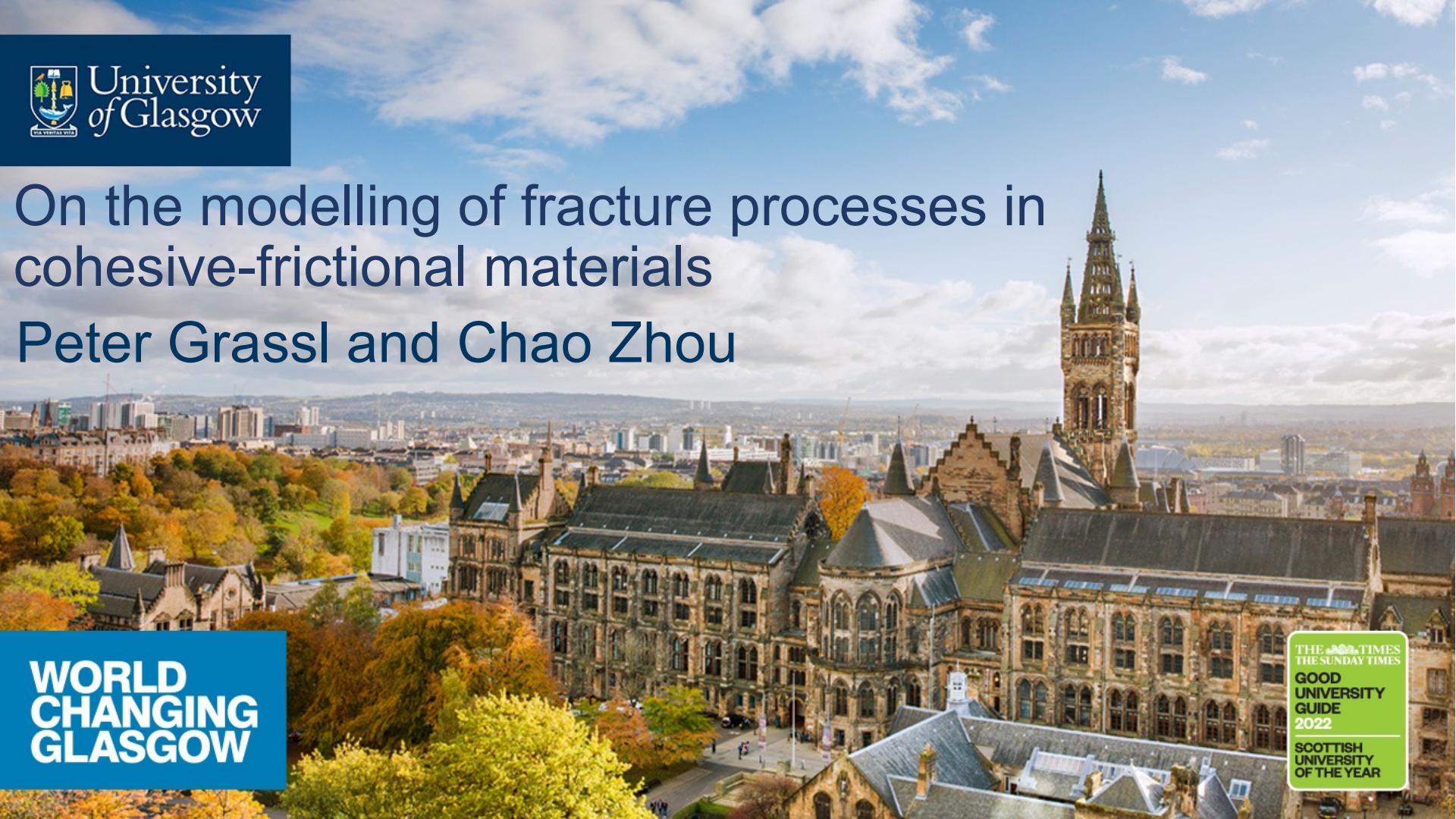


On the modelling of fracture processes in cohesive-frictional materials

Peter Grassl and Chao Zhou

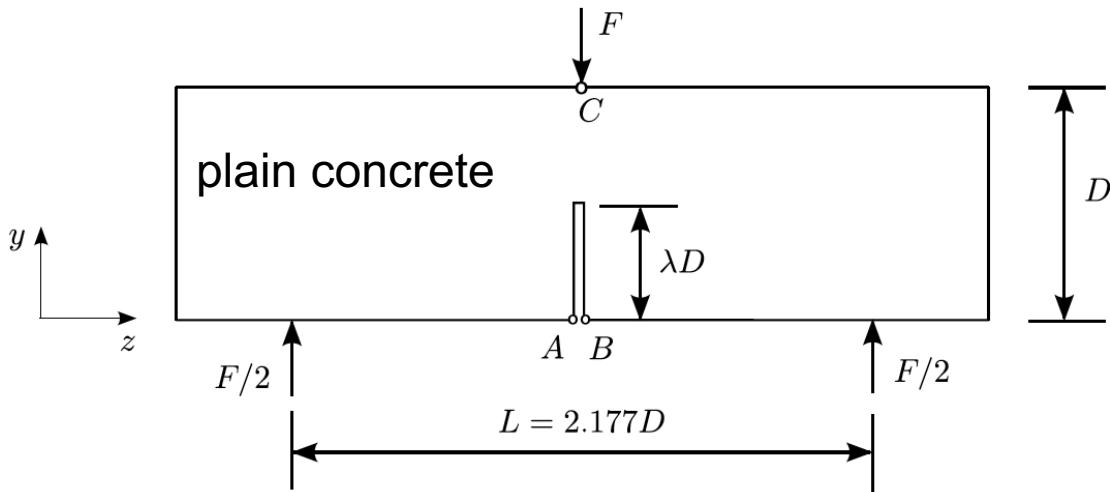


**WORLD
CHANGING
GLASGOW**

THE TIMES
THE SUNDAY TIMES
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2022
SCOTTISH
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OF THE YEAR

Introduction

Introduction - Size effect on strength



Nominal stress:

