FEA modelling of compressive impacts on closed- cell polymer foams

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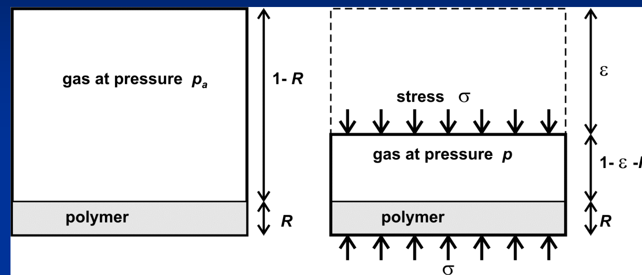
Talk outline

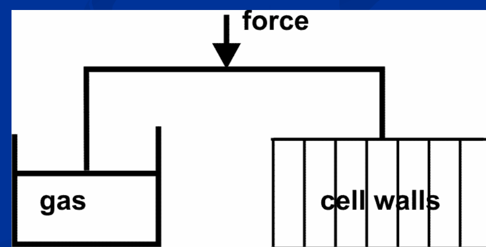
- Prior analyses
- Foam microstructures
- Geometric models
- FEA issues
- Results for EPS foams

Prior analyses (1)

Rusch 1970
cell gas compression

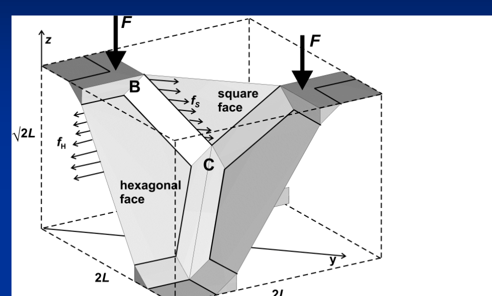


polymer and gas
compressed in parallel

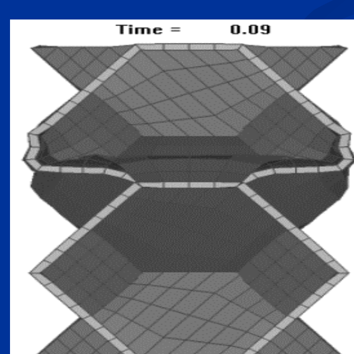


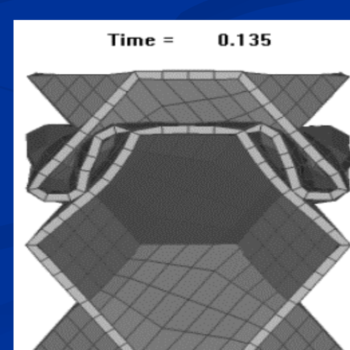
Prior analyses (2)

Mills & Zhu (1997)
numerical model
based on Kelvin foam
: needs thick edges
: EPS stresses x 2

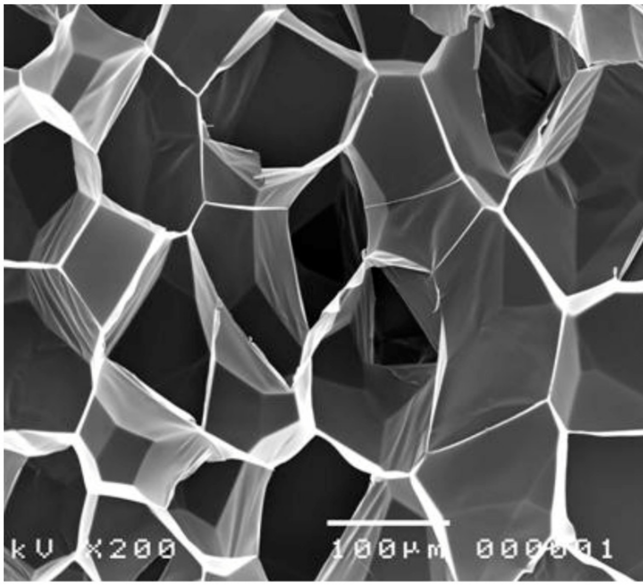


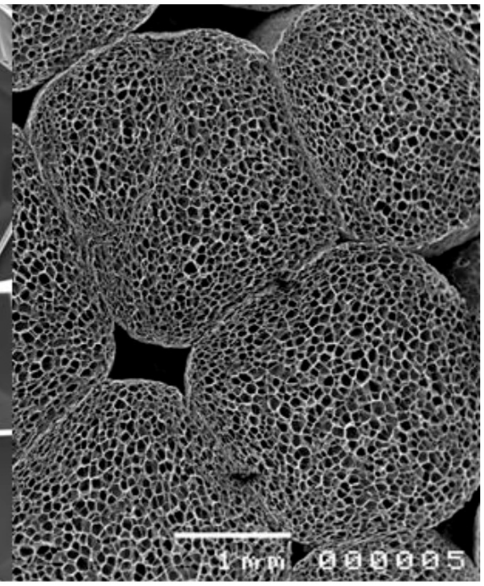
McKown PhD
L'pool (2005)
FEA of Kelvin
model of
aluminium foam
: gas ignored





Polystyrene bead foam (EPS)





