University of Maribor
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Simulations and Optimisation of Functionally Graded Auxetic Structures

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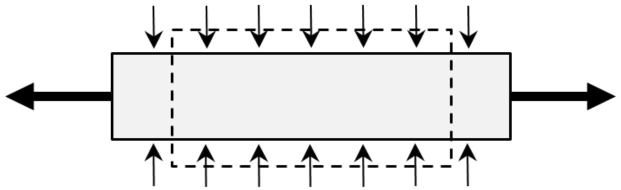
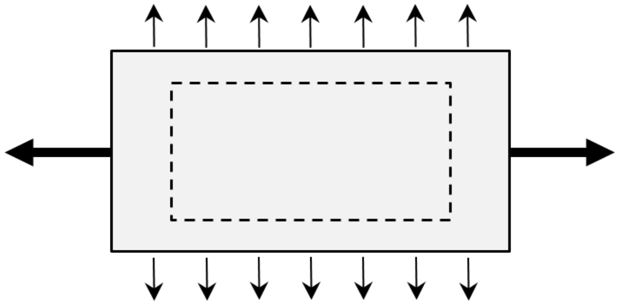
Summary

- Auxetic materials
- Motivation
- Introduction of auxetic cellular structures build from tetrapods
- Experimental testing
- Numerical modelling
  - Lattice numerical model built with beam finite elements (FE)
  - Homogenised numerical model built with volume FE
- Functionally graded porosity and response optimisation of auxetic cellular structure
- Conclusions and future prospects

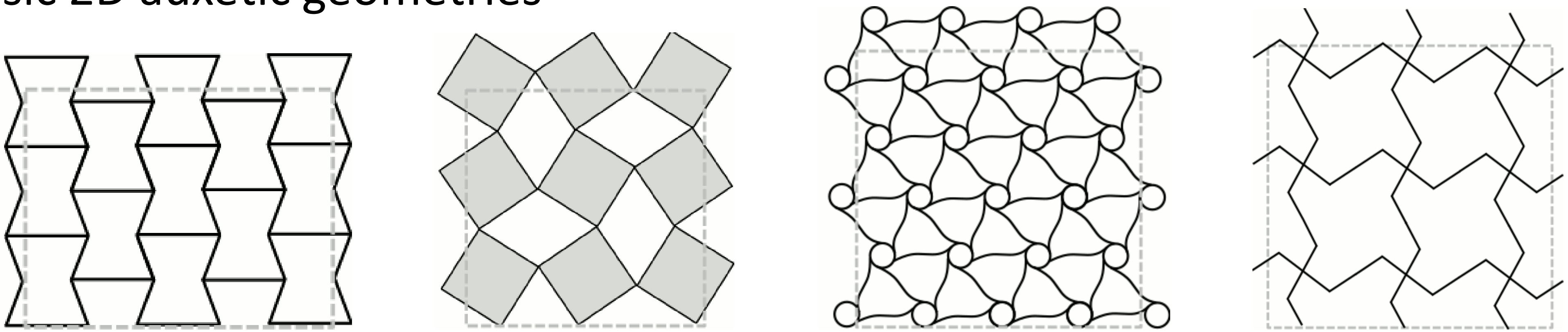
Auxetic materials

- Name originates from Greek word *auxetos* – „tends to increase“ (Evans et al., Nature, 1991)
- This group of materials includes materials with negative Poisson‘s ratio:



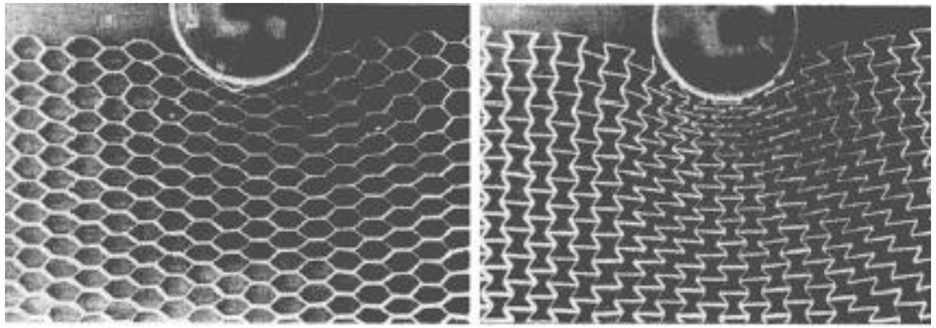


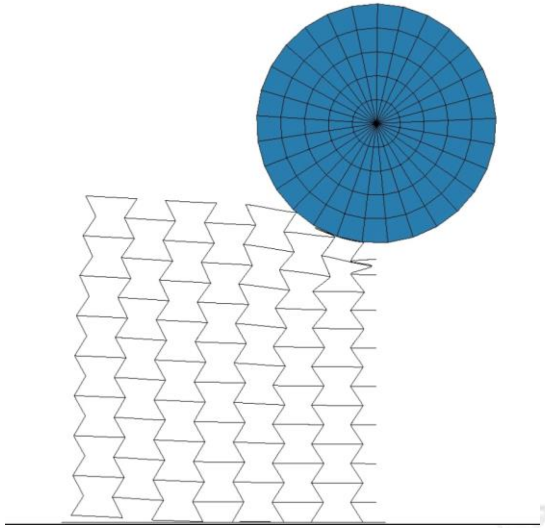
- Basic 2D auxetic geometries



Auxetic materials

- To achieve negative Poisson‘s ratio materials must be porous (cell walls can bend and deform in desired shape)
- The advantages that can be achieved using these materials:
  - unique deformation behaviour,
  - enhanced shear toughness $G = K\,\frac{3(1-2\nu)}{2(1+\nu)}$,
  - in case of impact material moves towards the impact zone,
  - better energy absorption.



