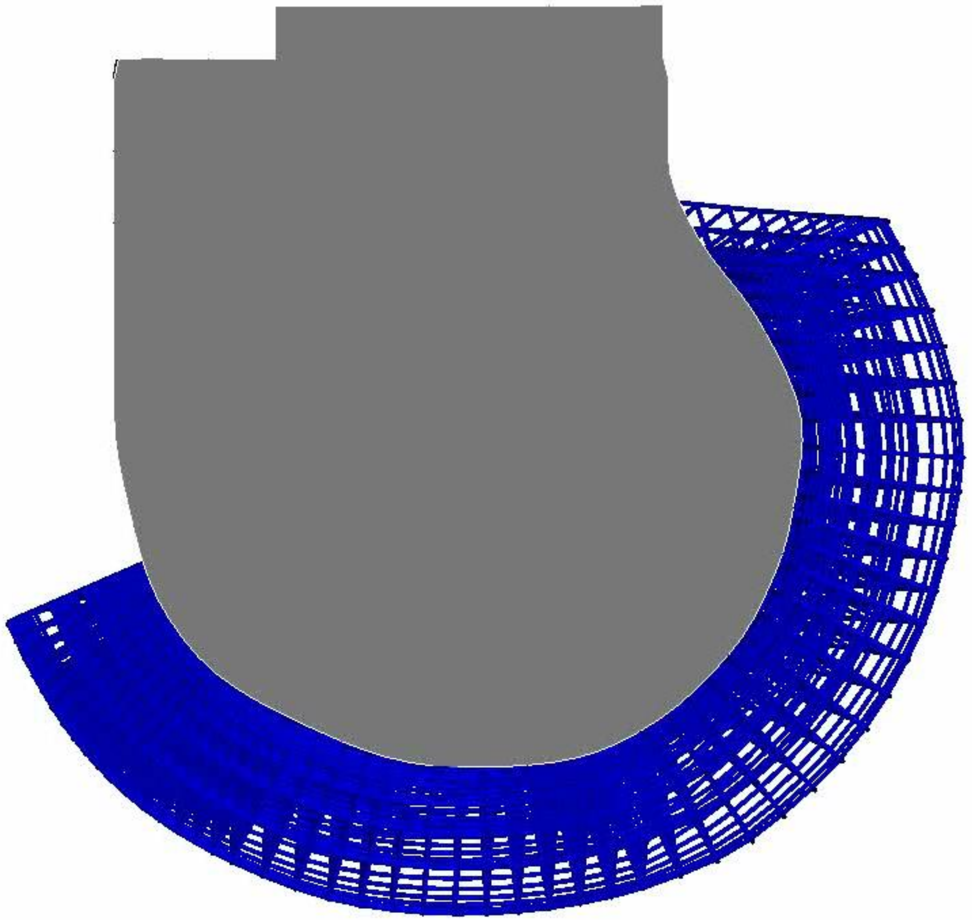
Uniform lattice structures

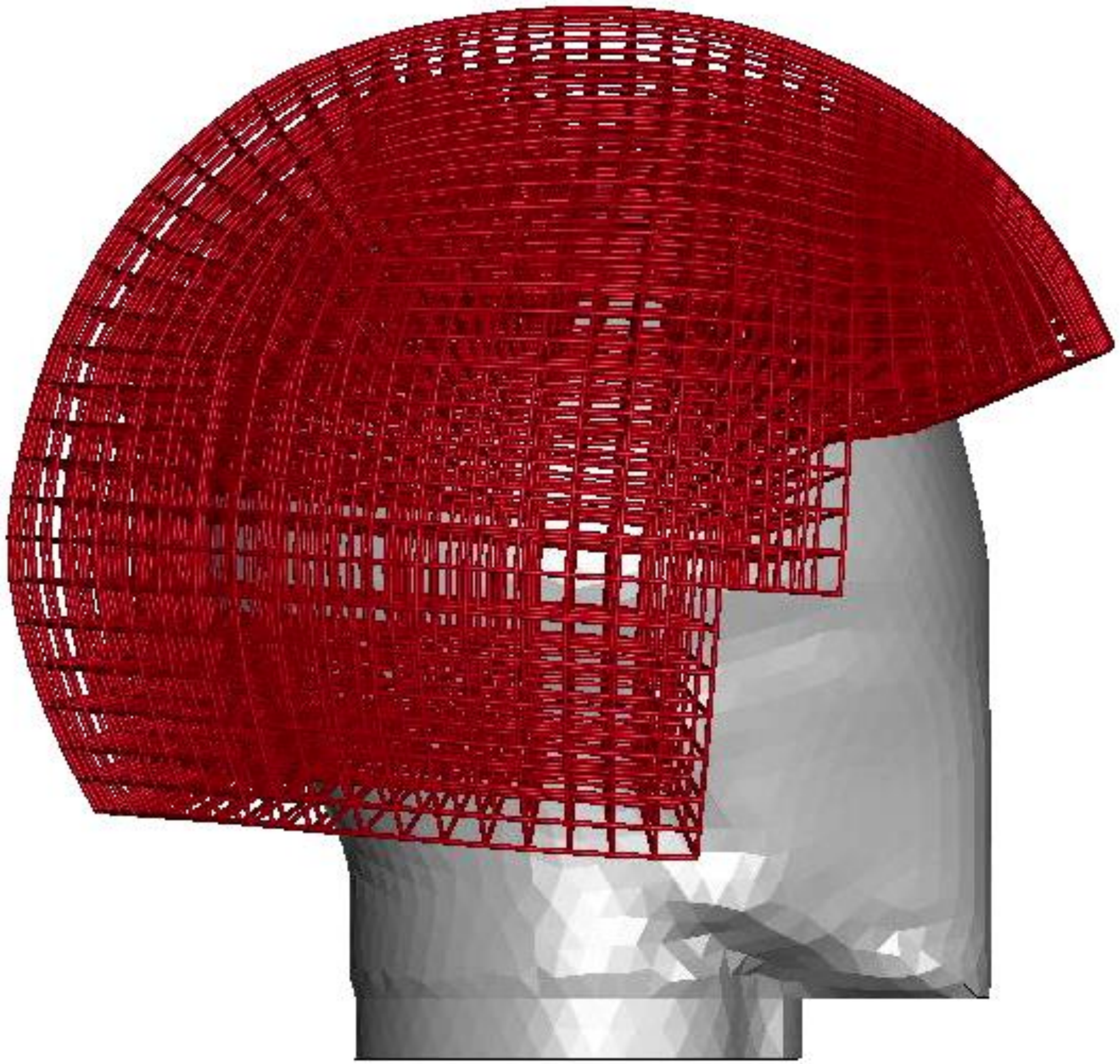


Uniform lattice structures



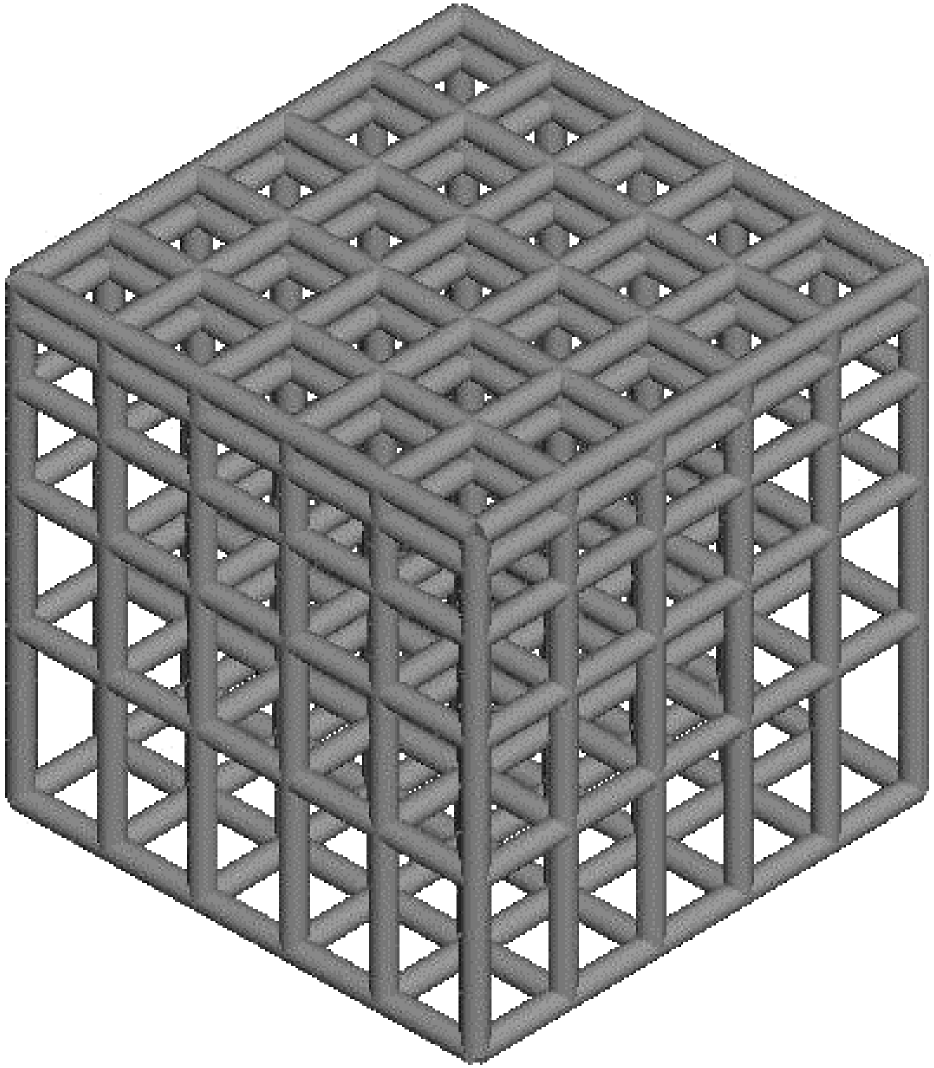
Lattice liners for helmets

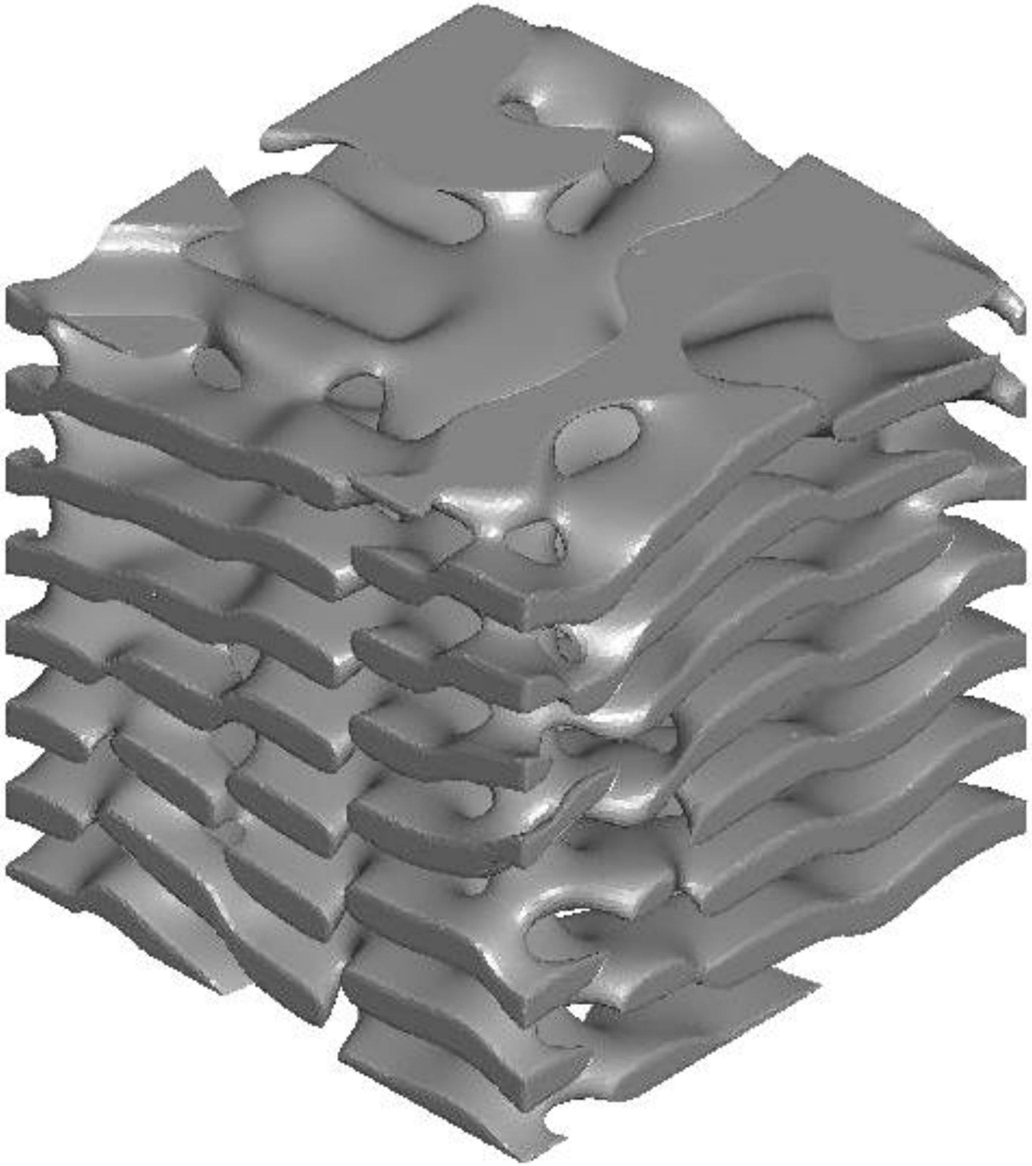




Graded lattice liner vs EPS liner

Lattice vs Spinodoids





Spinodoids topology = $f(\bar{\rho}, \theta_1, \theta_2, \theta_3)$

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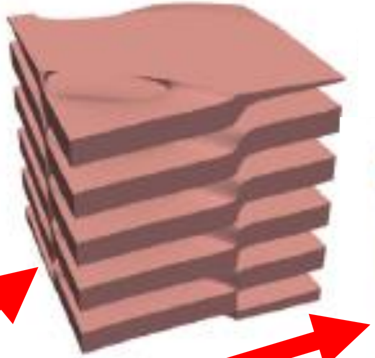
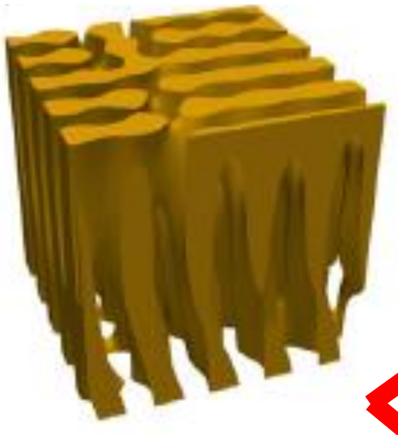
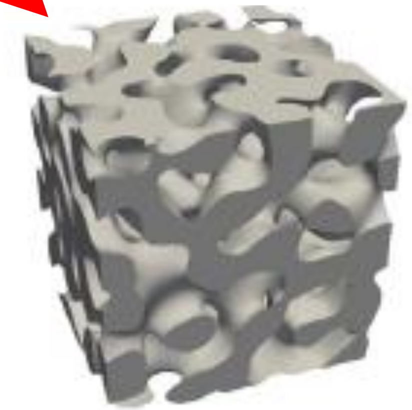
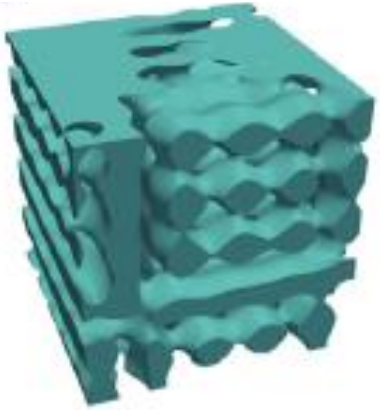
$$(\bar{\rho}, \theta_1, \theta_2, \theta_3)$$