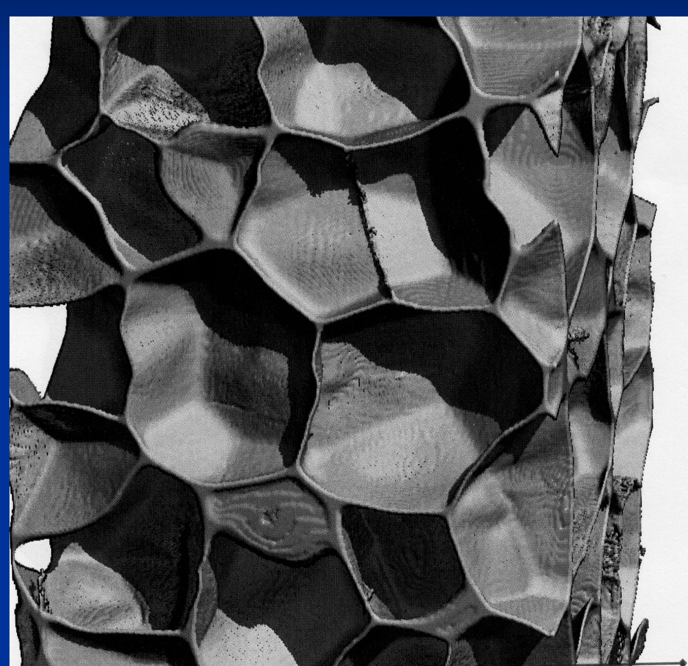
20 kg m^{-3} density

bead structure

Polyethylene (LDPE) foam

CT analysis of synchrotron data from Swiss Light Source

faces wrinkled due to process

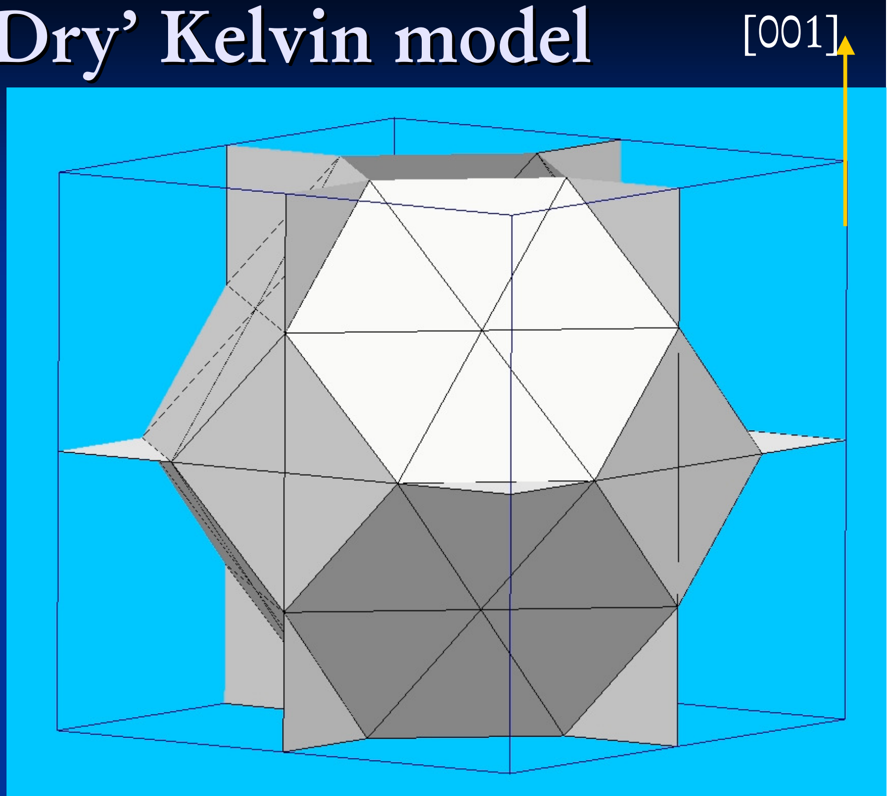


‘Dry’ Kelvin model

Regular 14 sided cells

hexagon & square faces

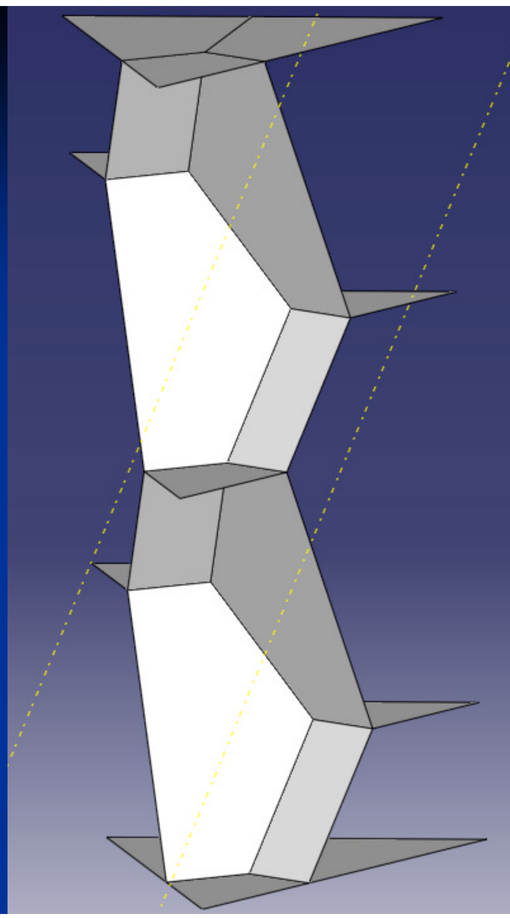
All material in cell faces hence ‘dry’