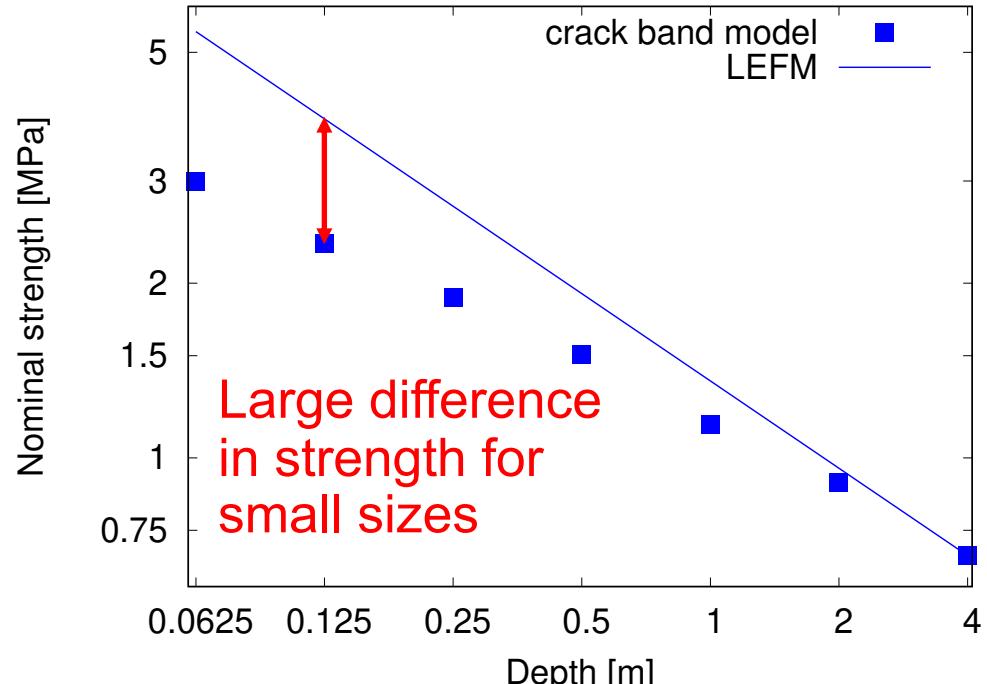
$$\sigma_N = 1.5FL/(bD^2)$$

$$\lambda = 0.3$$

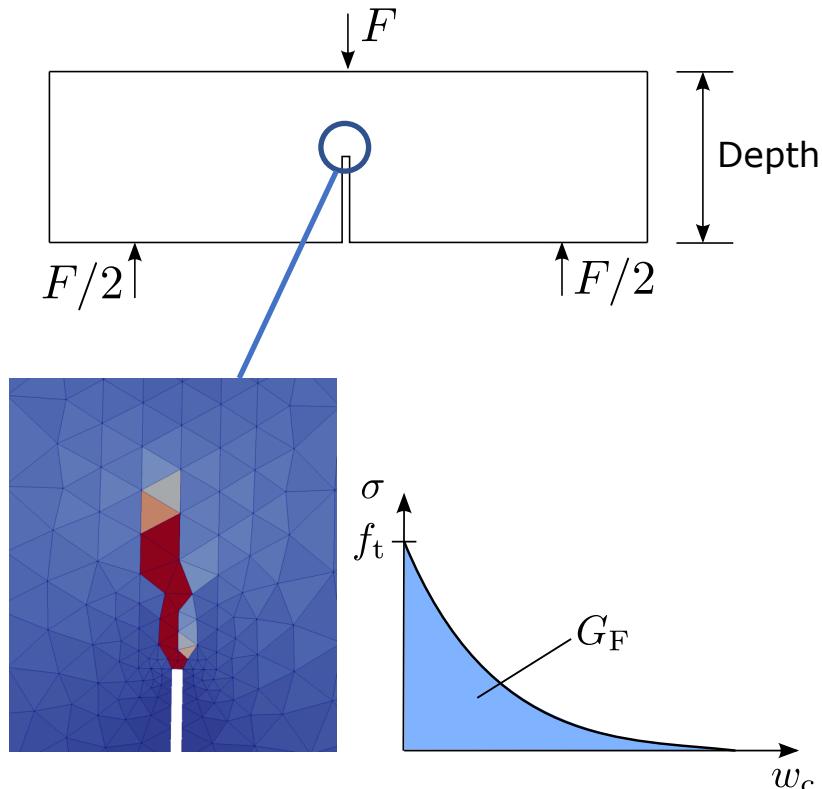
Linear elastic fracture mechanics (LEFM): $E = 35.6$ GPa, $\nu = 0.172$, $G_F = 60$ N/m

Crack band model: $E = 35.6$ GPa, $\nu = 0.172$, $G_F = 60$ N/m, $f_t = 5$ MPa

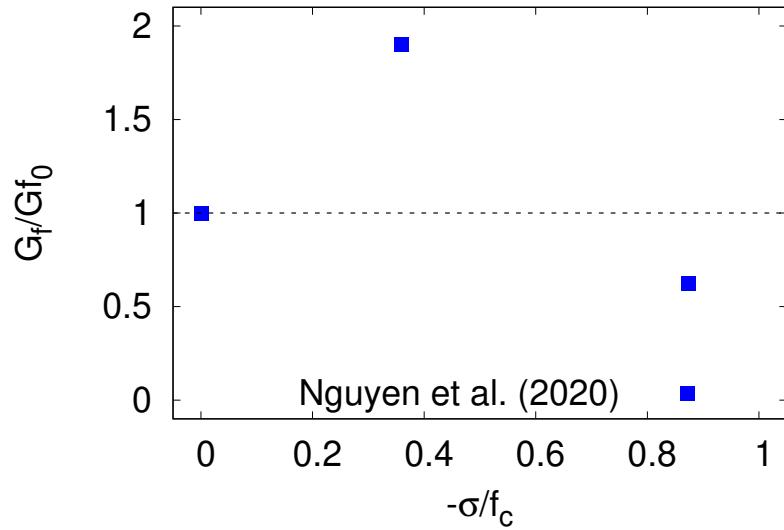
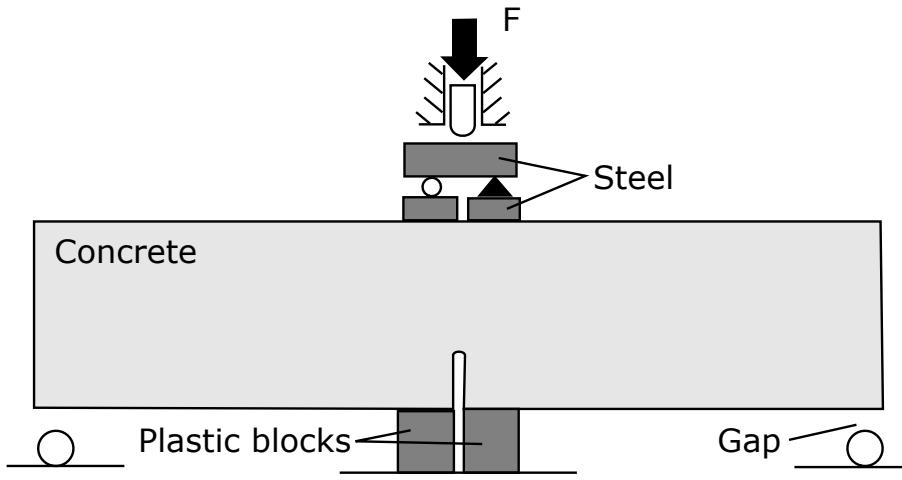
Background



Size effect



Background



What is the reason for the increase in fracture energy due compression parallel to the crack?

Possible explanations: more friction, wider FPZ

Aim

Investigate the mechanisms responsible for the effect of compression parallel to the crack on dissipated energy.

Approach

Perform meso-scale analyses using a 3D periodic cell. Study width of fracture process zone and composition of dissipated energy.