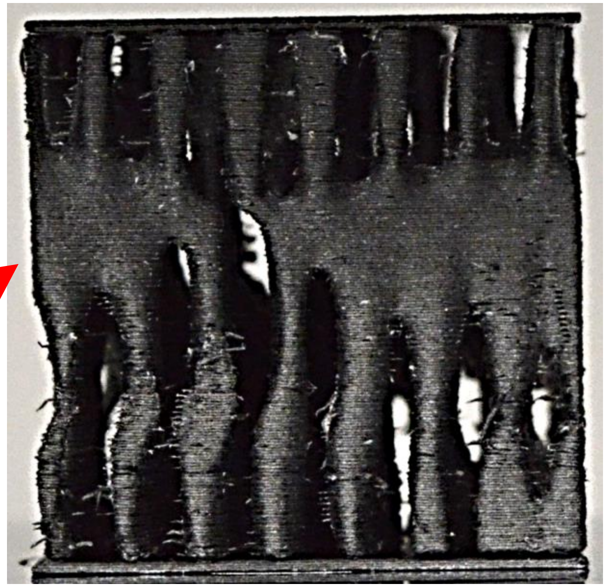
MATLAB

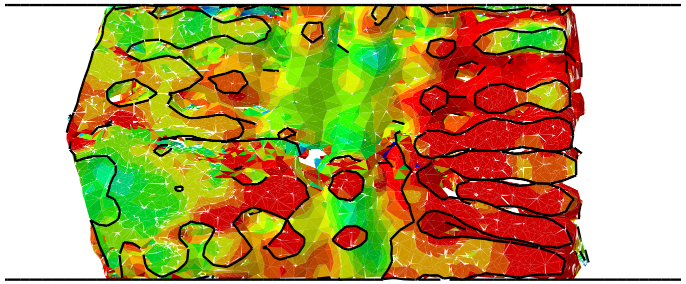






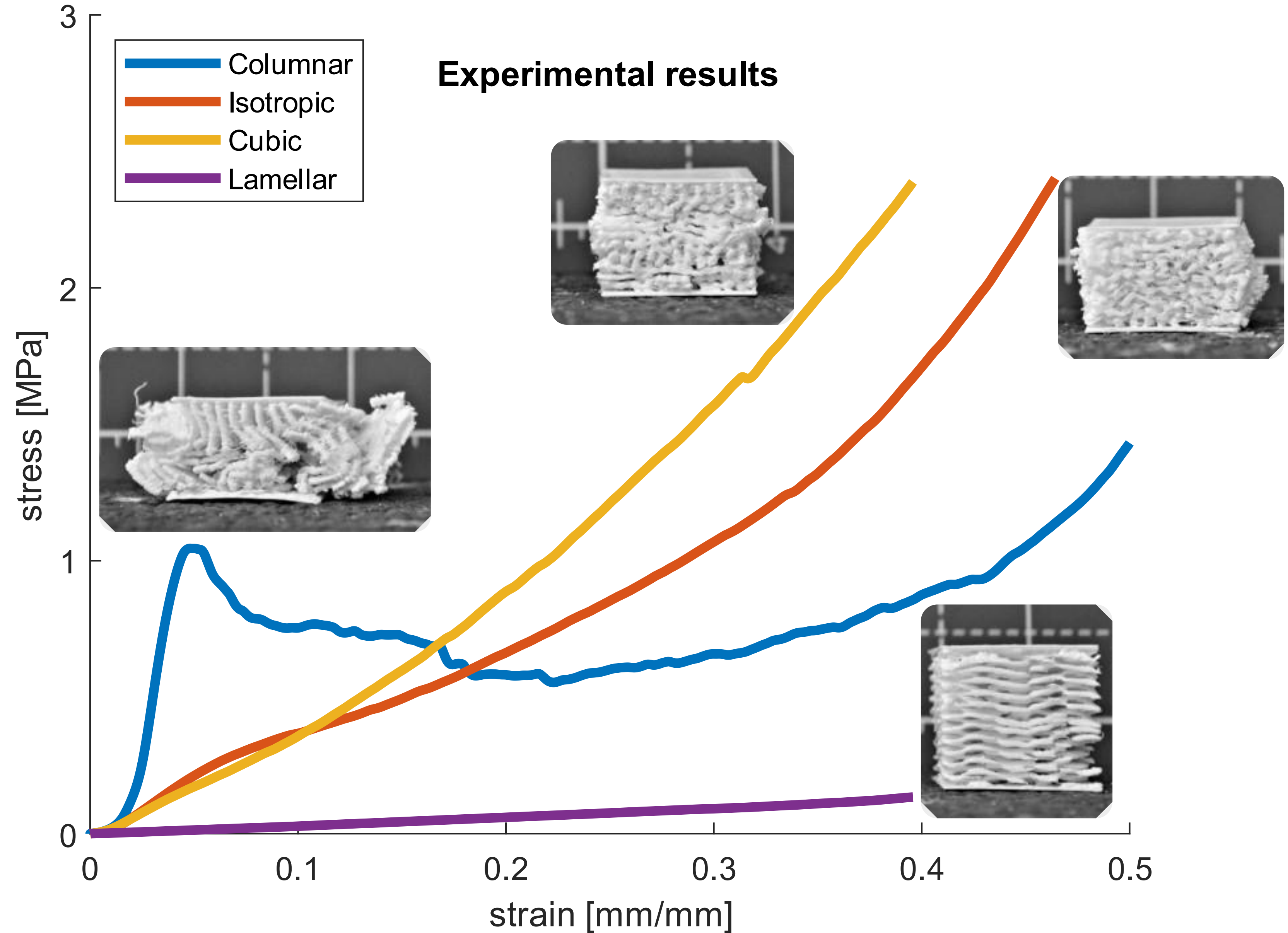




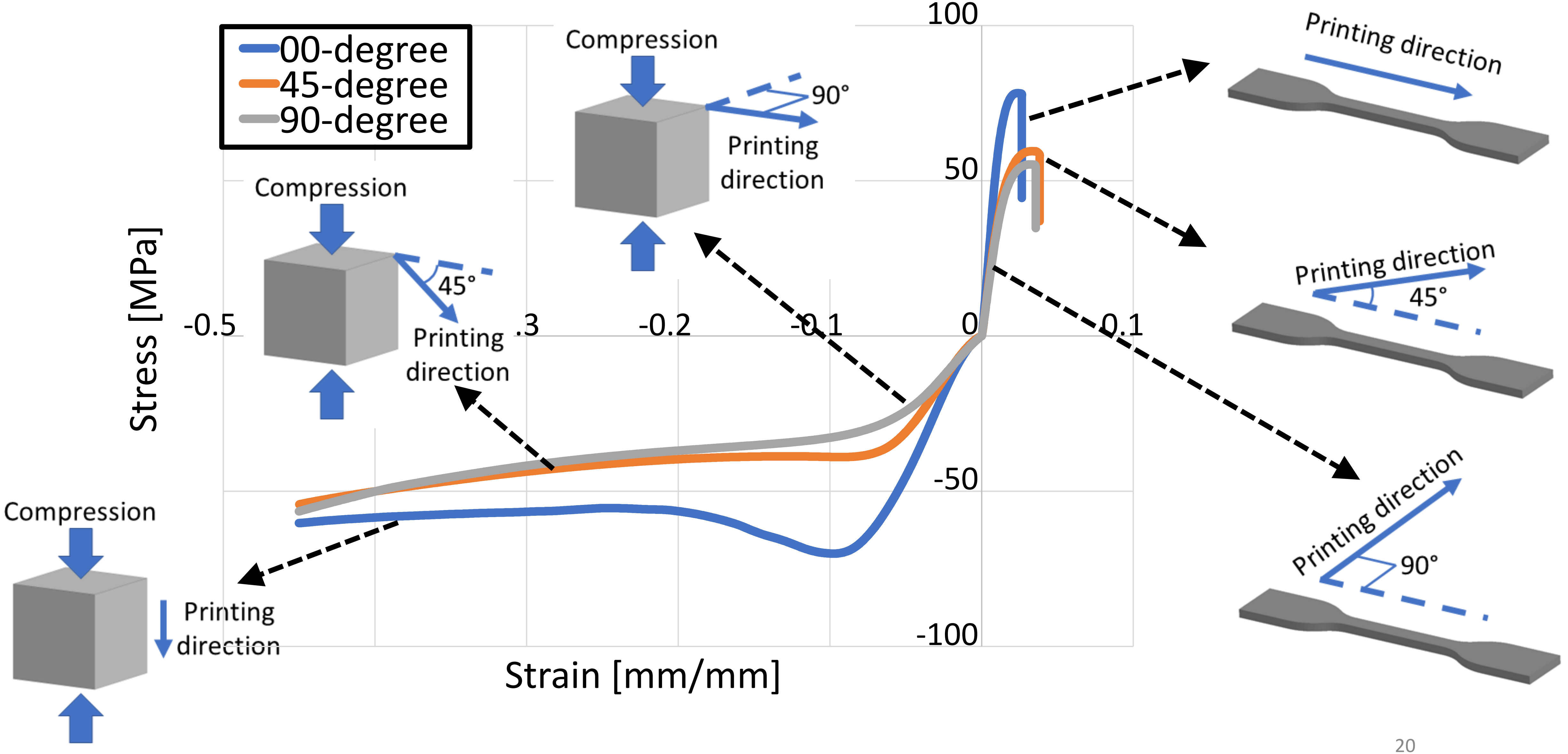


Experimental tests


Spinodoids_under compression_PET_G



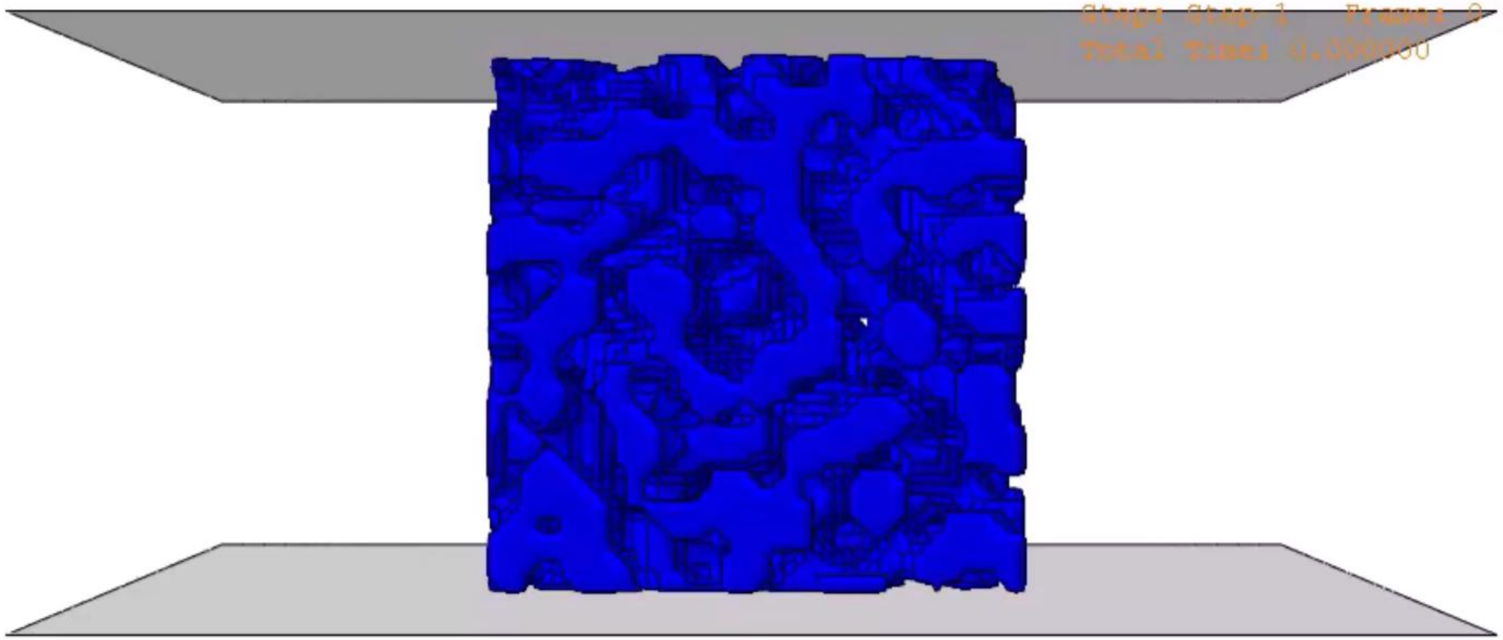
Experimental results: Carbon_P