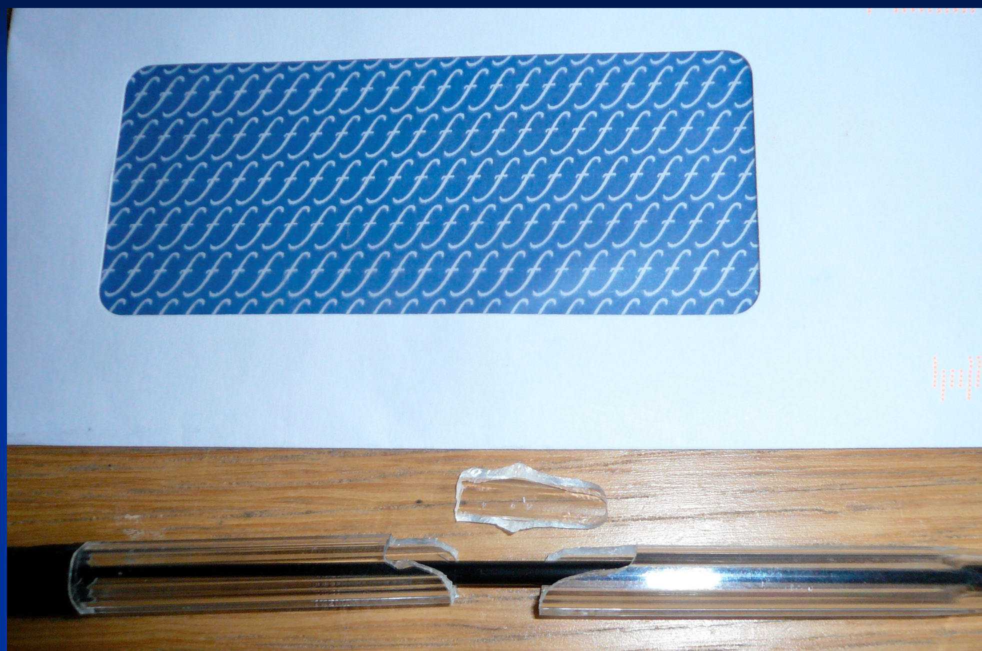
[111] direction compression of Kelvin model foam sheet