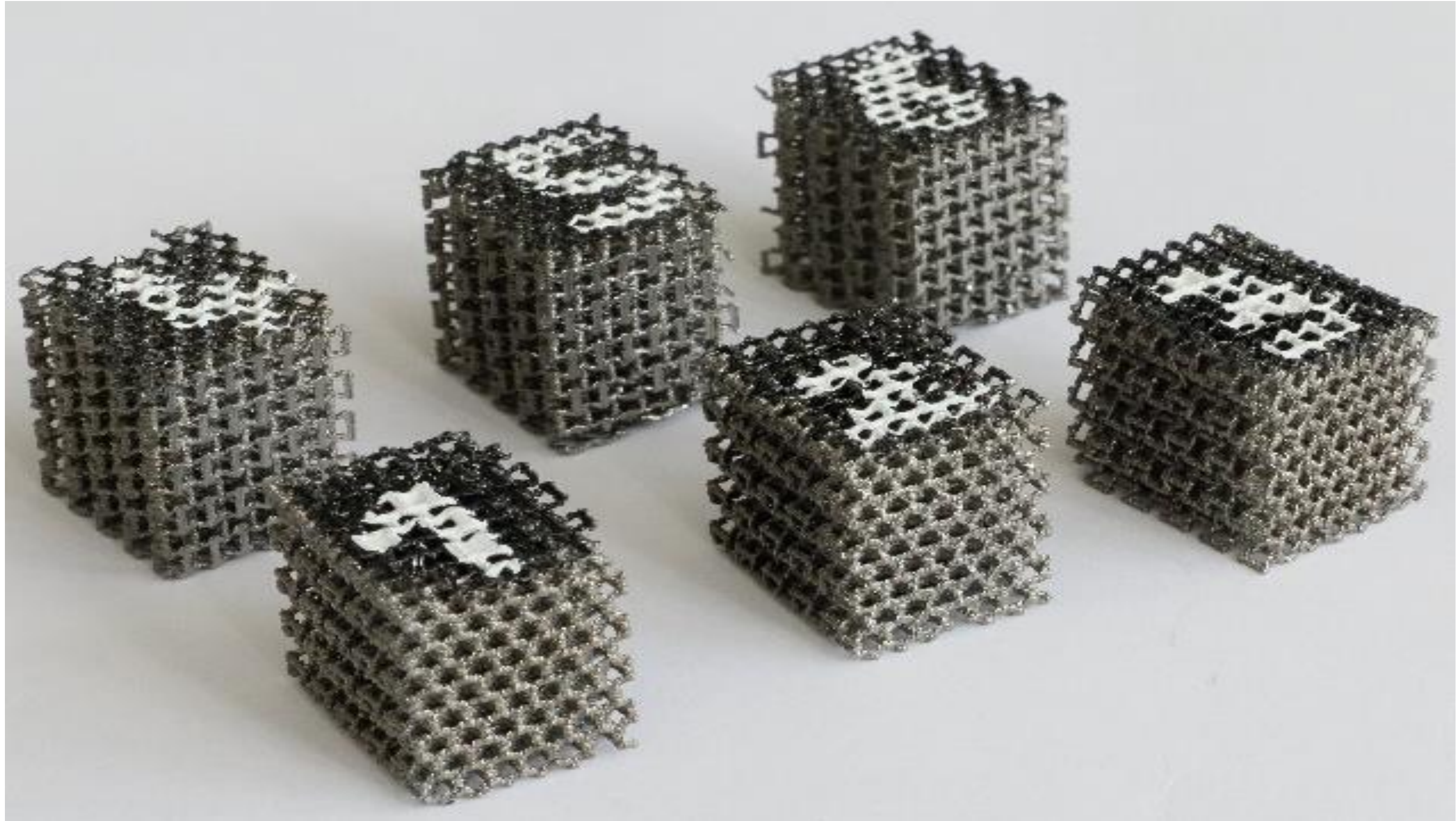


Motivation

- Great potential of auxetic structures in improving energy absorption in case of an impact
- This can be further enhanced with introduction of graded porosity (N. Novak, M. Vesenjak, and Z. Ren, “Auxetic cellular materials - a Review,” *Strojniški Vestn. - J. Mech. Eng.*, vol. 62, no. 9, pp. 485–493, 2016)
- User defined response of graded auxetic structures can be achieved using optimisation techniques and numerical simulations
- Dynamic response of graded auxetic structures at different strain rates must be evaluated with numerical models and experiments

Geometry of auxetic structure

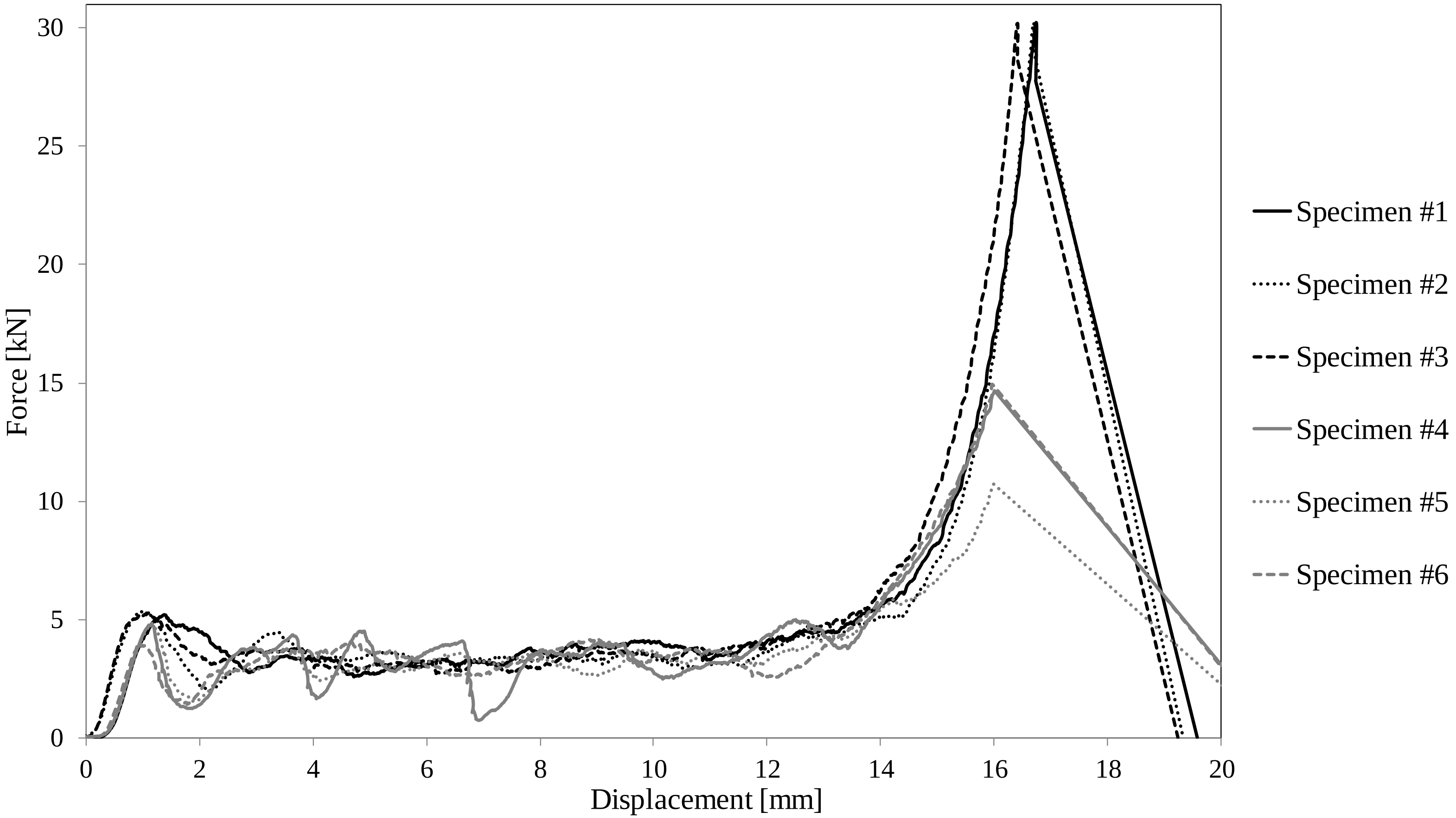
- Build from „inverted tetrapods“ (Schwerdtfeger et al., Physica Status Solidi (B), 247 (2), 2010)