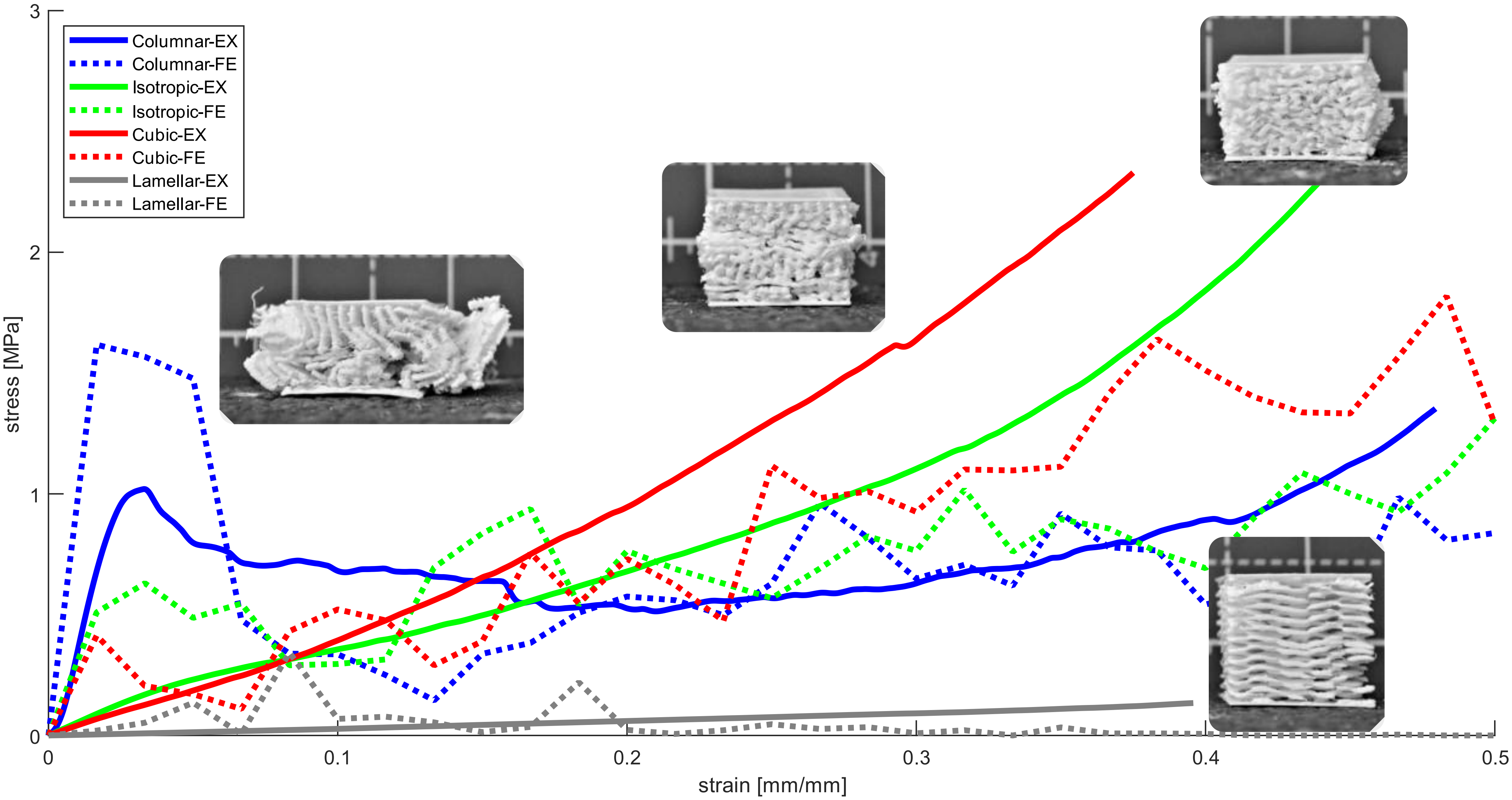
FE Modelling

FEM

- Hill plastic anisotropic model.
- Tetrahedral Elements
- General contact:
  - Contact between the specimen and the anvil and the loading upper plate
  - Self contact: internal surfaces contacting each other.
- Maximum strain failure.