Outline

Lattice modelling approach

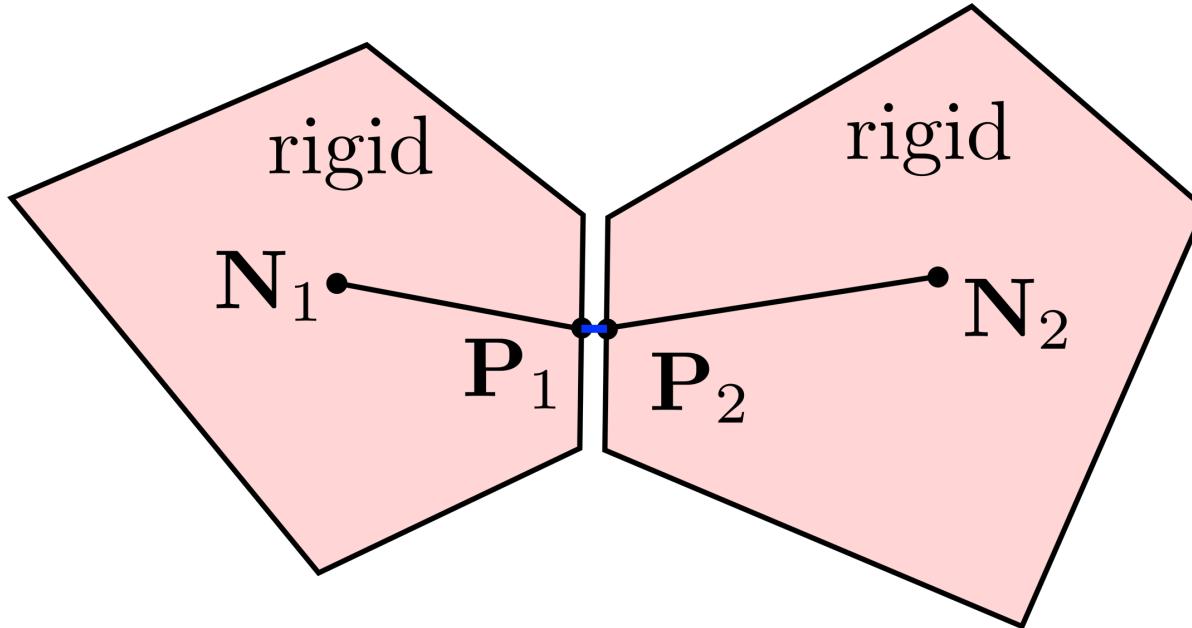
Comparison of experiments

Analysis of fracture process zone

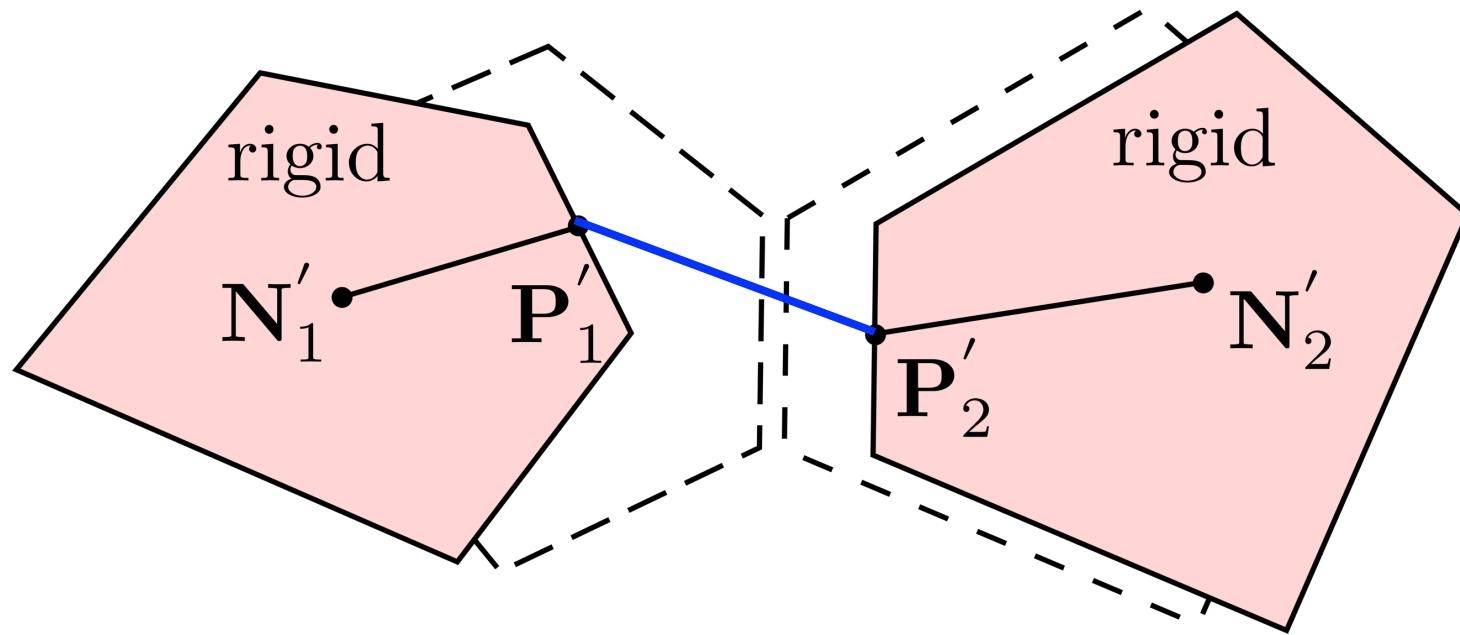
Conclusions

Lattice modelling approach

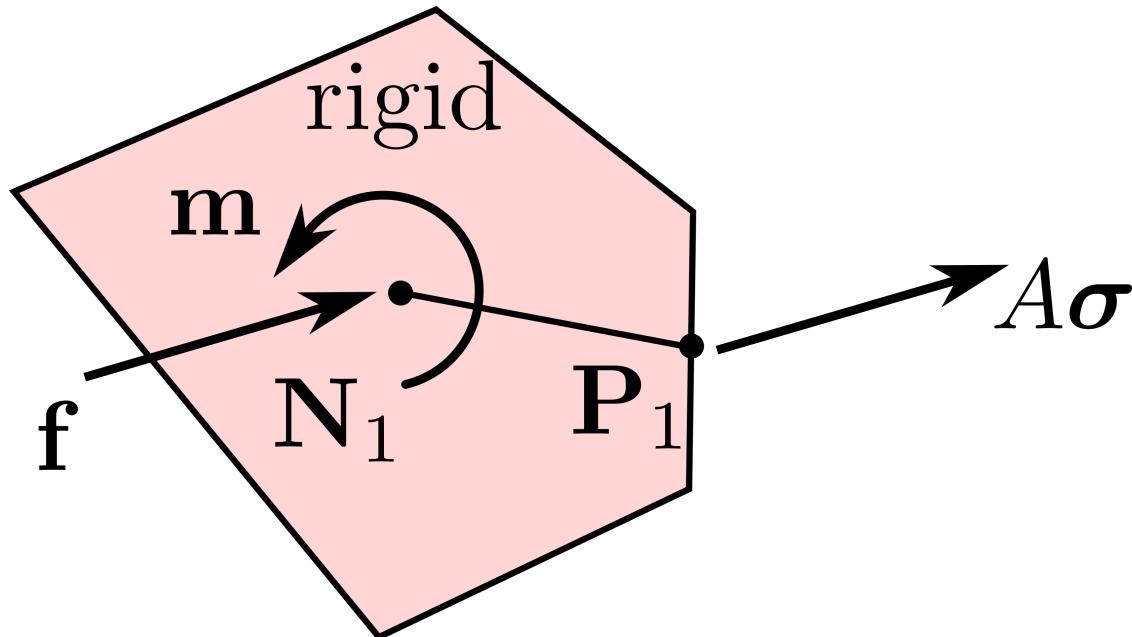
Lattice modelling approach



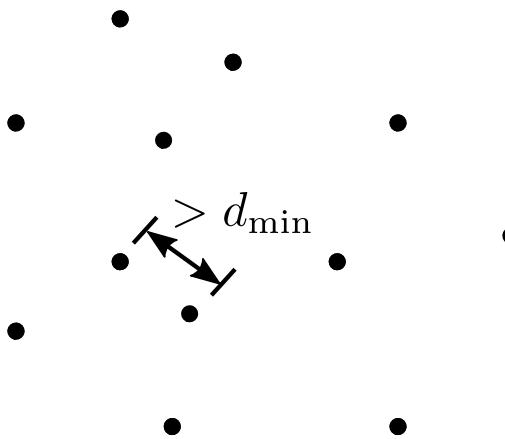
Lattice modelling approach