2 (or 4 cells) high

Infinite lateral extent by mirror symmetry

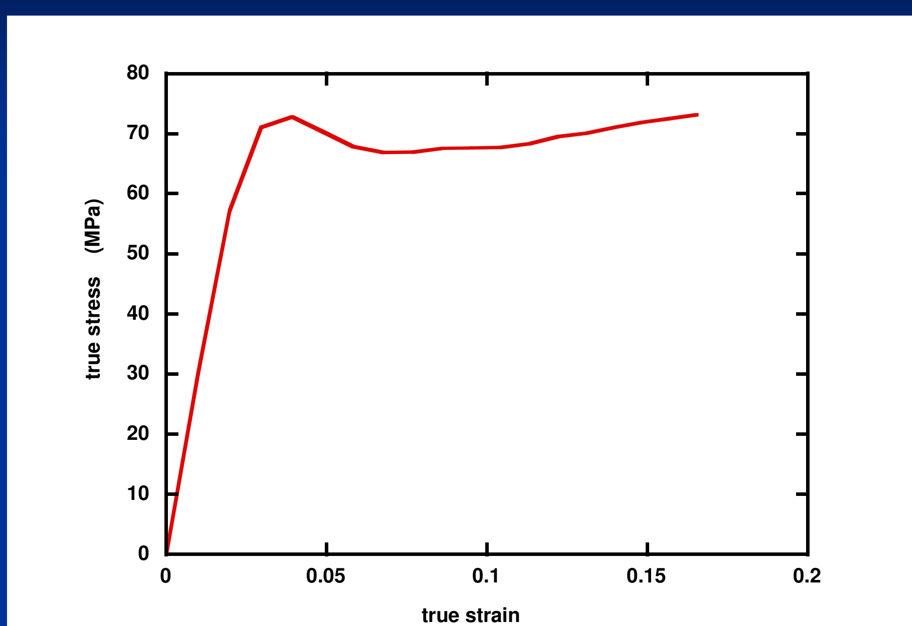


Mechanical properties of cell faces



Bulk PS is brittle, but biaxially-stretched PS film yields

Mechanical properties of cell faces

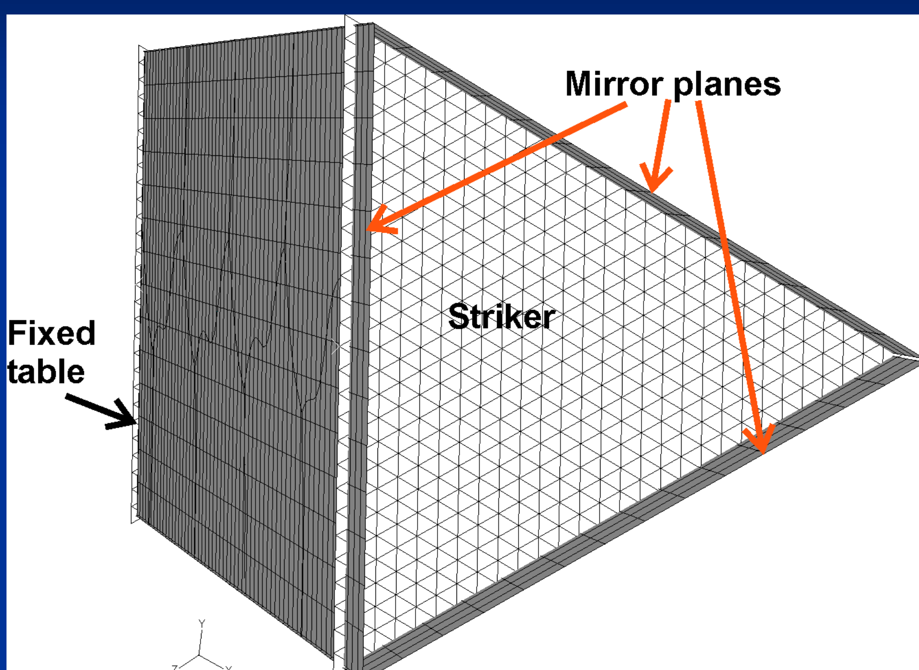


biaxially stretched polystyrene film, E = 3 GPa

FEA issues

- Dynamic (explicit) FEA simulates impacts
- 1 mm foam cells need 'mass scaling' to reduce run times
- Air cavities defined via their surfaces
- Symmetry planes use 'surface elements' of zero mass. So must couple constrain.

Dynamic (explicit) FEA simulates impact

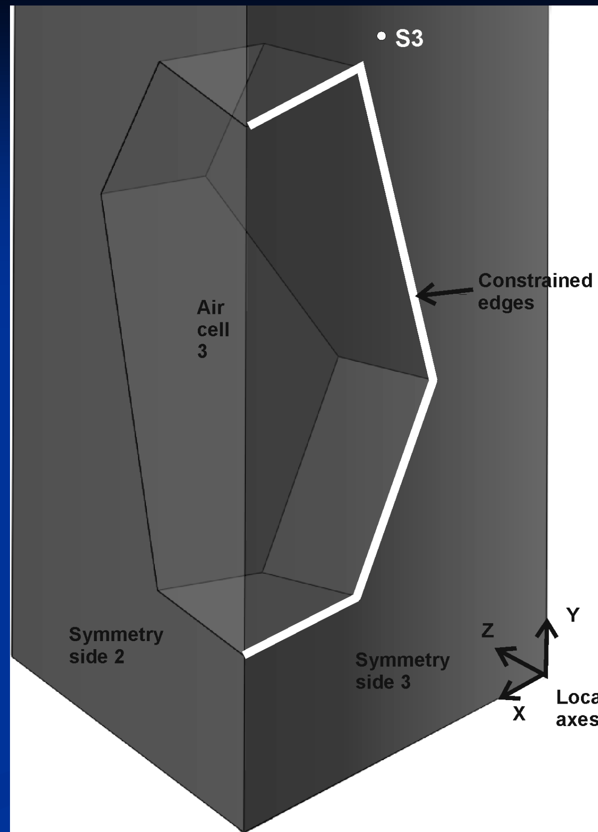


FEA issues

Air cavities defined by their surfaces

isothermal air compression

at symmetry plane, faces stay perpendicular



Results

- Deformation mechanisms
- Stress-strain predictions cf experiment
- Yield stress as function of foam density
- Is model isotropic?

Deformation mechanisms

Near-simultaneous cell collapse as faces concertina, then form plastic hinges

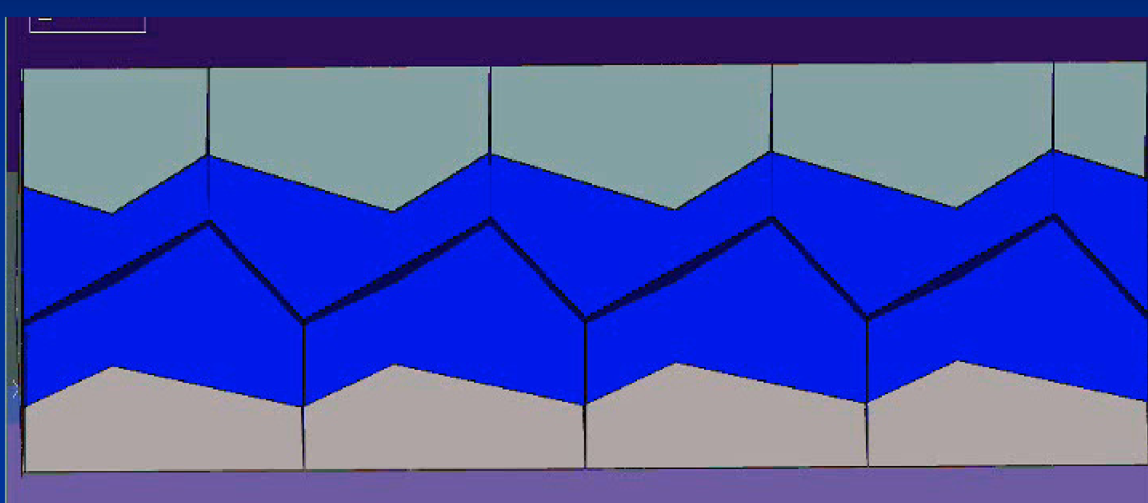
Stress increase:

due to cell air compression below strain 0.7

face-to-face-contact contribution at $e > 0.7$,

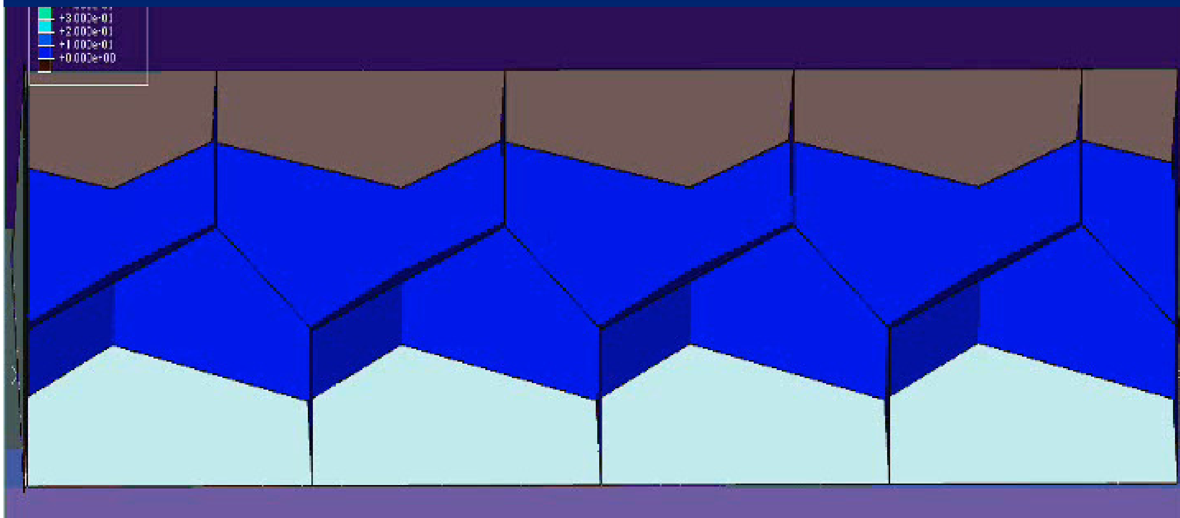
Poisson's ratio is very small

Drop impact PE foam 43 kg m^{-3}



Plastic strain contours, strain rate 50 s^{-1}

Shock impact on EPS 51 kg m^{-3}



Plastic strain contours, strain rate 500 s^{-1}

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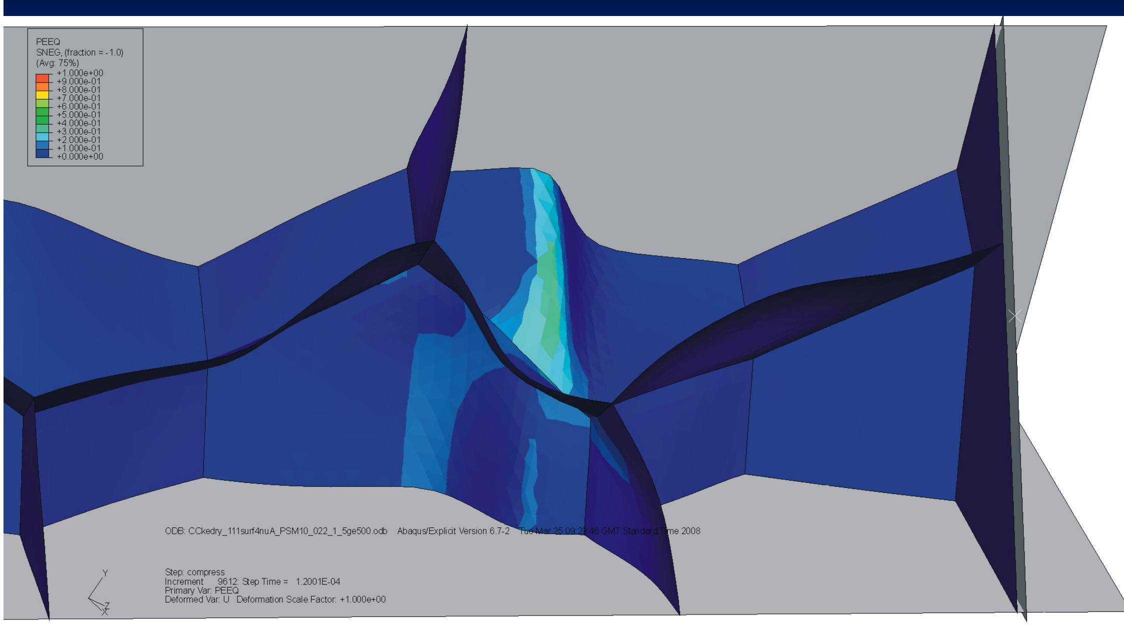
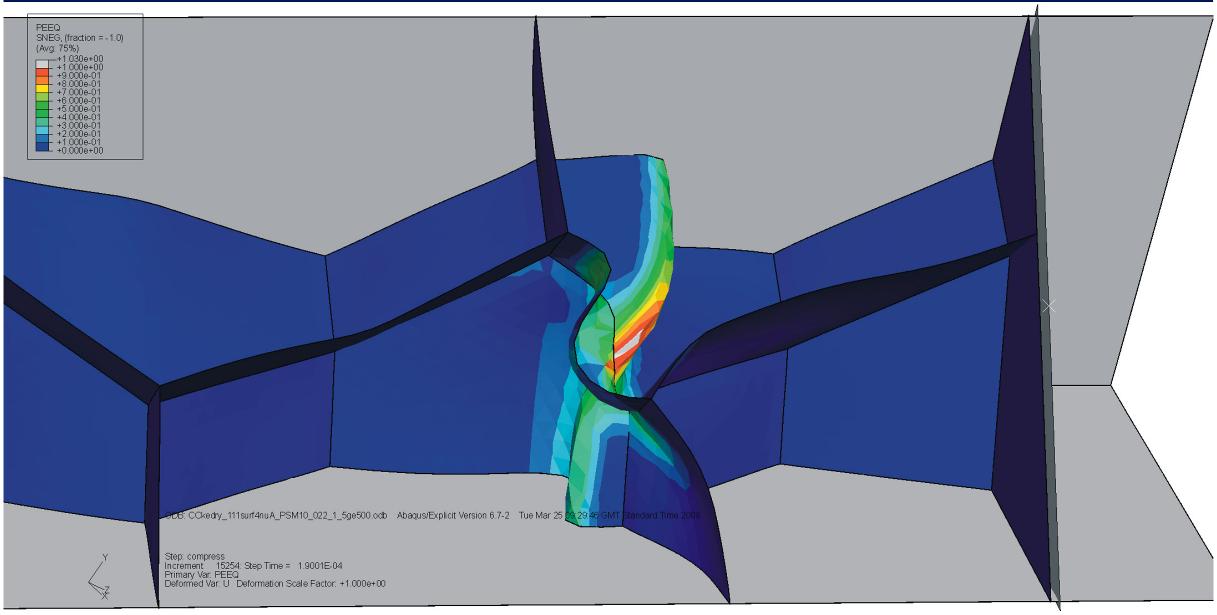