Method: SEBM
Material: $Ti6Al4V$
Struts thickness: ≈0.5 mm

Compression testing

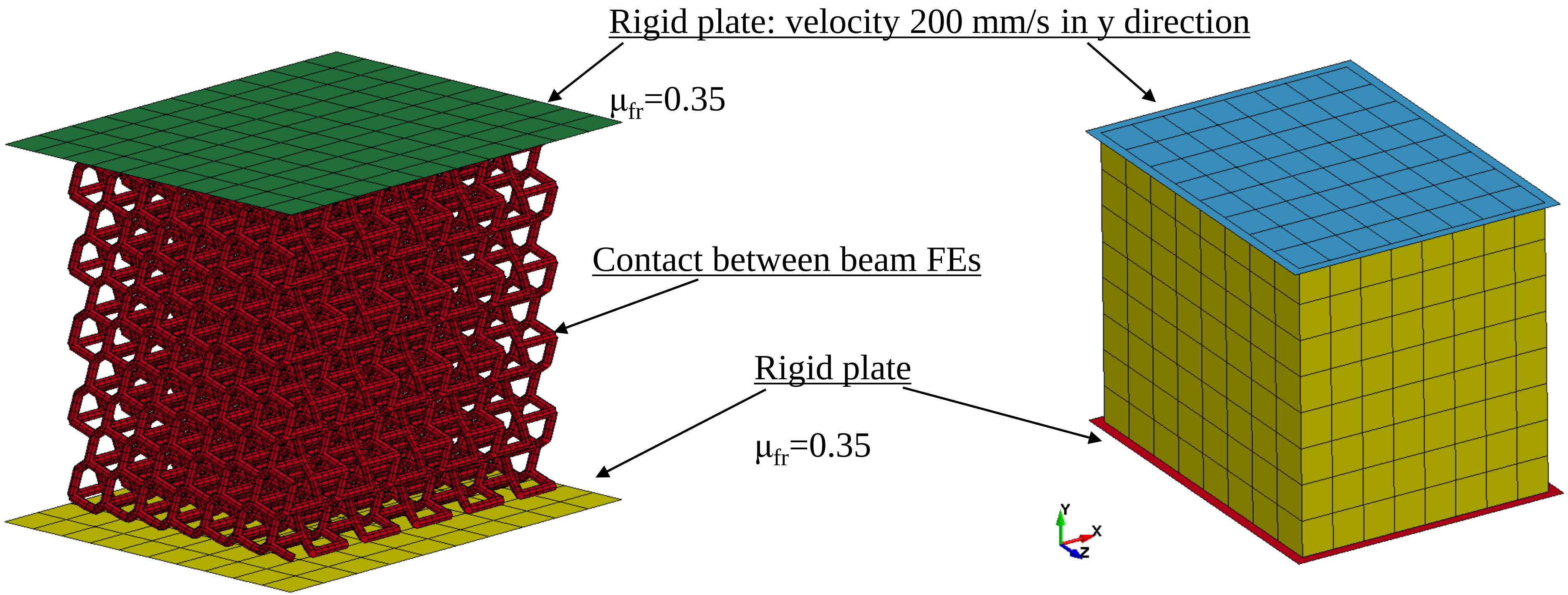
- Instron 8801 testing machine
- Cross-head rate 0.1 mm/s
- Specimens were compressed in two orthogonal directions



Numerical models in Ls-Dyna

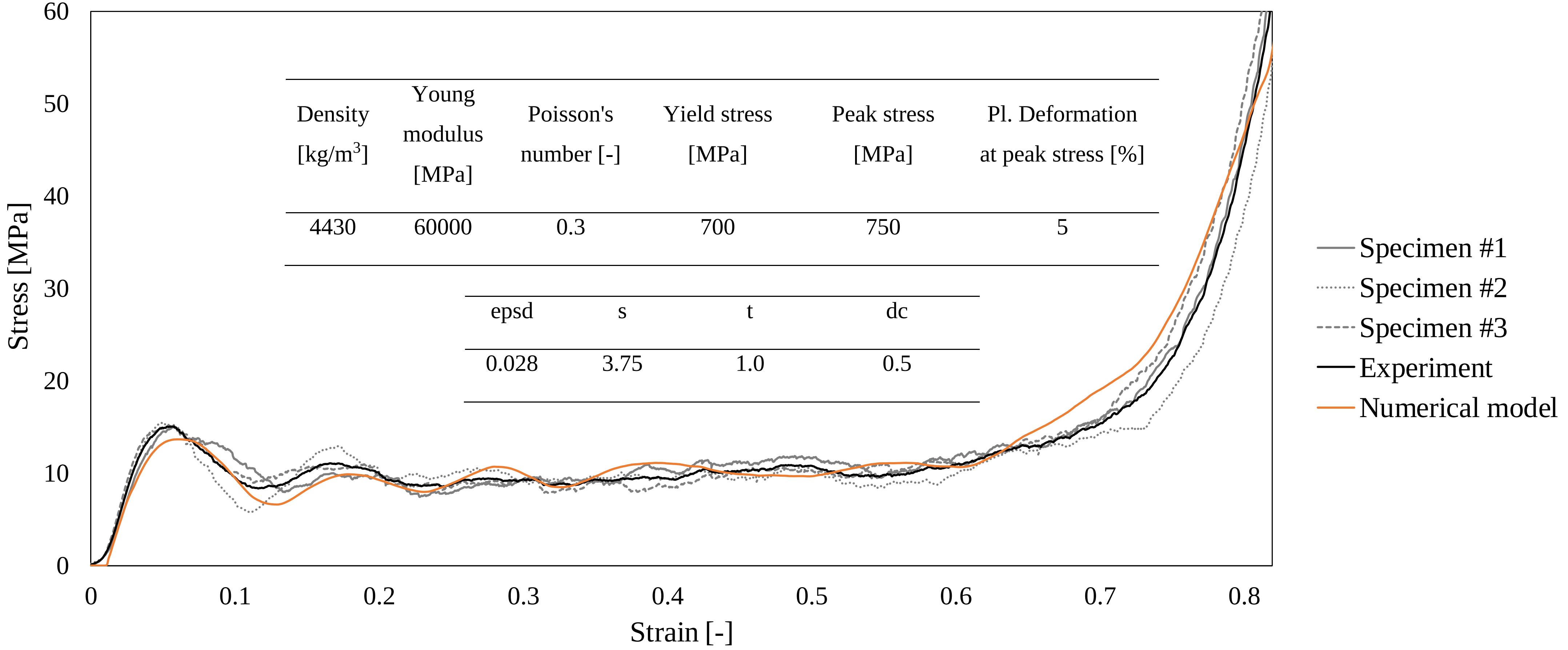
Lattice model
described with beam FE

Homogenised numerical model
described with volume FE



Results from numerical models (beam FE)