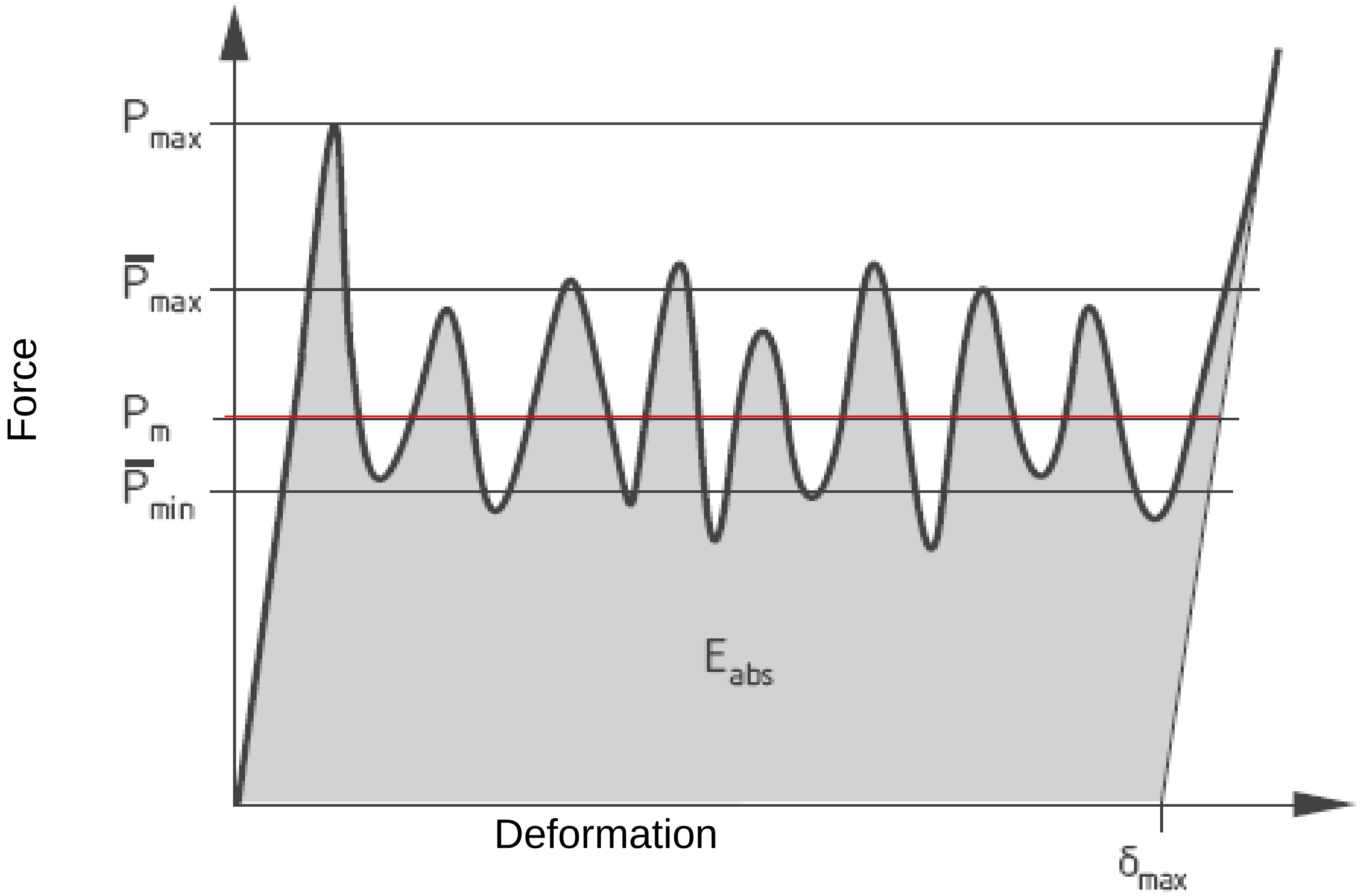


FEM vs Experiments-PETG



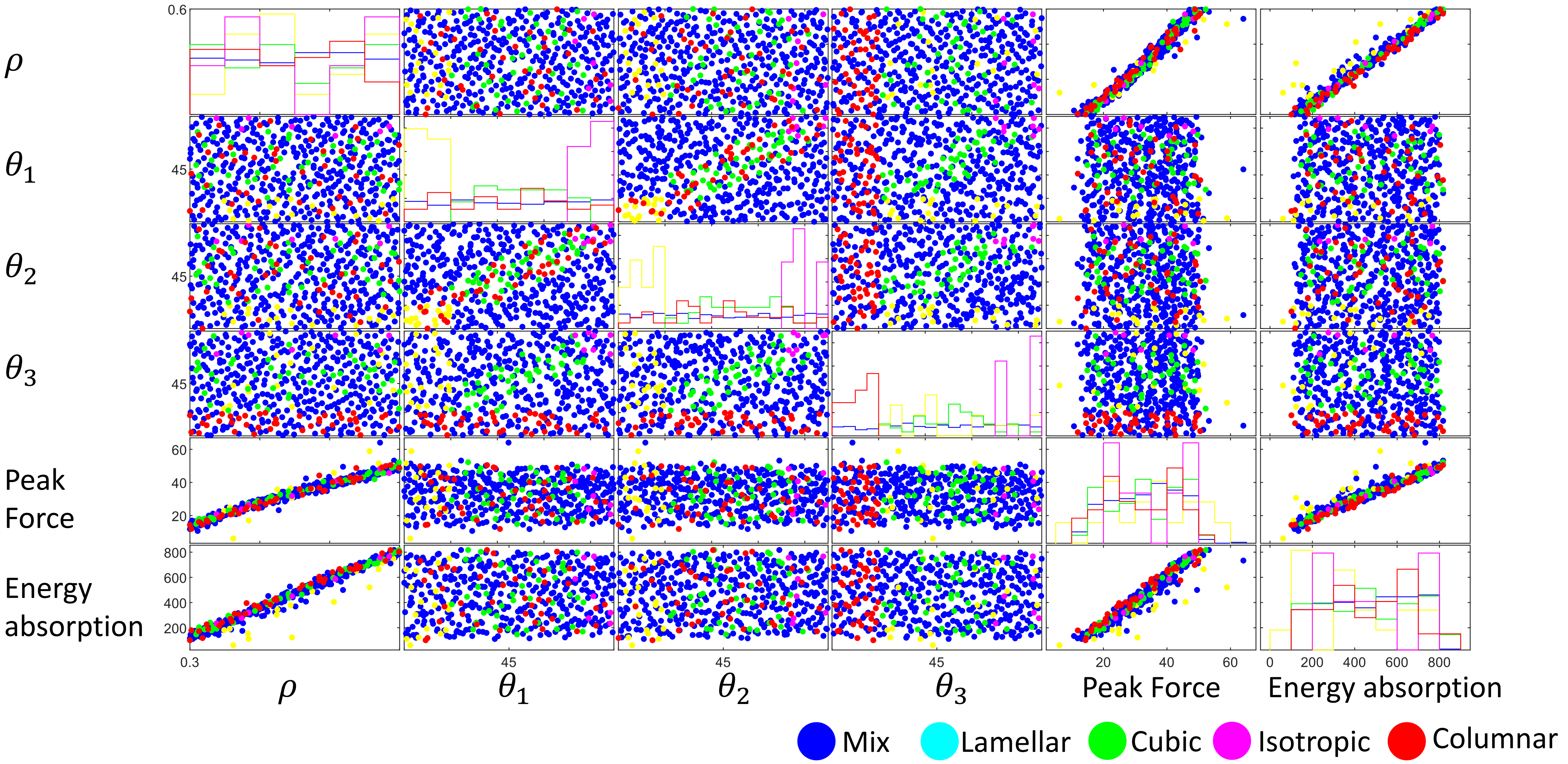
Optimisation

Objectives: Crush efficiency & Energy absorption

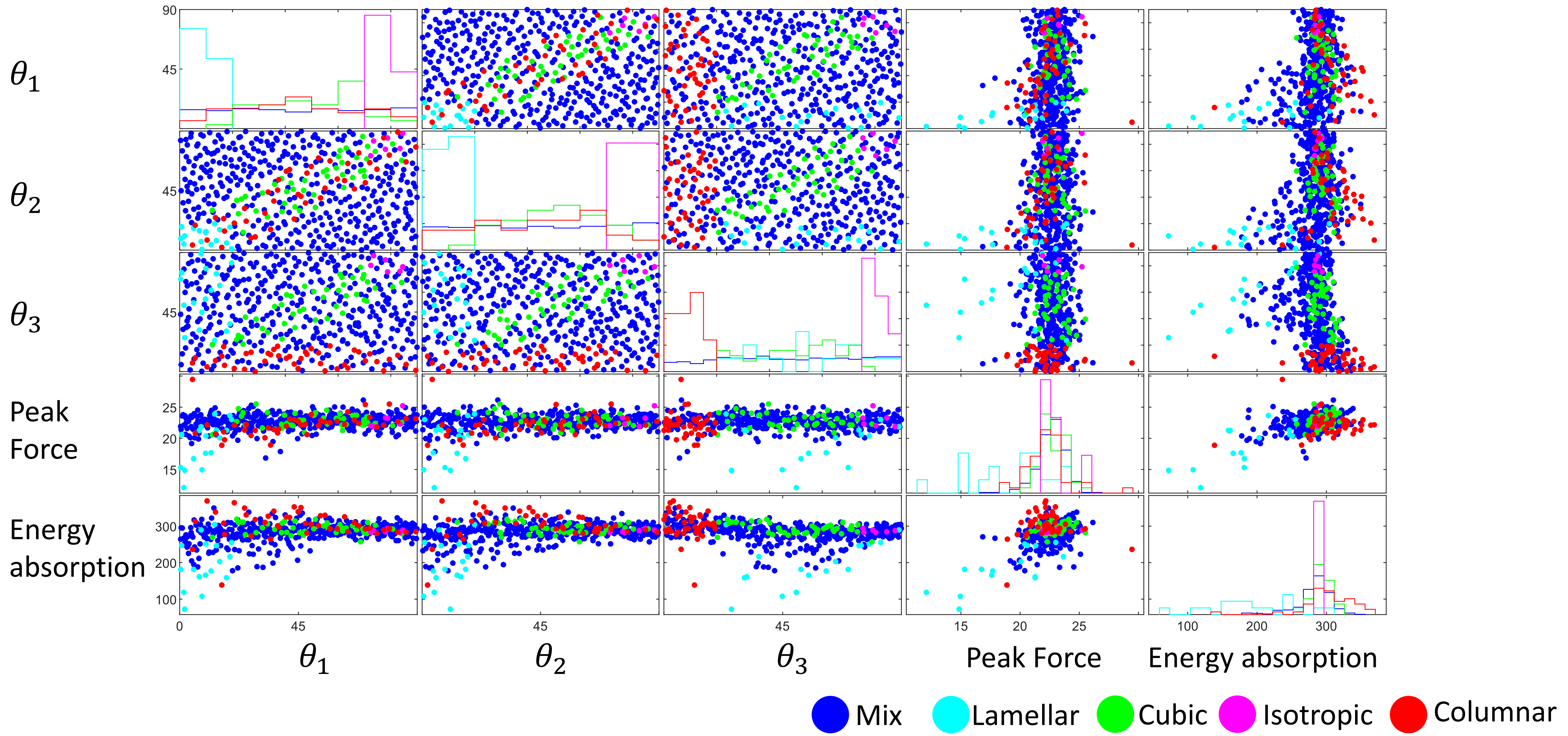


$$e_E = \frac{E_{absorb}}{P_{max} L_0} \approx \frac{P_m \delta_{max}}{P_{max} L_0}$$

Strong correlation between Ro and the objective functions despite the others!

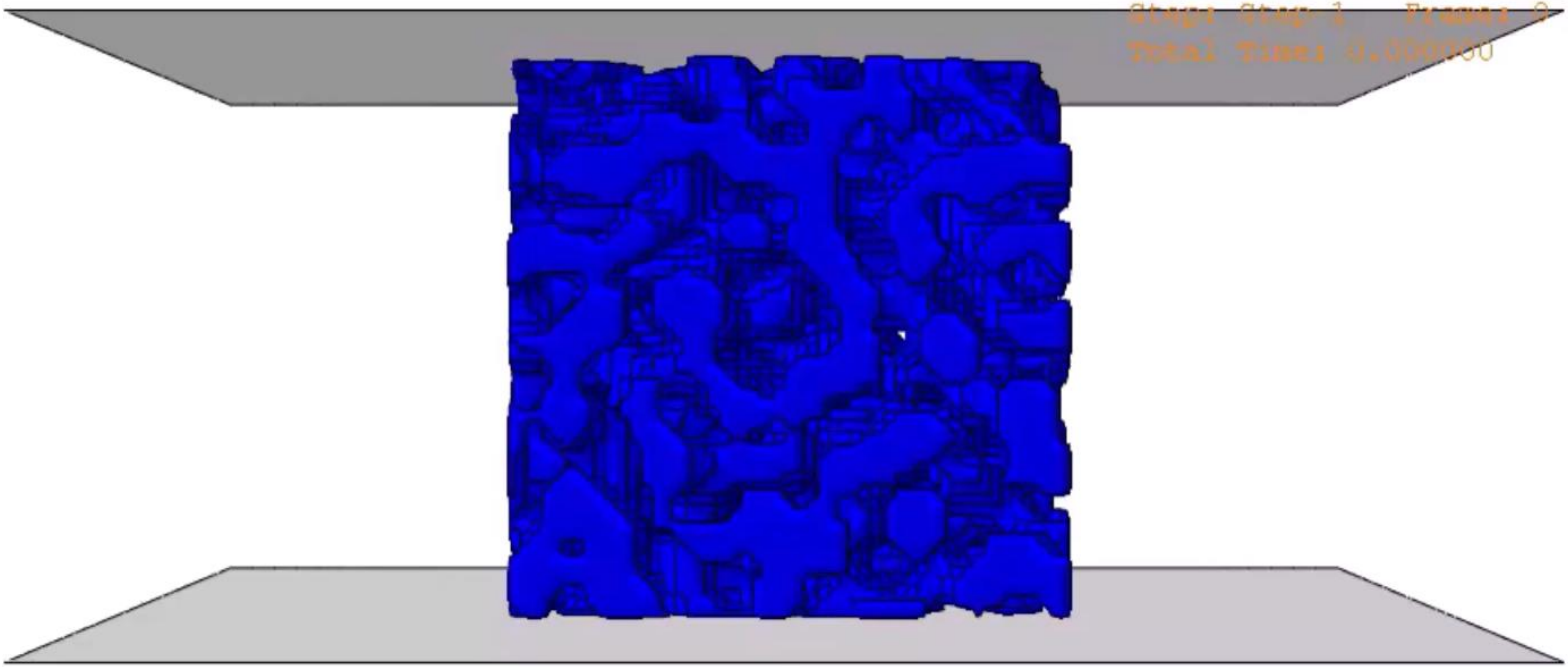


$\rho = 40\%$



θ_1
θ_2
θ_3
Peak Force
Energy absorption
90
45
0
15
20
25
100
200
300
Mix
Lamellar
Cubic
Isotropic