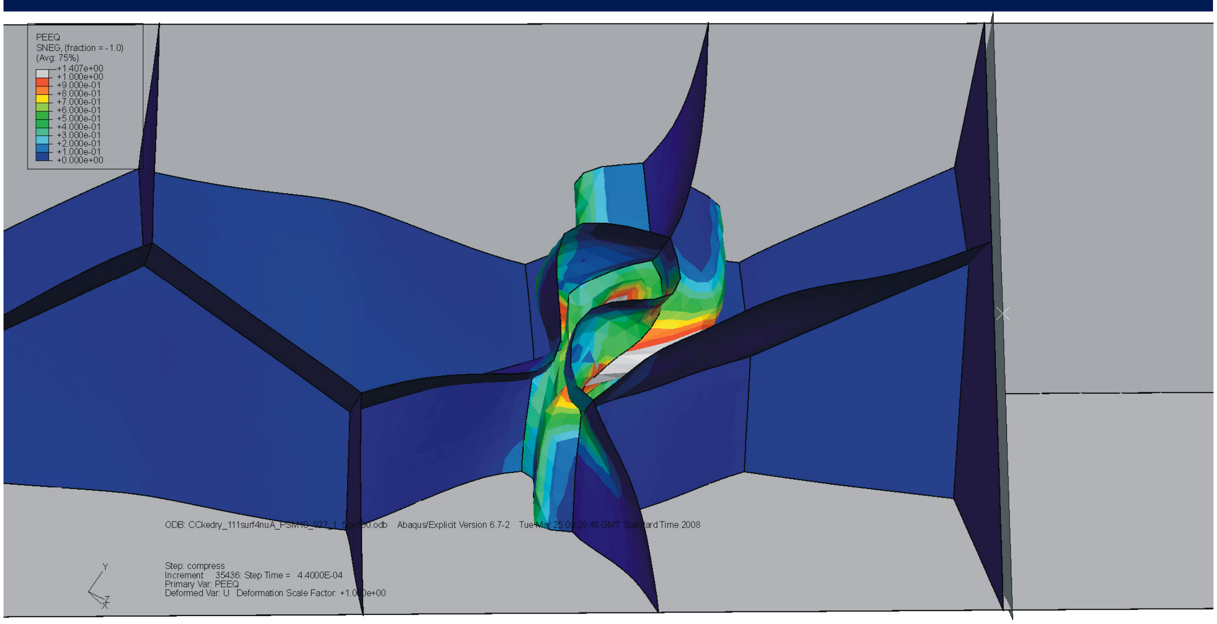
Plastic strain contours, 0.12 ms, foam strain 4.7%