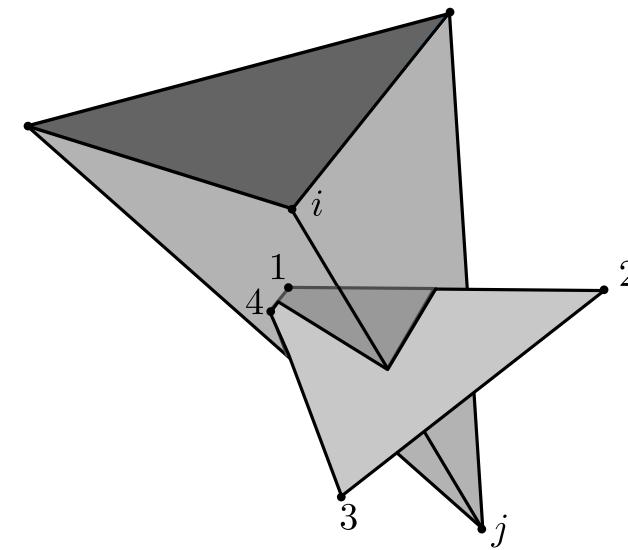
Lattice modelling approach



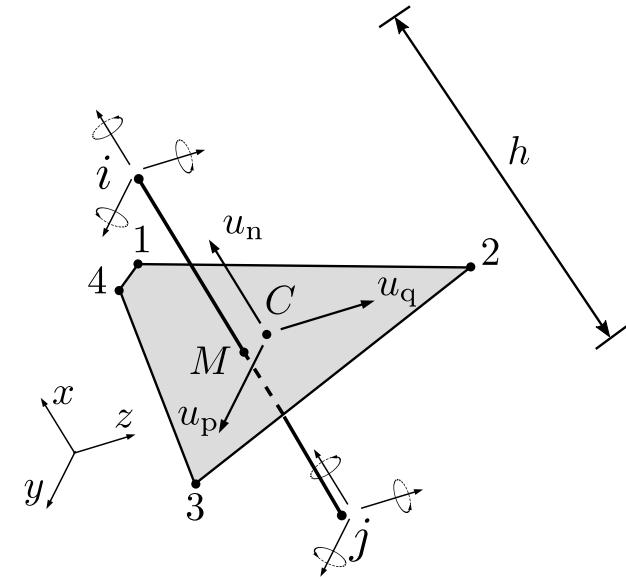
3D Lattice discretisation



Constrained
random points



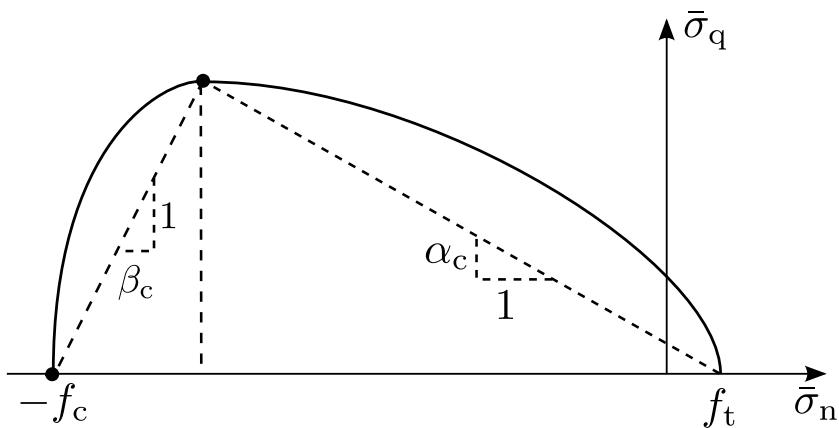
Tessellations



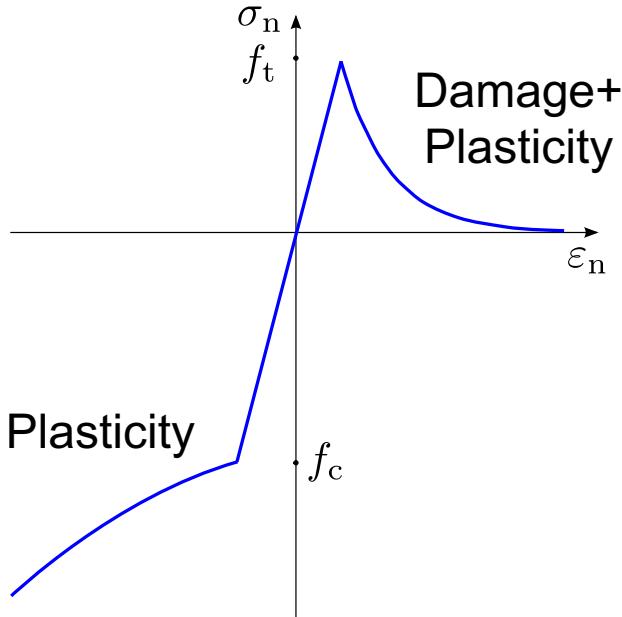
Lattice element

Lattice constitutive model

$$\sigma = (1 - \omega) D_e (\varepsilon - \varepsilon_p) = (1 - \omega) \bar{\sigma}$$