Columnar

Why Bayesian optimisation?!



Why Bayesian optimisation?!

- ❑ Highly nonlinear relationship between the topology and mechanical response.
- ❑ Computationally expensive.
- ❑ Large design space

⬇

Bayesian optimisation

Bayes's Theorem $P(A|B) = \frac{P(A|B)P(A)}{P(B)}$

$P\left(E_A^{max} | \left[\rho, \theta_i^{i=1,2,3}\right]\right)$

Maximum Probability Estimation for a dataset

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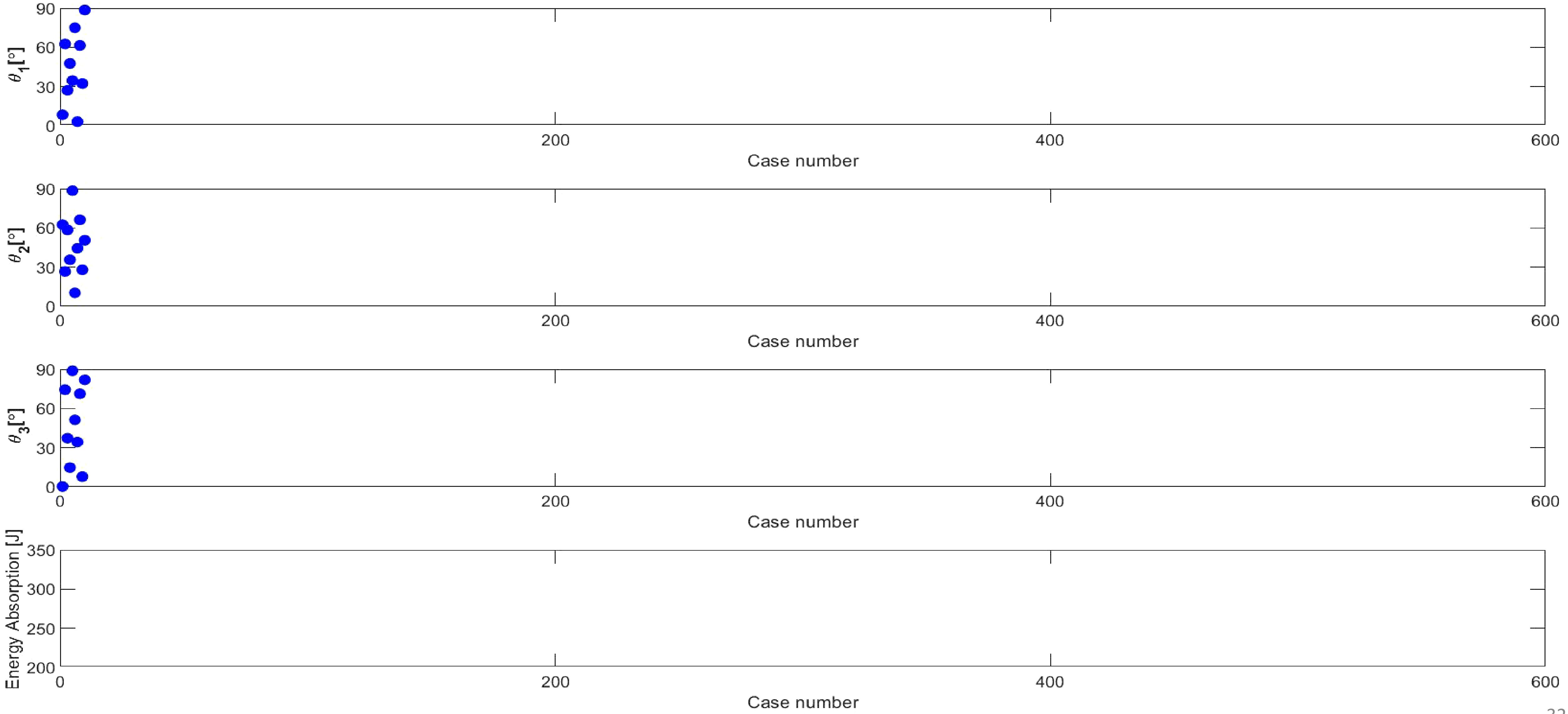
$\Sigma_{i,j}$: Covariance: how x_i and x_j are correrlated