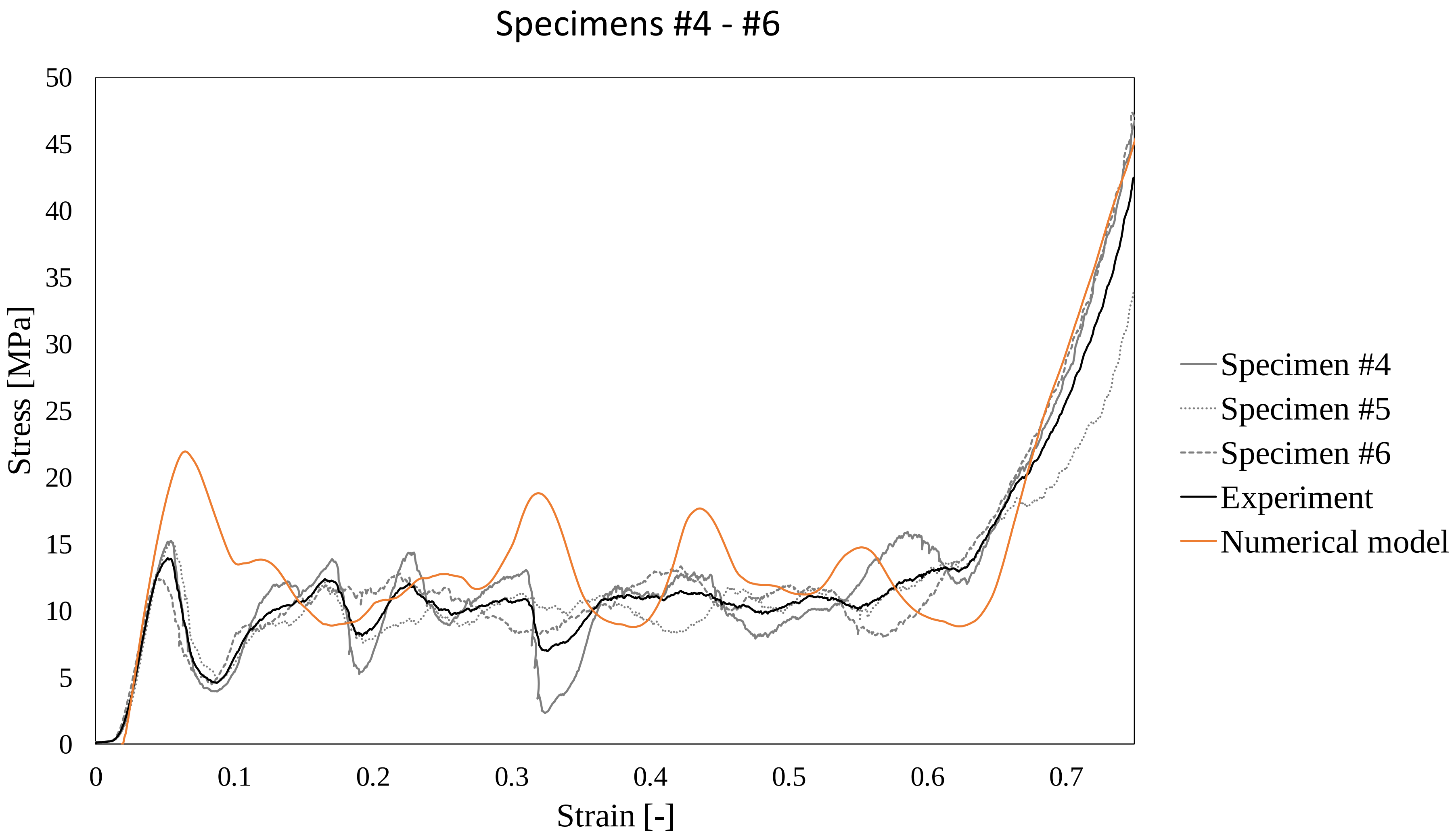
- Material parameters of MAT_153 were determined using parametrical simulations



Density [kg/m^3]	Young modulus [MPa]	Poisson's number [-]	Yield stress [MPa]	Peak stress [MPa]	Pl. Deformation at peak stress [%]
4430	60000	0.3	700	750	5

epsd	s	t	dc
0.028	3.75	1.0	0.5

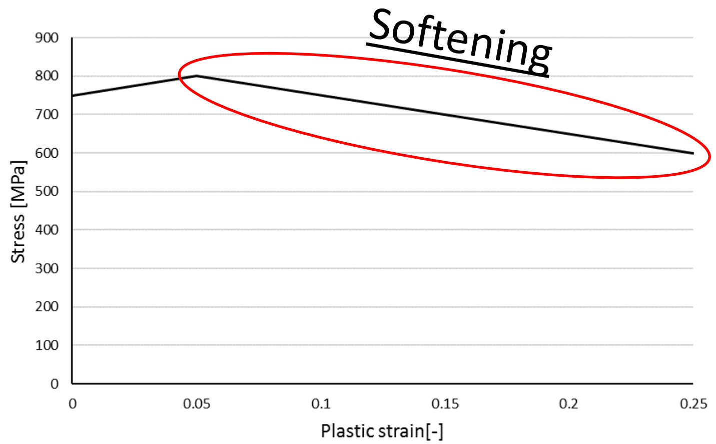
Results from numerical models (beam FE)