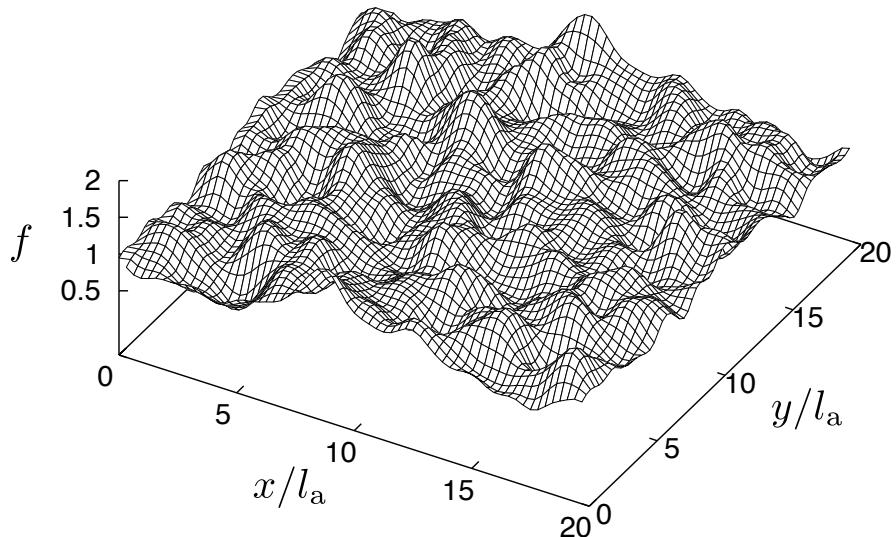


Yield surface

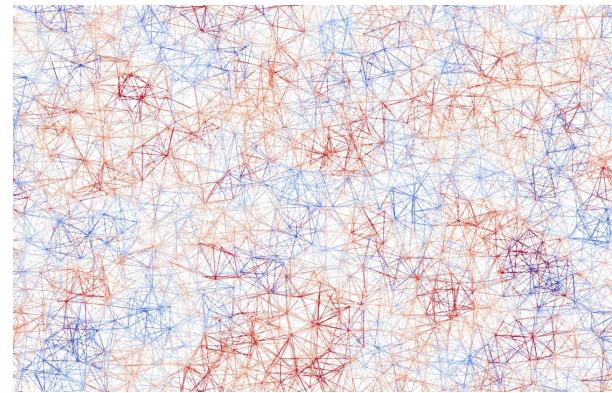


Stress-strain

Meso-structure



Autocorrelated
random field

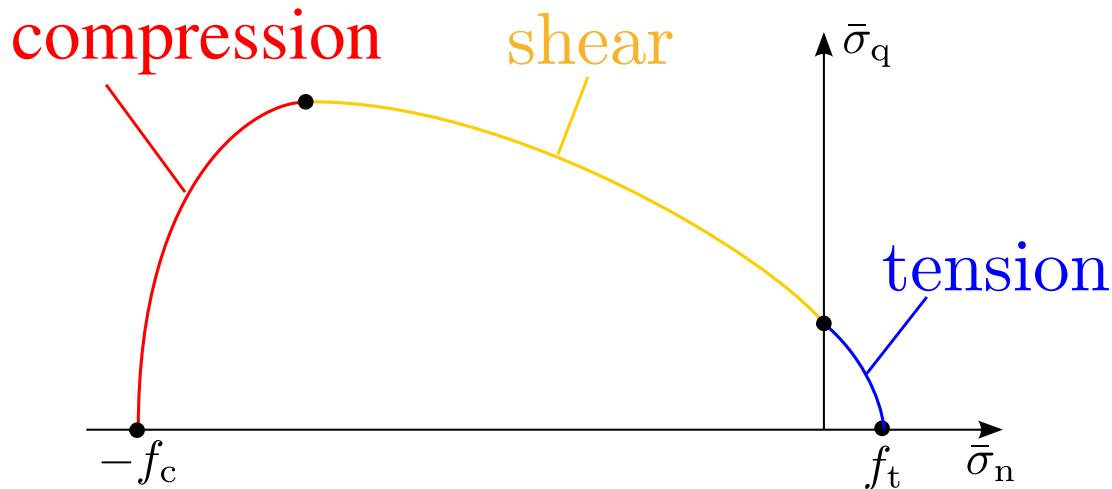


Lattice with random properties
(strength and fracture energy)

Post processing

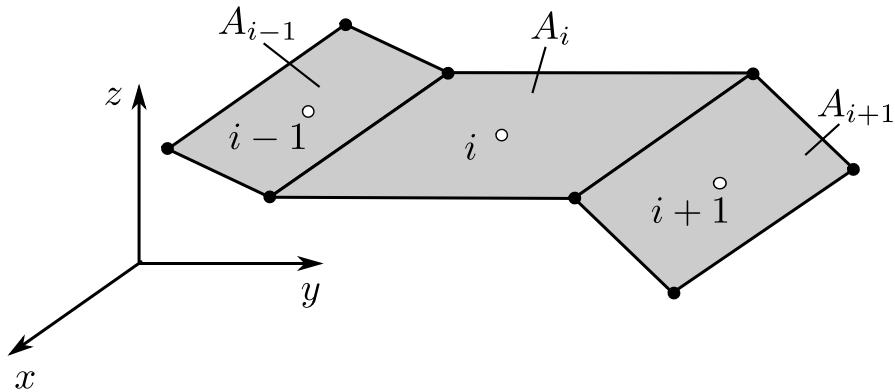
1) Dissipation:

$$\dot{D} = (1 - \omega) \mathbf{D}_e (\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}_p) \dot{\boldsymbol{\varepsilon}}_p + \frac{1}{2} (\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}_p) \mathbf{D}_e (\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}_p) \dot{\omega}$$



Post processing

2) Roughness

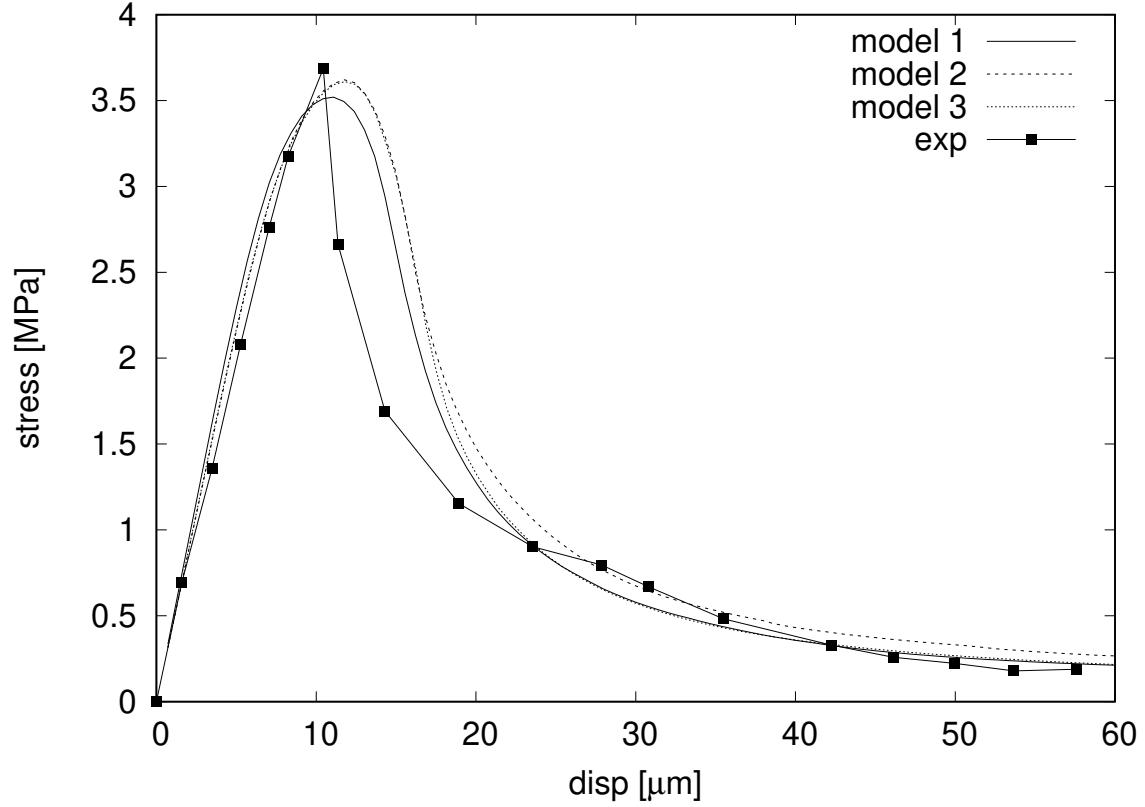
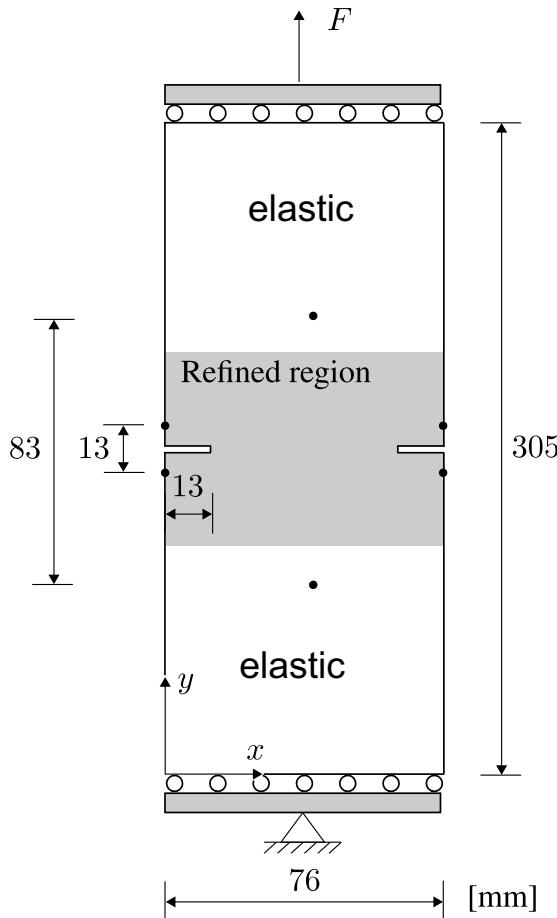