$$P(x;\mu,\Sigma)=\frac{1}{(2\pi)^{\frac{d}{2}}|\Sigma|}e^{-\frac{1}{2}\left((x-\mu)^T\Sigma^{-1}(x-\mu)\right)}$$

We use Kernel function to estimate $\Sigma_{i,j}$

Results of the Optimisation

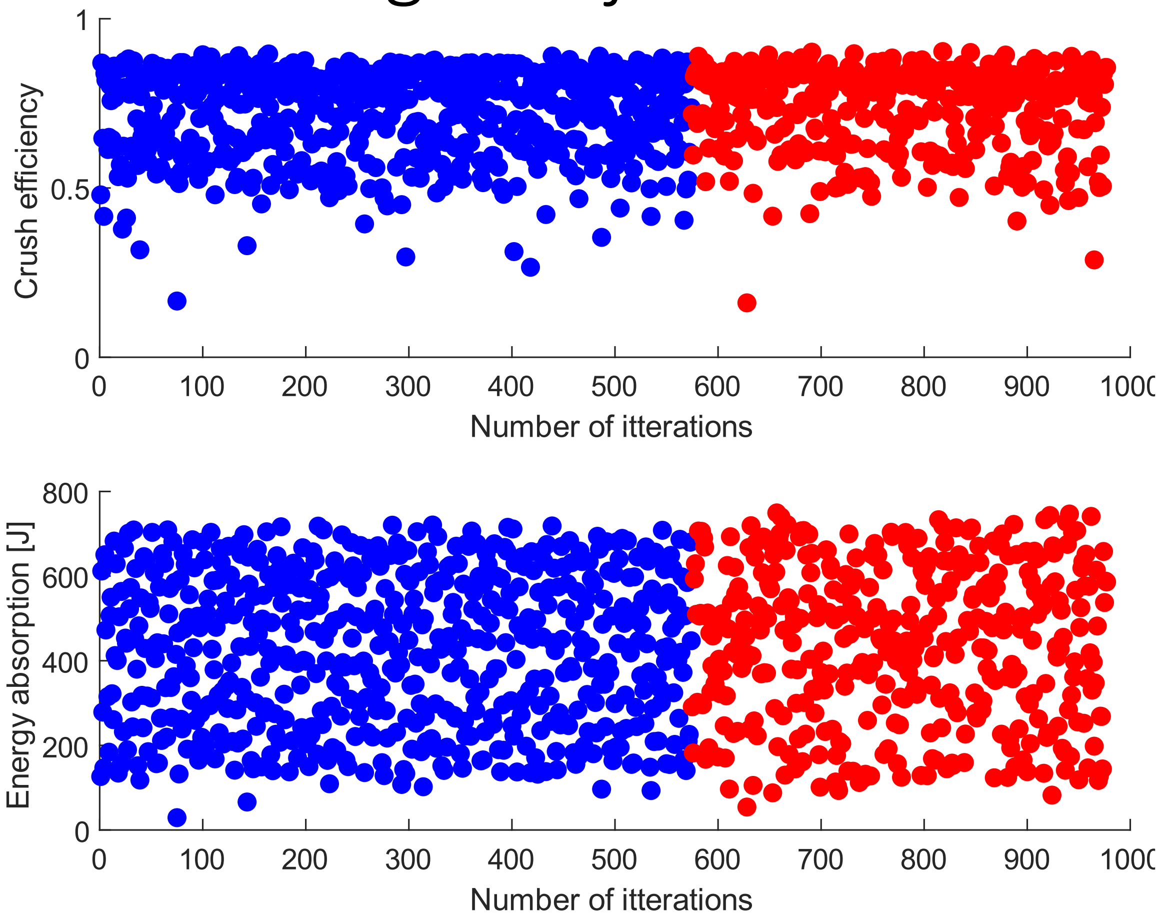
Optimisation: 1 Objective function & 3 variables



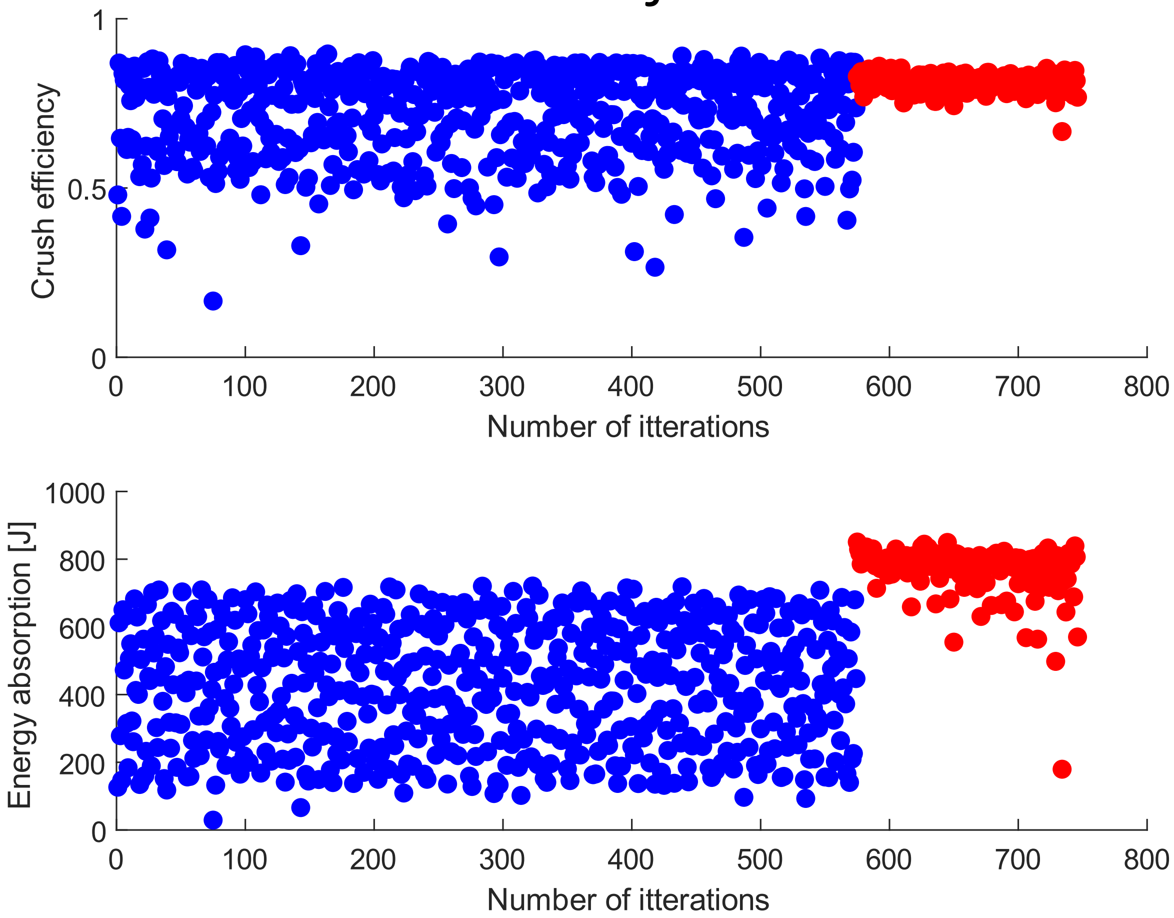
Single VS Multi objective function

- ❑ Objective functions: Crush efficiency and Energy absorption.
- ❑ Converging much quicker in the case of multi-objective optimisation.