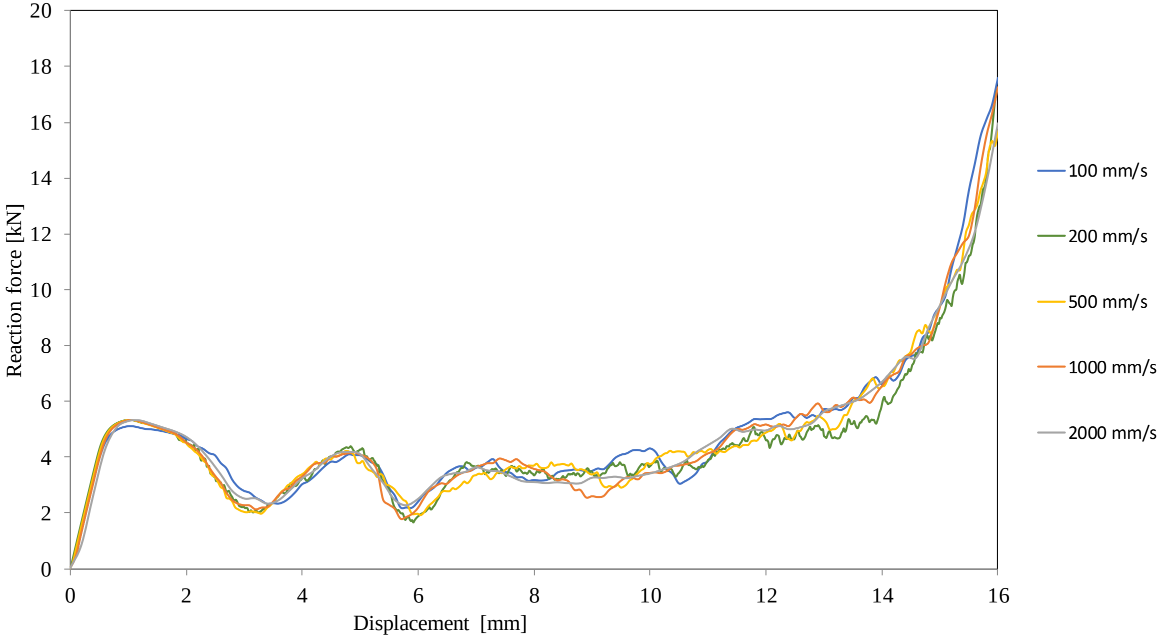
MAT_024

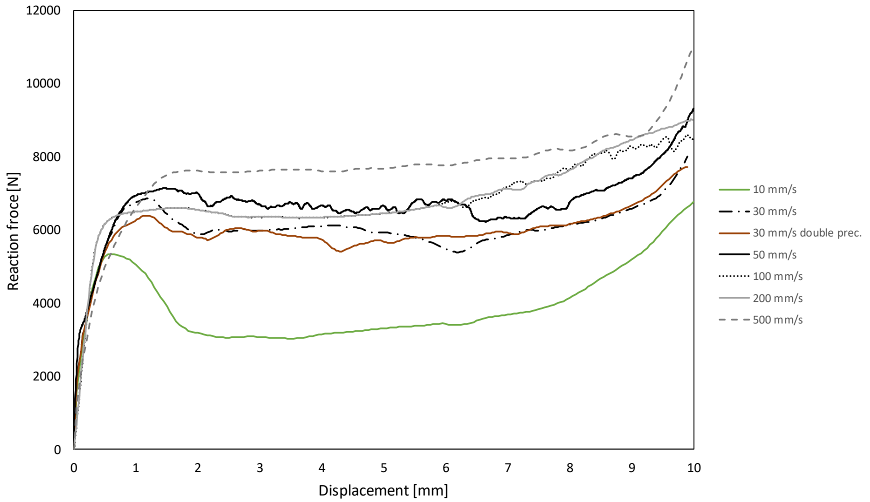
- Material parameters:

E [MPa]	$\sigma_{y,1}$ [MPa]	$\sigma_{y,2}$ [MPa]	$\varepsilon_{pl,2}$ [%]	$\sigma_{y,3}$ [MPa]	$\varepsilon_{pl,3}$ [%]
60000	750	800	5	600	25

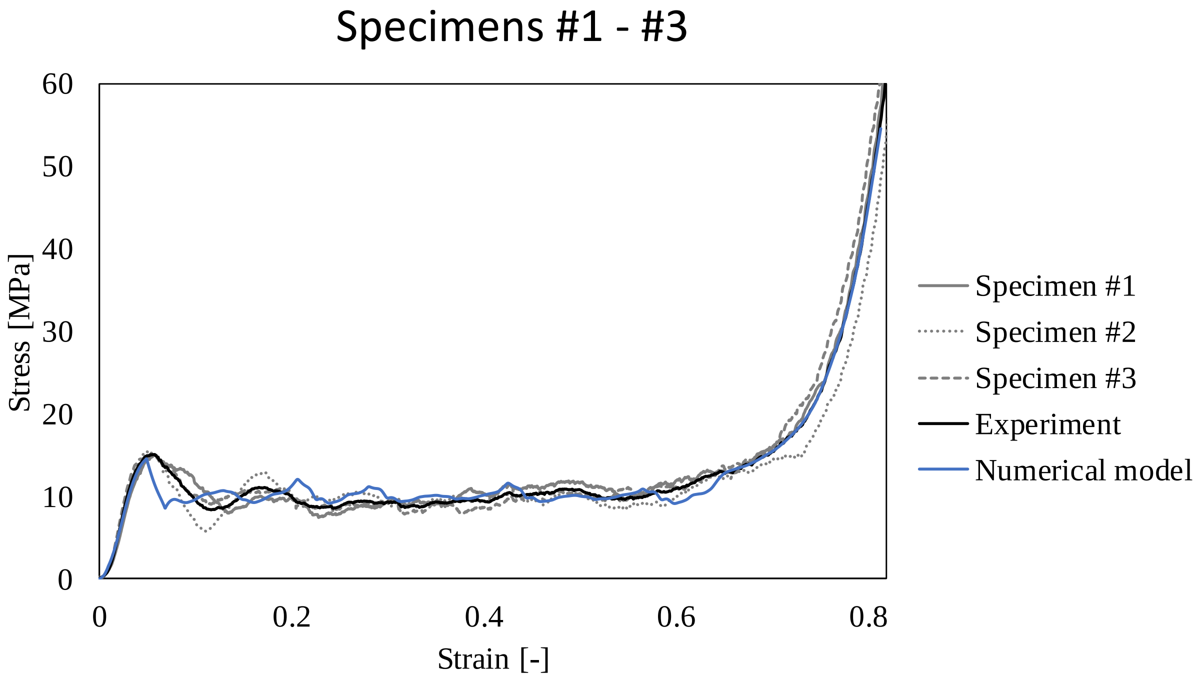


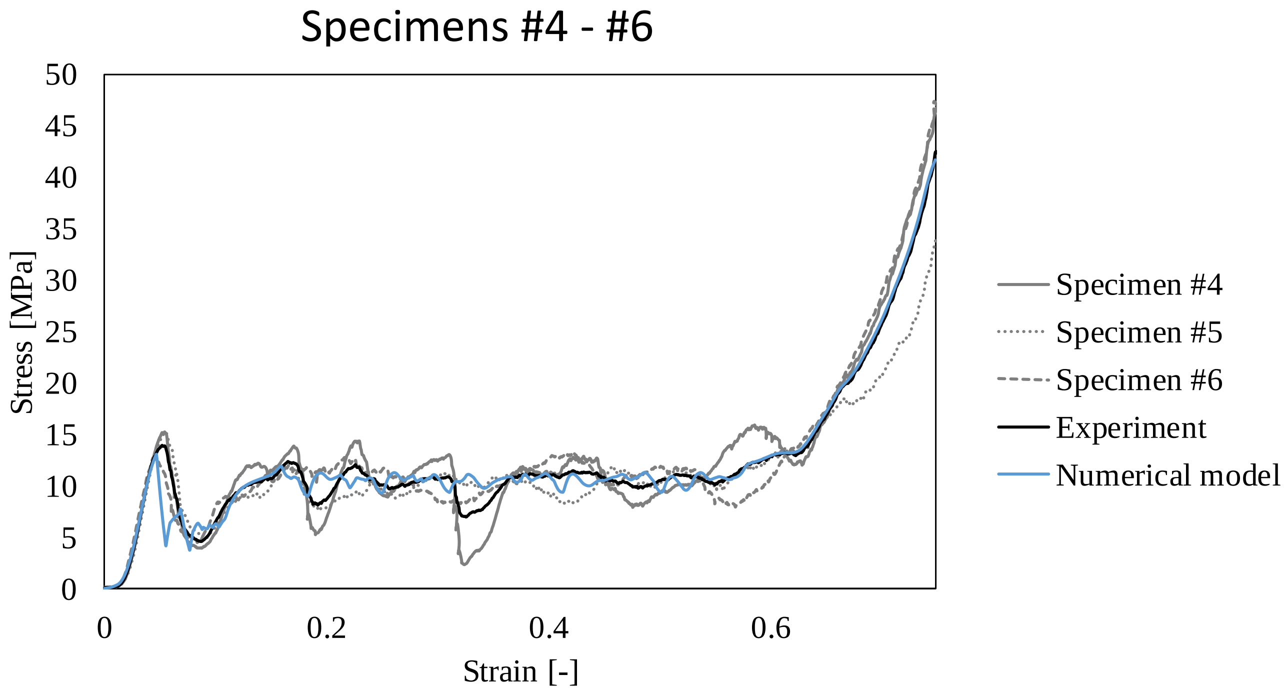
- Velocity of the impacting plate analysis:
    - MAT_024
    - MAT_153