$$\bar{z} = \sum_{i=1}^N w_i z_i \quad w_i = \frac{A_i \Delta d_i}{\sum_{k=1}^N A_k \Delta d_k}$$

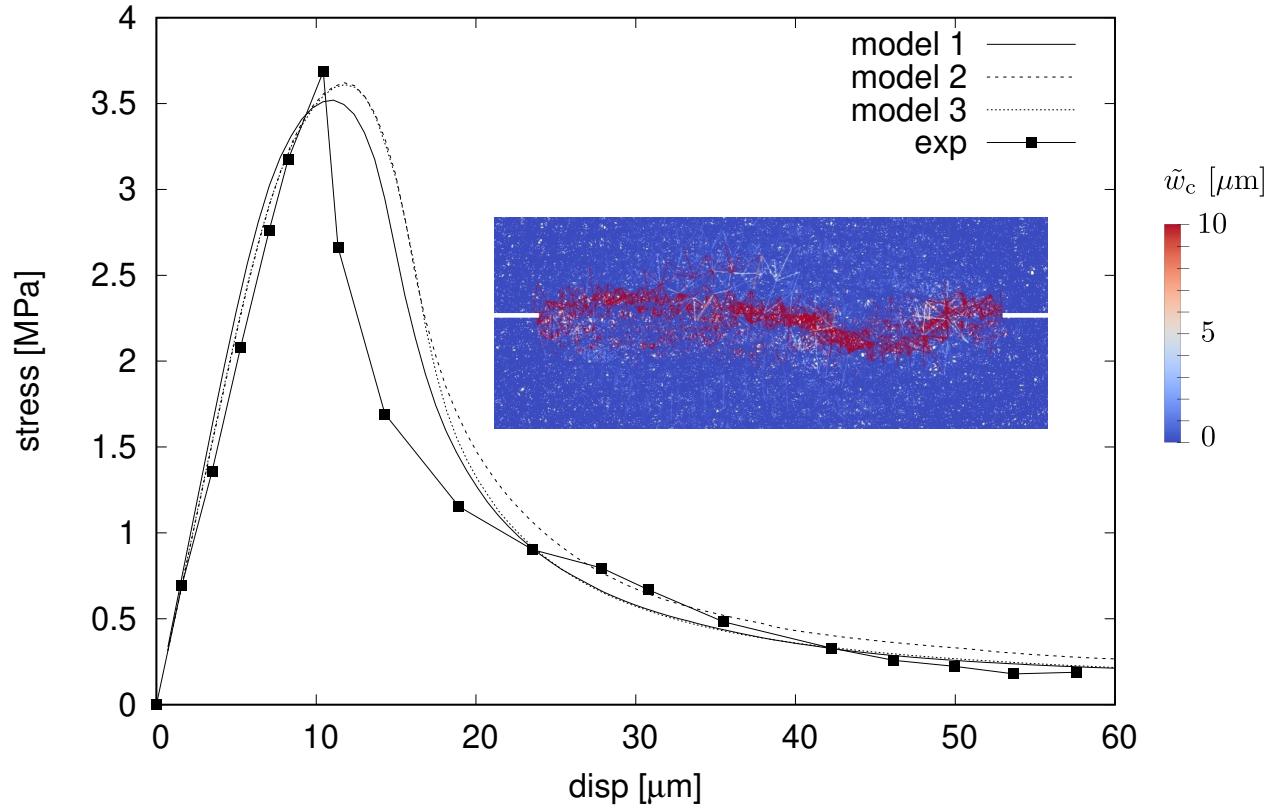
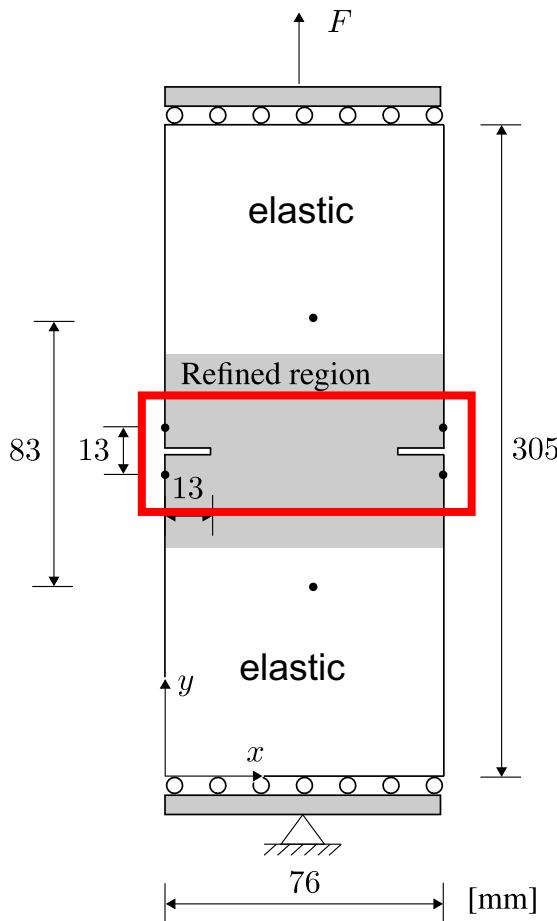
$$\Delta h = \sqrt{\sum_{i=1}^N w_i (z_i - \bar{z})^2}$$