Single Objective



Multi Objective



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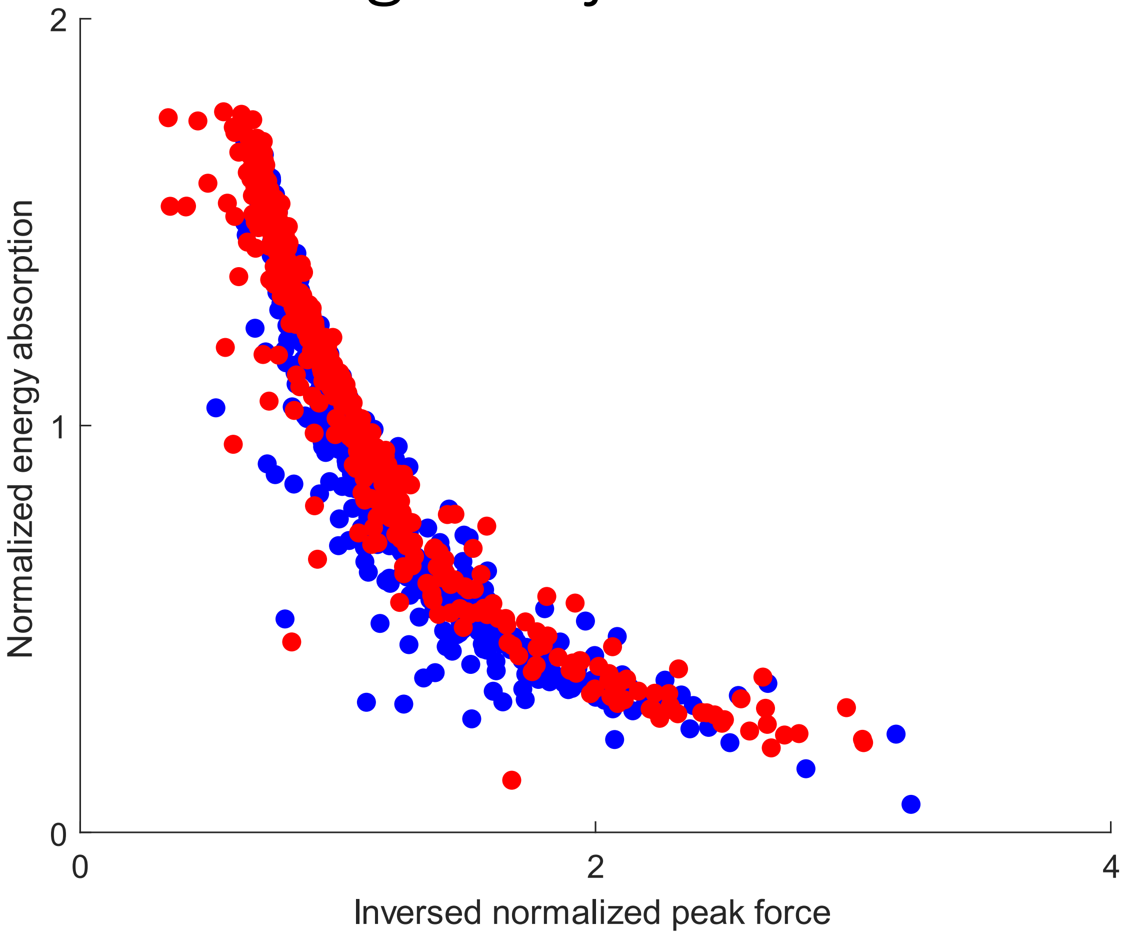
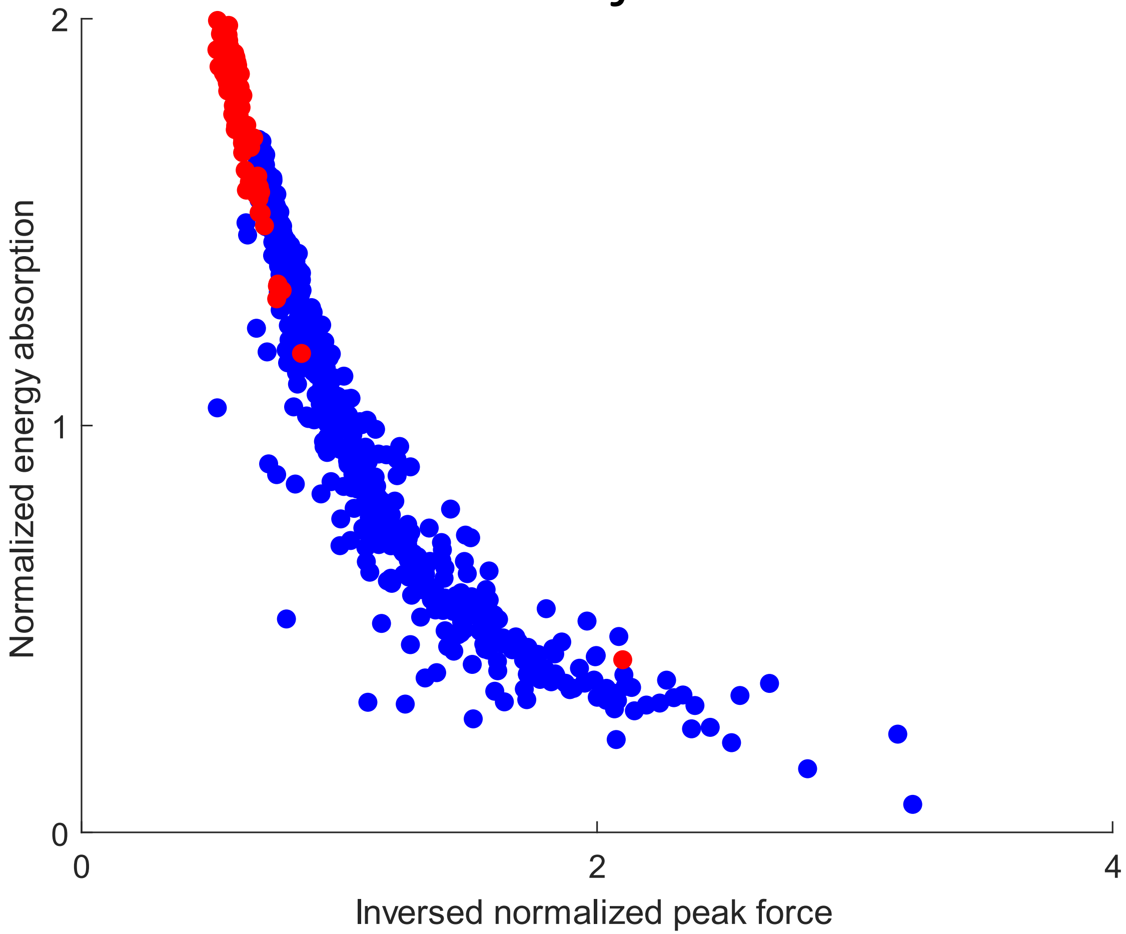


Multi Objective



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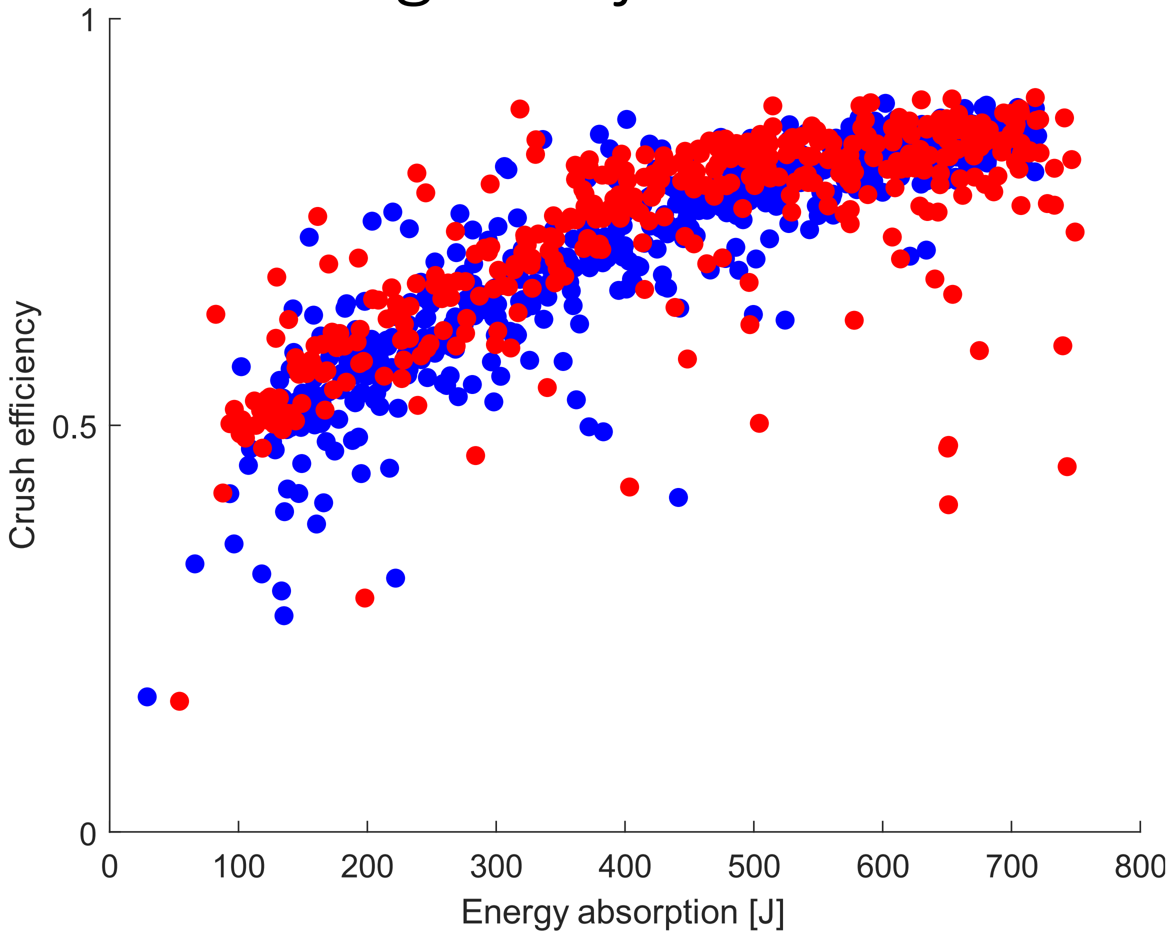
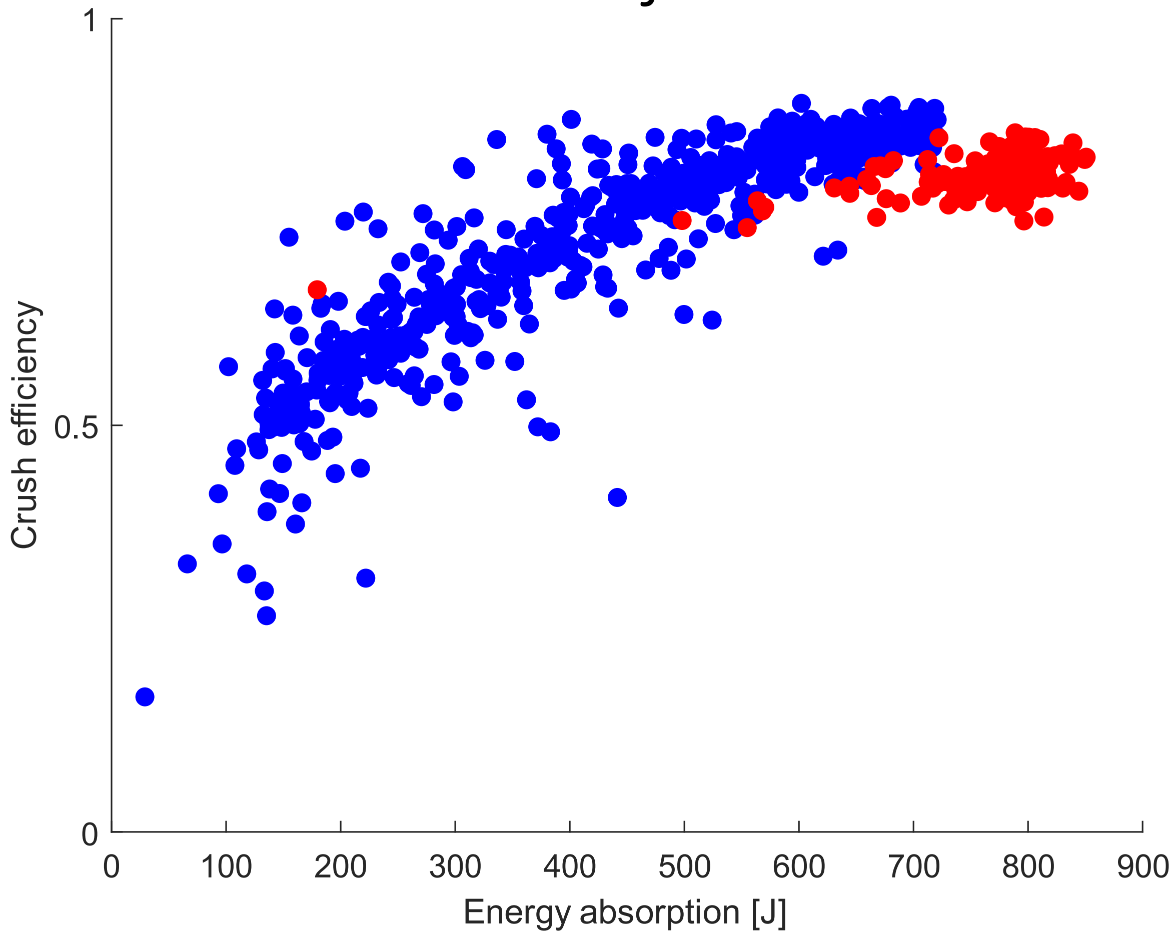