Results from homogenised numerical model with material model MAT_063

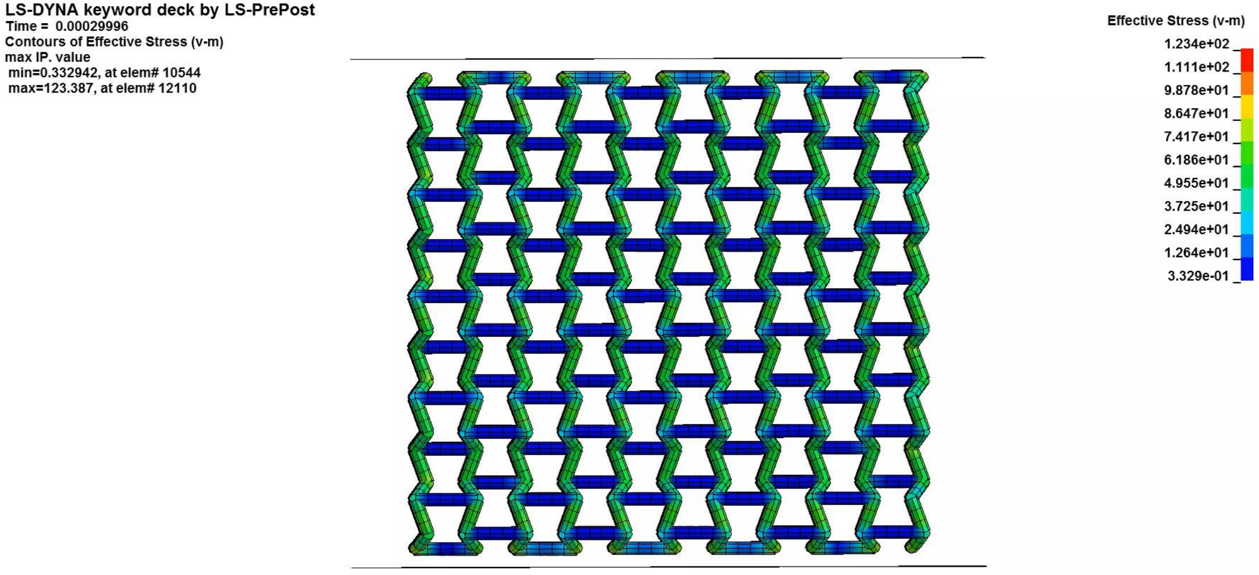


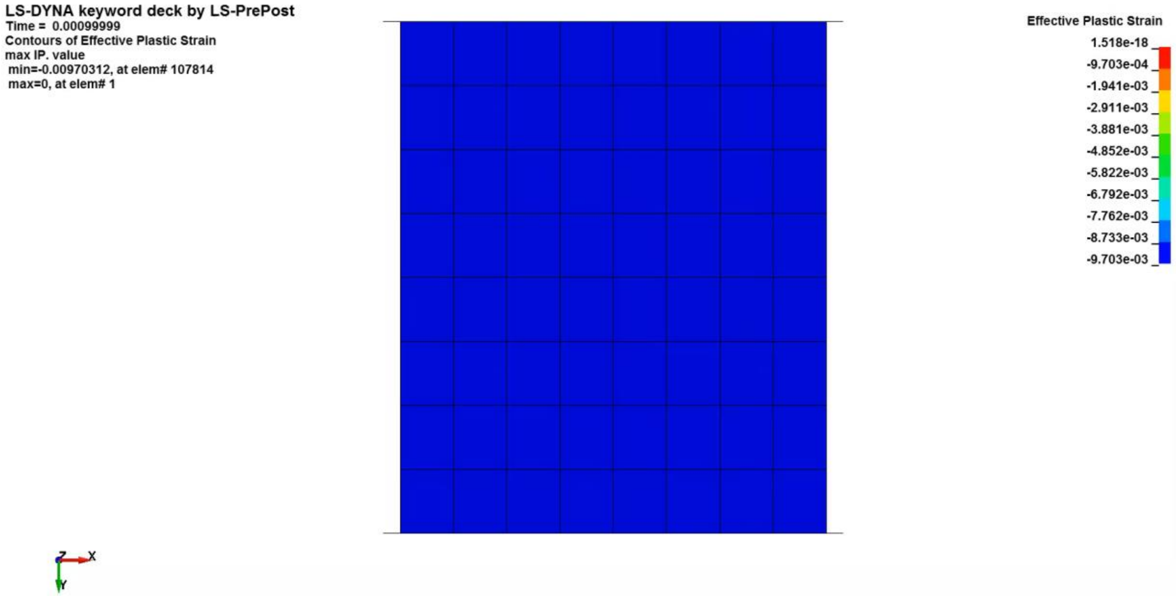


	Specific deformation energy [J/kg]
Experiment	9.66
Homogenised numerical model	9.64

	Specific deformation energy [J/kg]
Experiment	9.19
Homogenised numerical model	9.24