Comparison with experiments

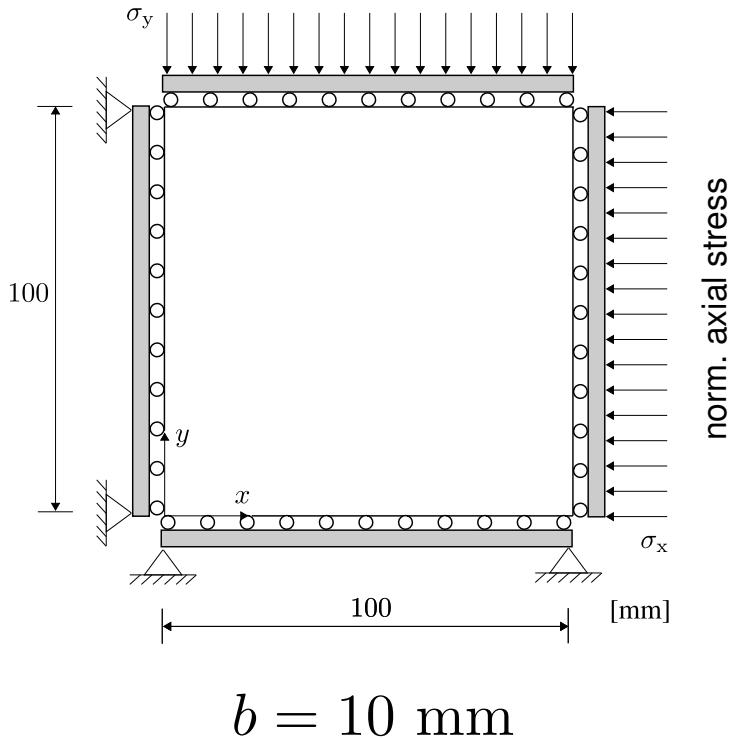
Direct tension



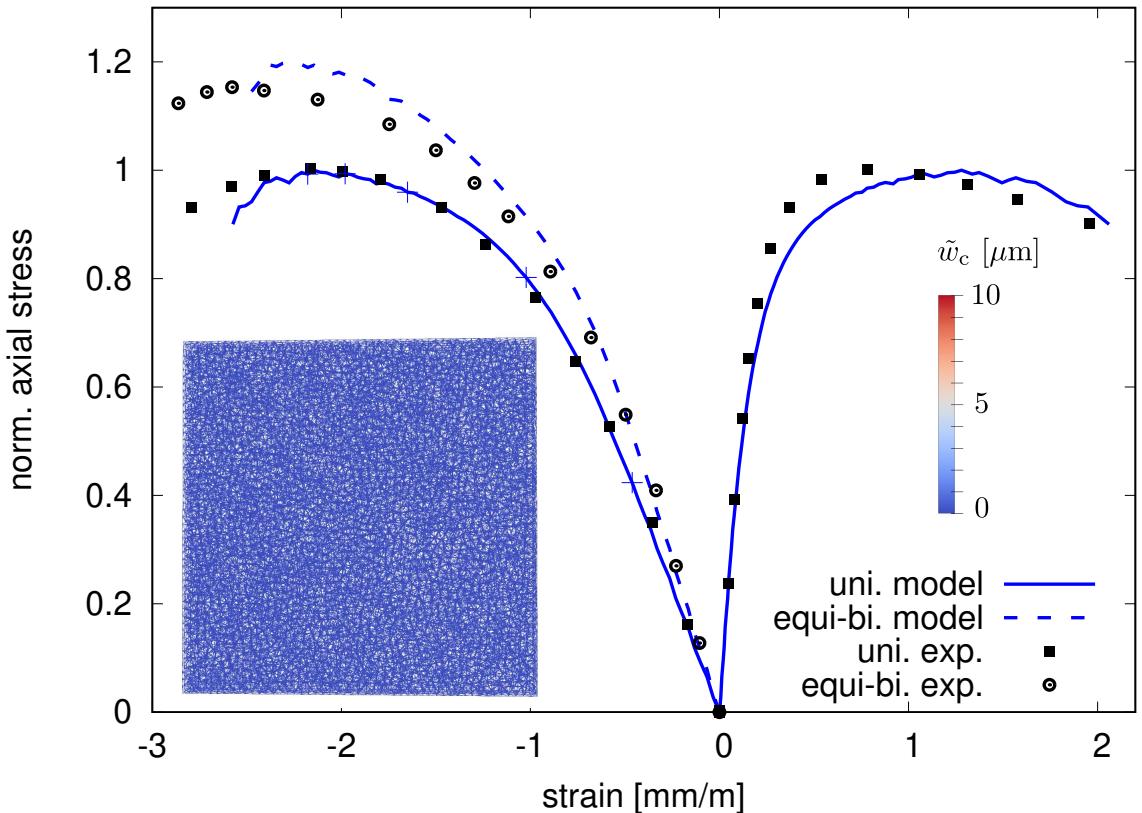
Direct tension



Uni- and biaxial compression

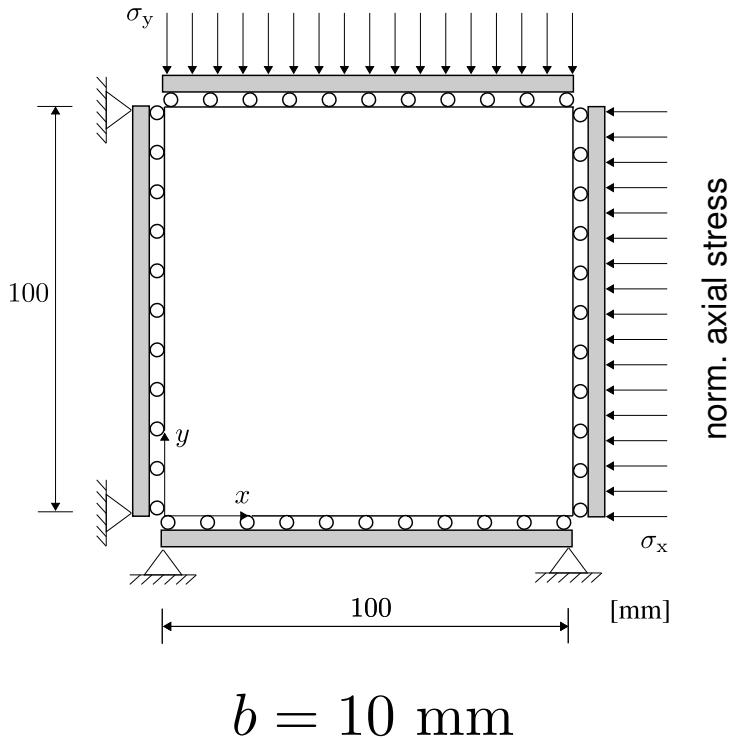


Ref: Kupfer et al. (1969)