Shock impact on EPS 51 kg m^{-3}



Plastic strain contours, 0.19 ms, foam strain 7.6%

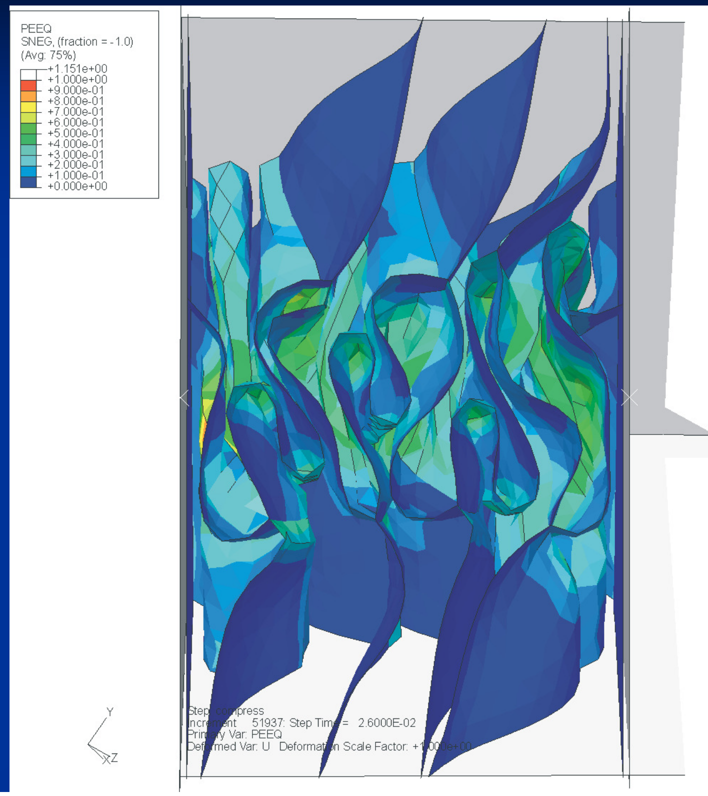
Shock impact on EPS 51 kg m^{-3}



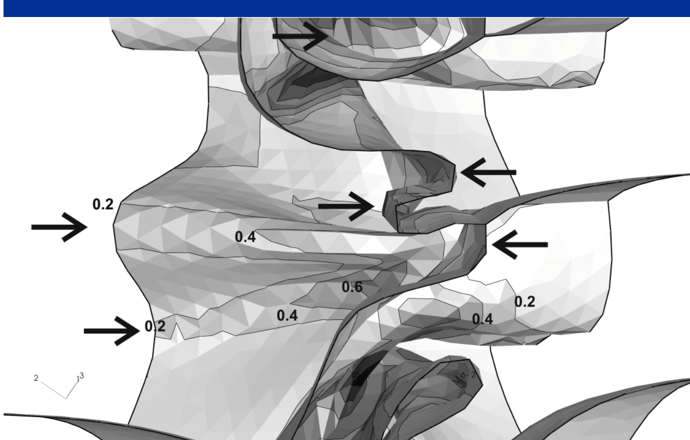
Plastic strain contours, 0.44 ms, foam strain 18%

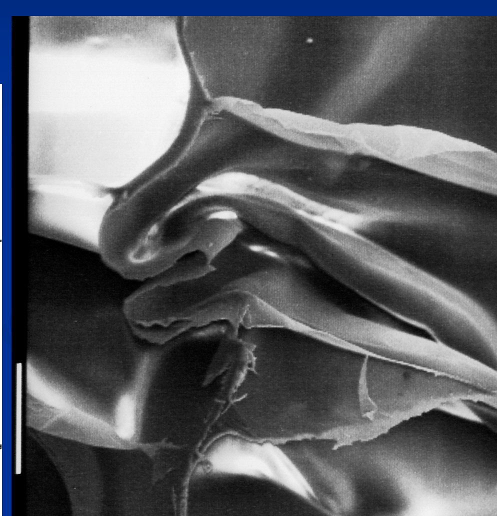
Face-to-face contact

LDPE foam
43 kg m^{-3}
at foam
strain 0.73



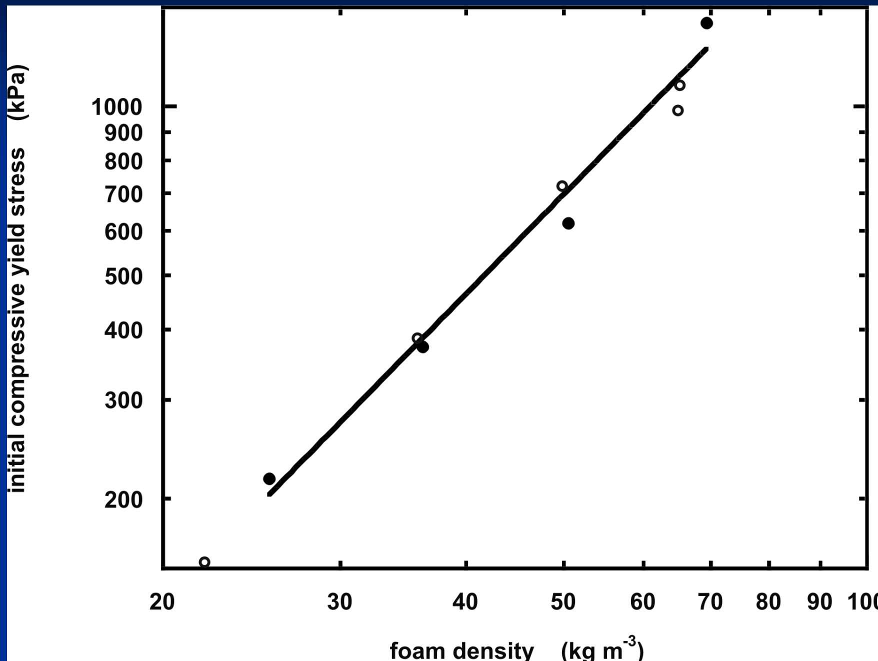
EPS 51 kg m^{-3} foam unloaded after impact