Visual comparison between experiment and numerical models

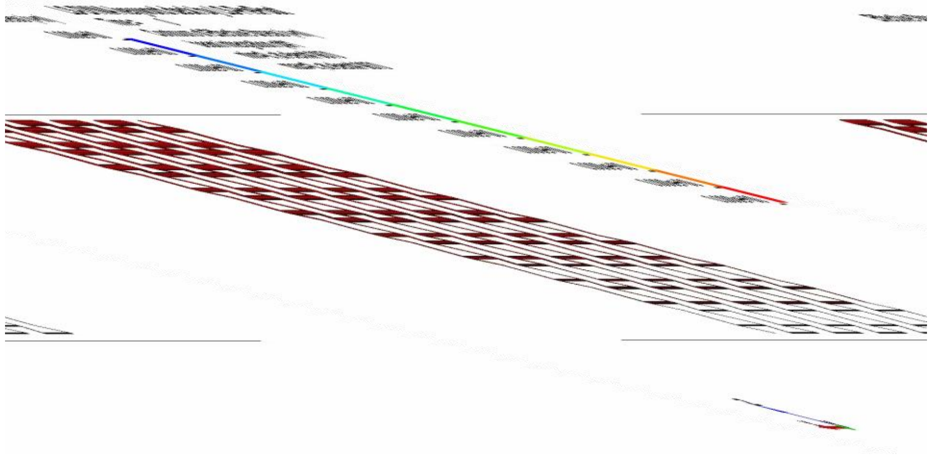




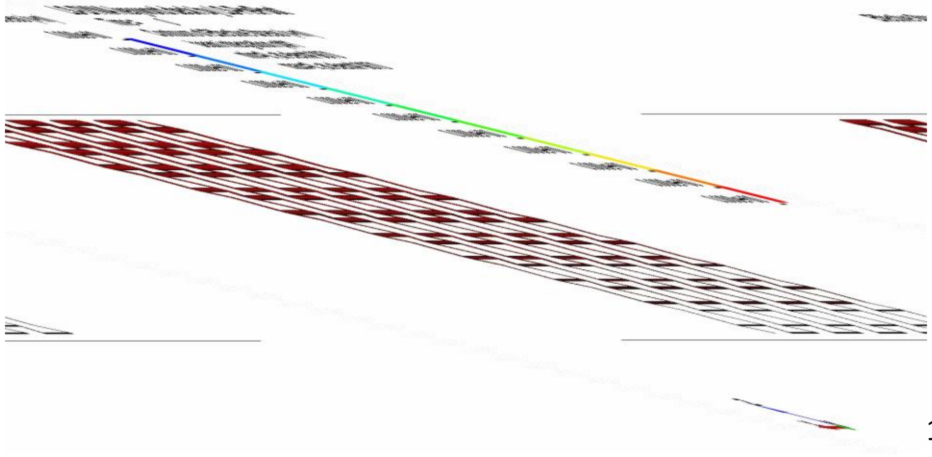
Functionally graded porosity

- With functionally graded porosity we can tailor the response of the structure
- Effect of graded porosity is more important above the critical strain rates (due to inertia effects main deformation occurs only on the deformation front between impacting plate and structure)

High velocity impact (200 m/s)

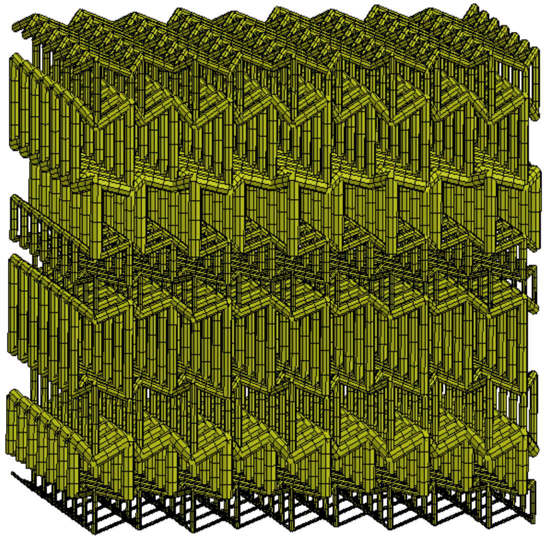
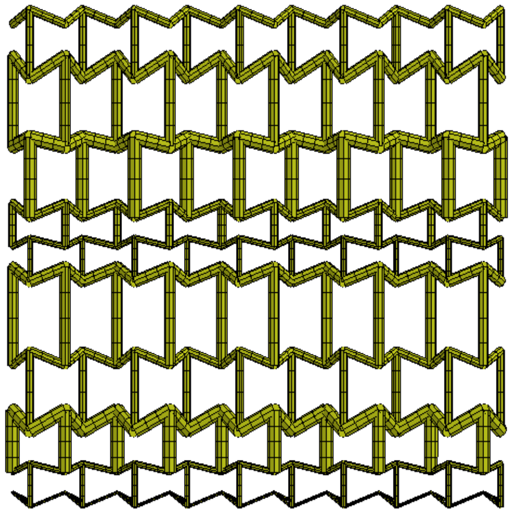
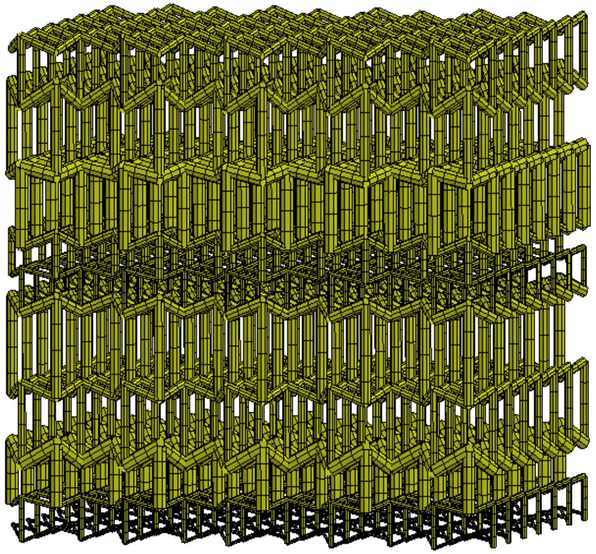


Low velocity impact (200 mm/s)



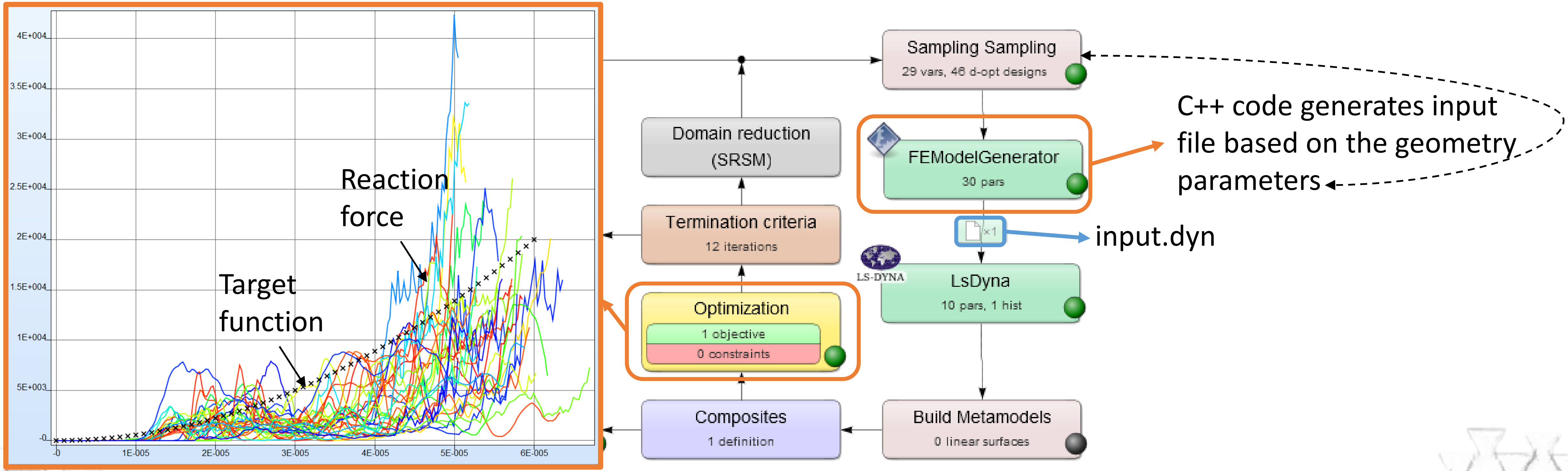
Functionally graded porosity

- How can we achieve graded porosity?
  - To modify struts thickness
  - To modify geometry of the structure
  - To modify struts thickness and geometry of the auxetic structure

Functionally graded porosity

- Ls-Opt optimisation software
  - <u>curve matching and MSE composite</u> (e.g. compare reaction force with target function)