Multi Objective



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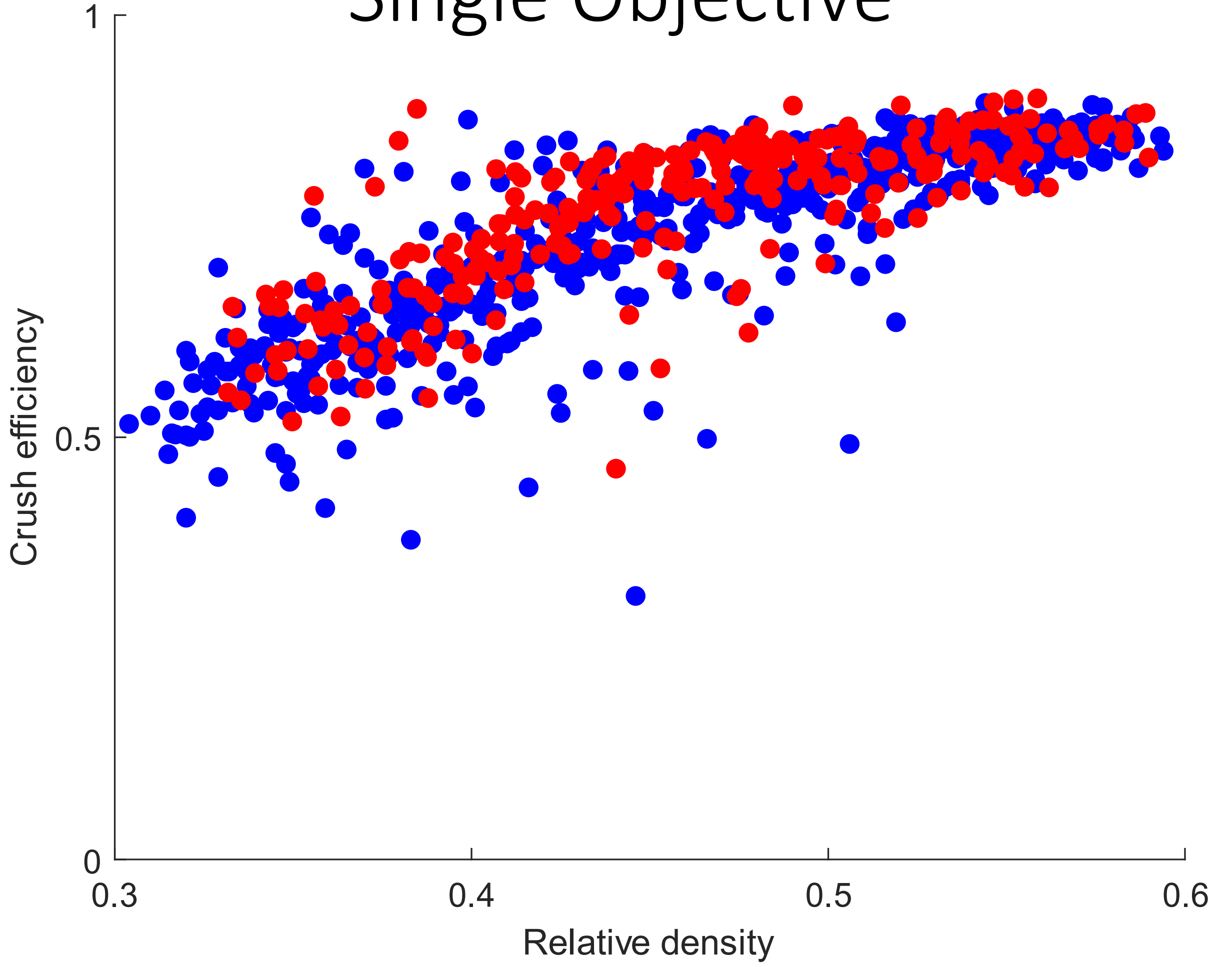
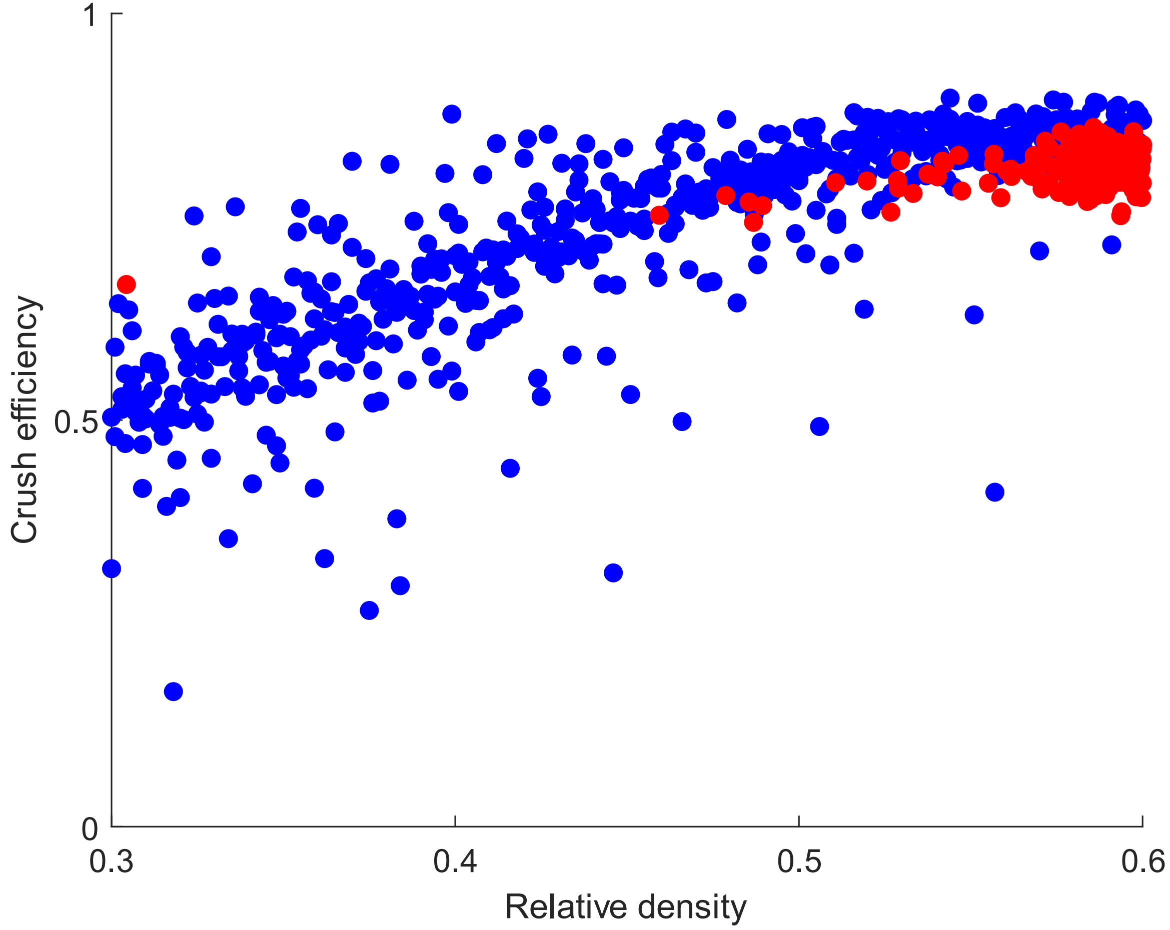


Multi Objective



Summary and future work

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Experimental tests

- ❑ Material characterization
- ❑ Crushing spinodal structures

FE modelling

- ❑ The results of FEM are in good agreement with the experimental tests results.

Optimisation

- ❑ A data-driven optimisation framework has been developed for multi-objective topology optimisation of spinodal structures.
- ❑ The framework has been successfully used to find the best spinodal structure to maximise CE and EA simultaneously.

Future work

- ❑ Scale up the framework for larger structures featuring different types of spinodal structures at different points.

github.com/MCM-QMUL/CELLCOMP

Thanks!

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FEM vs Experiments-PETG: Columnar