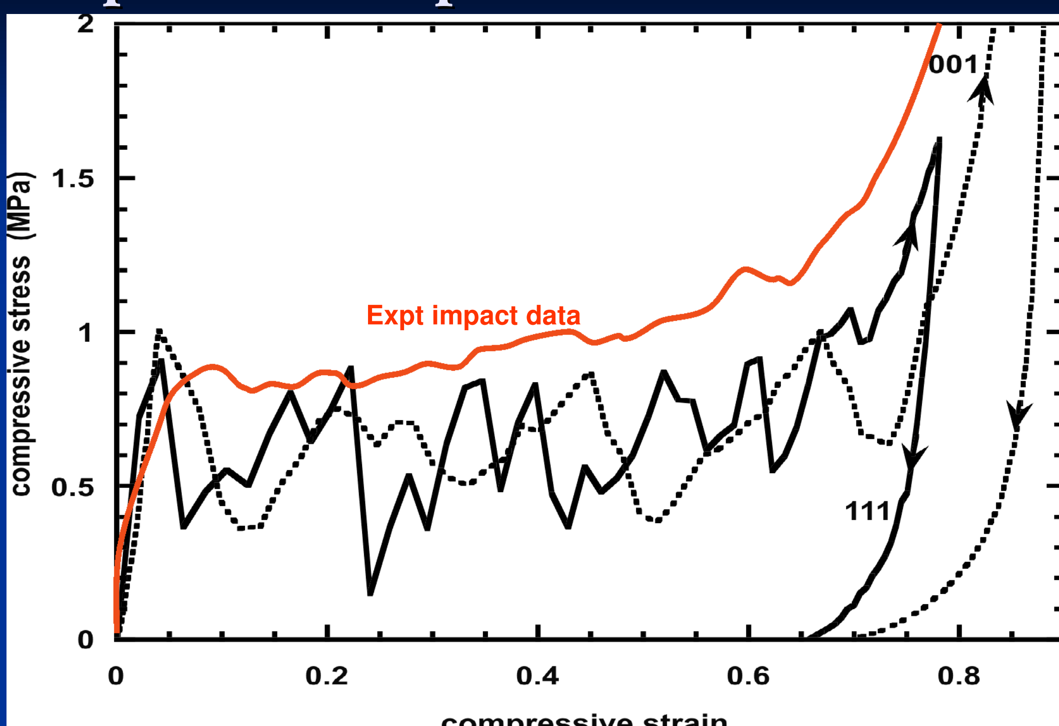
Predicted plastic hinges vs. SEM photos

Yield stress vs EPS foam density



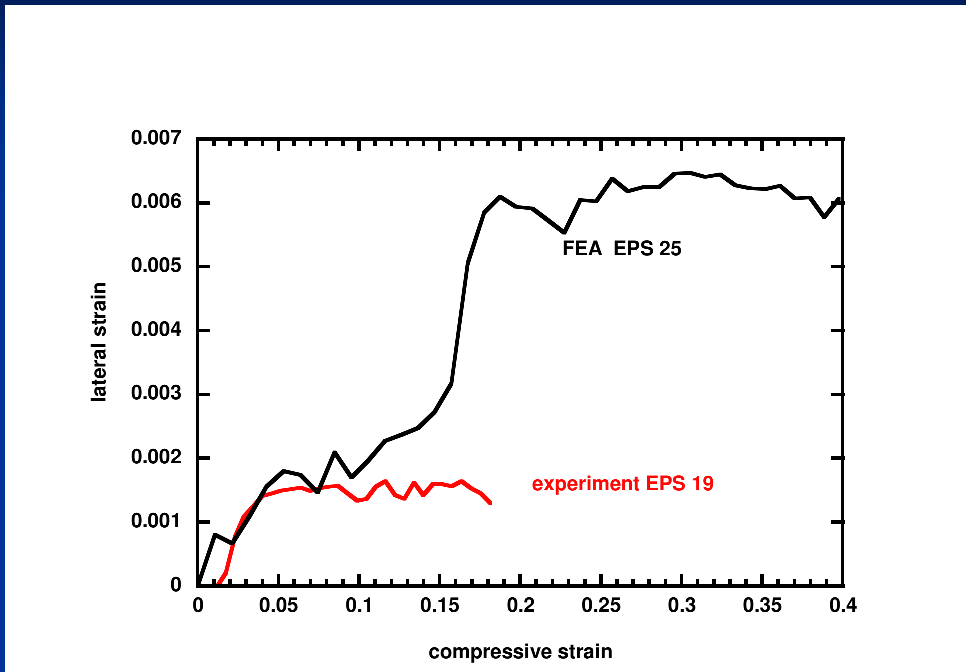
O are experimental data

Compressive responses in 2 directions



EPS of density 51 kg m^{-3}

Lateral strain on compression



Low lateral expansion strains

Results for foam densities < 80 kg m^{-3}

- Cell faces dominate the foam response
- foam yield stress predicted within 20%
- model yield is nearly isotropic
- lateral expansion < 1.0%

Conclusions (2)

- Glassy polystyrene, with 'all-face' foam structure, provides high specific yield stress
- Model can predict responses of other foams
- to appear in Int J Solids & Structures

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