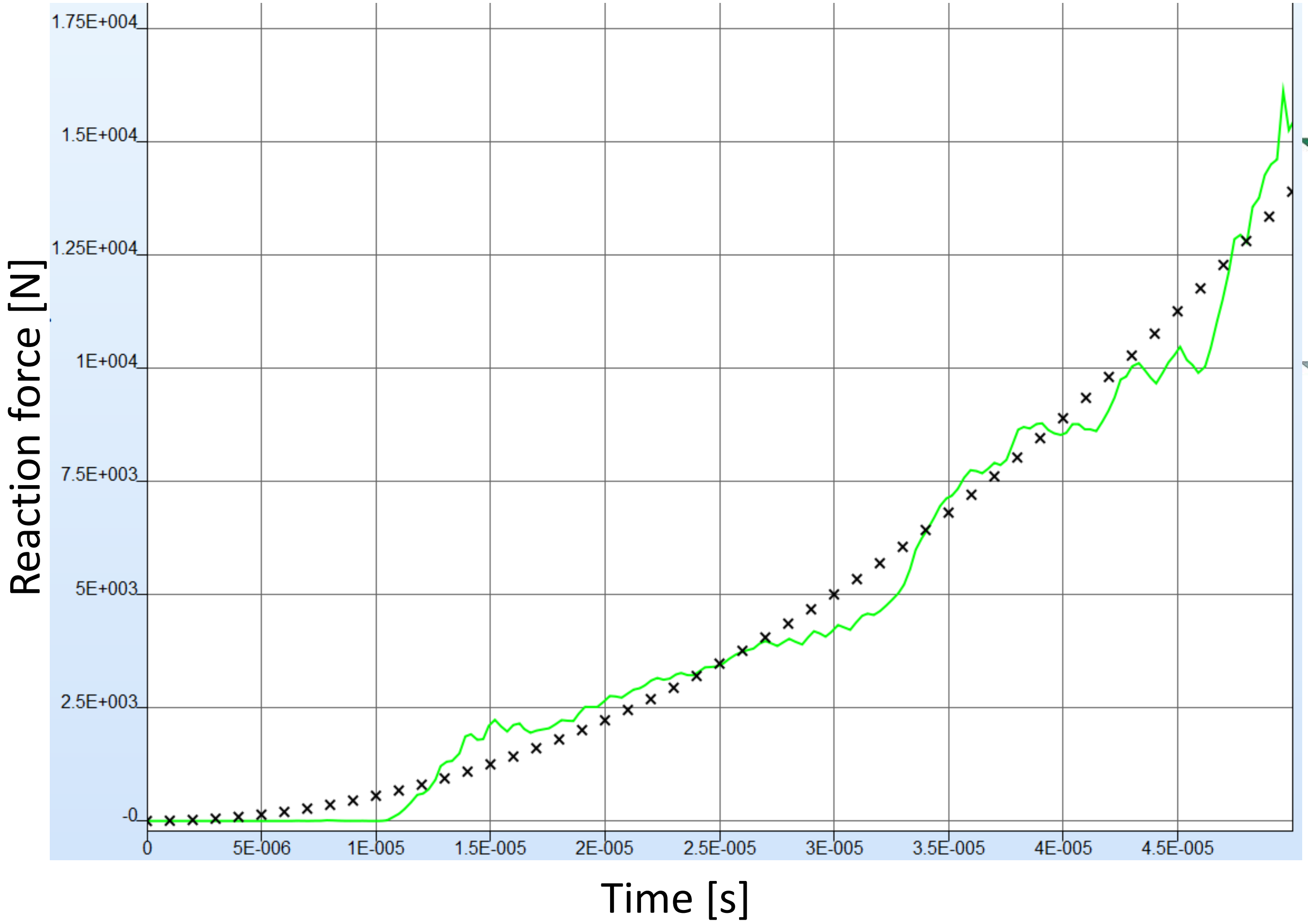


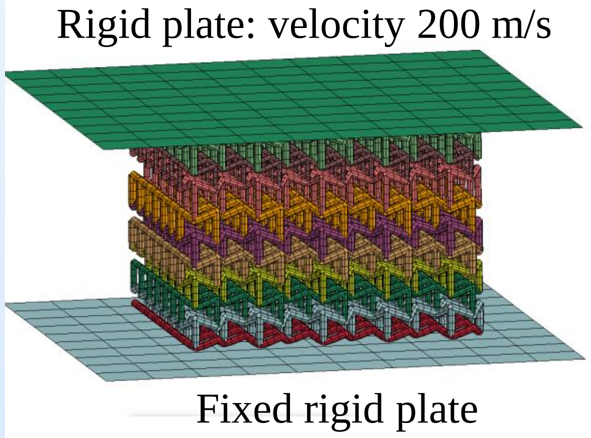
Case study

- Reaction force on bottom plate have progressive characteristic

Iteration 12

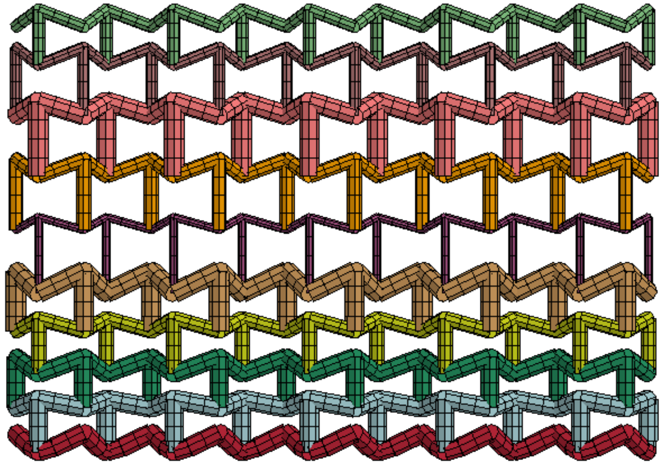
Curve mapping

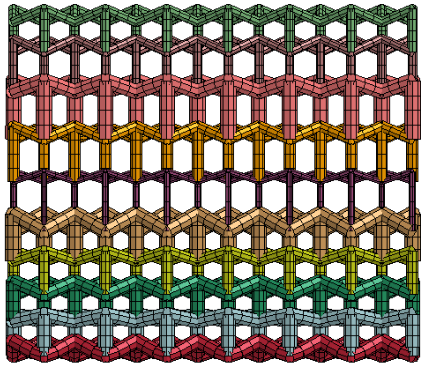




Case study

- Reaction force on bottom plate have progressive characteristic





Conclusions and future prospects

- Auxetic cellular structures built from inverted tetrapods were introduced
- Auxetic structures were experimentally tested
- Two different numerical models were developed and validated
- New auxetic geometries with functionally graded porosity were developed based on validated numerical models
- Future work:
  - Auxetic structures built from more ductile material
  - Validation of numerical models with dynamic experimental testing of functionally graded auxetic materials
  - Detect limit velocity at which structure still have adequate time to react in Ls-Dyna and experiments
  - Development of new graded auxetic structures with user defined response on particular loading conditions

Thank you for your attention!