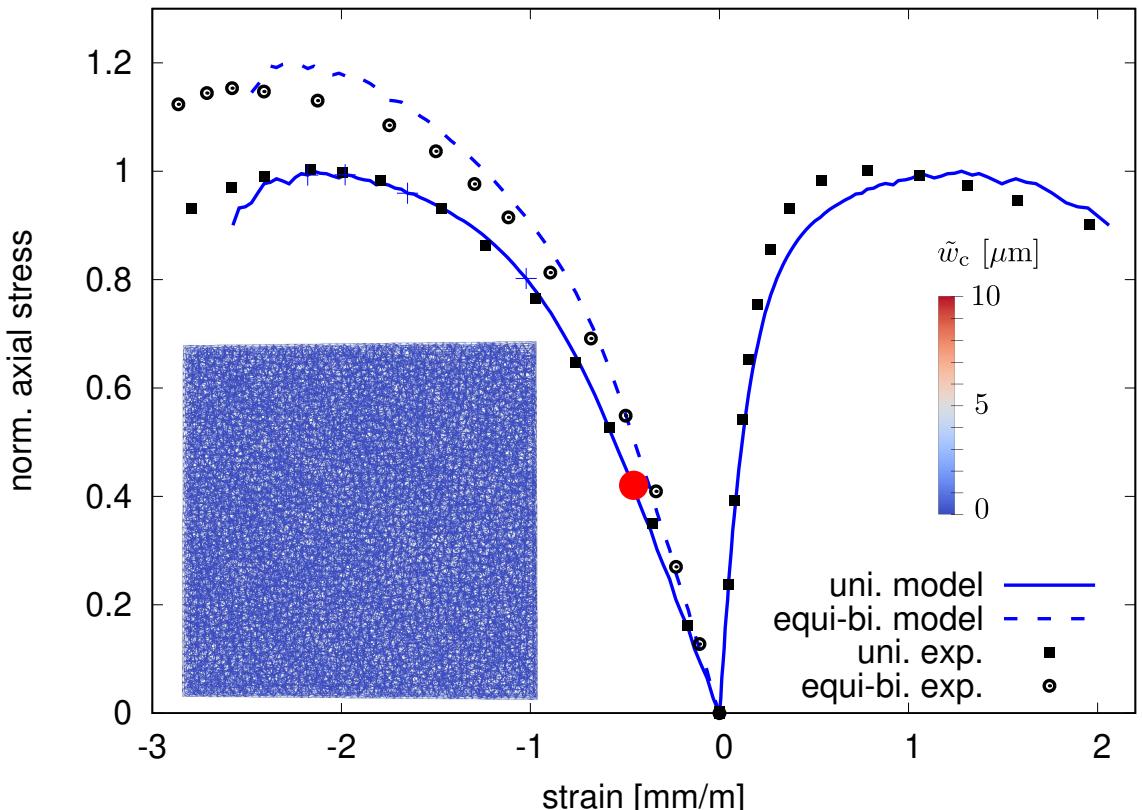


3D explicit

Uni- and biaxial compression

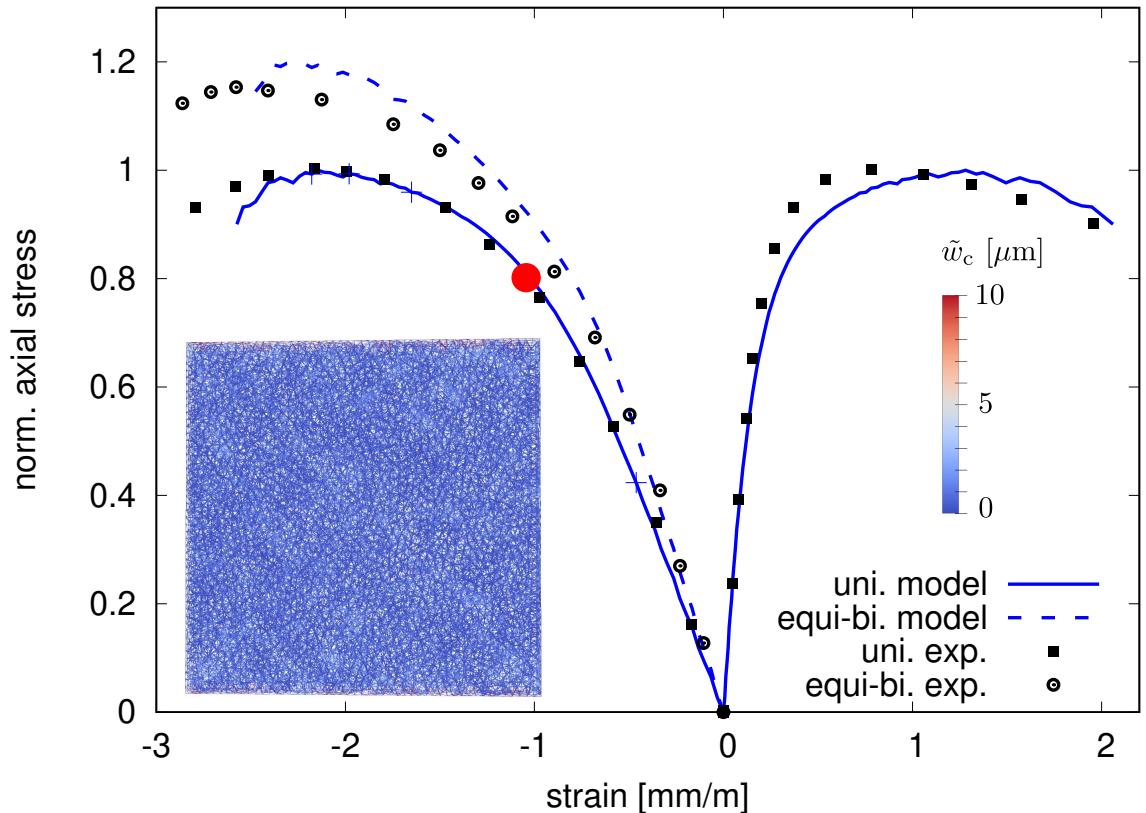
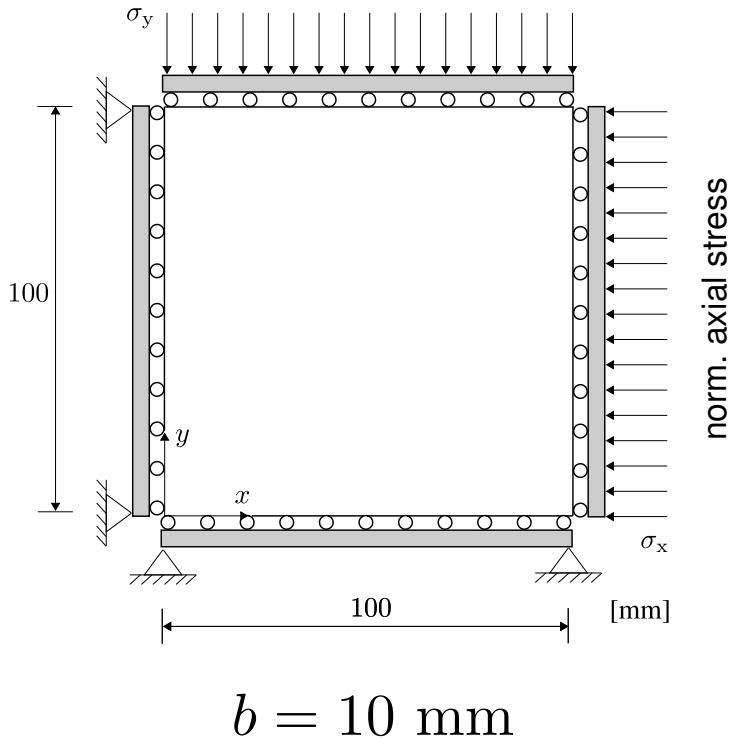


Ref: Kupfer et al. (1969)

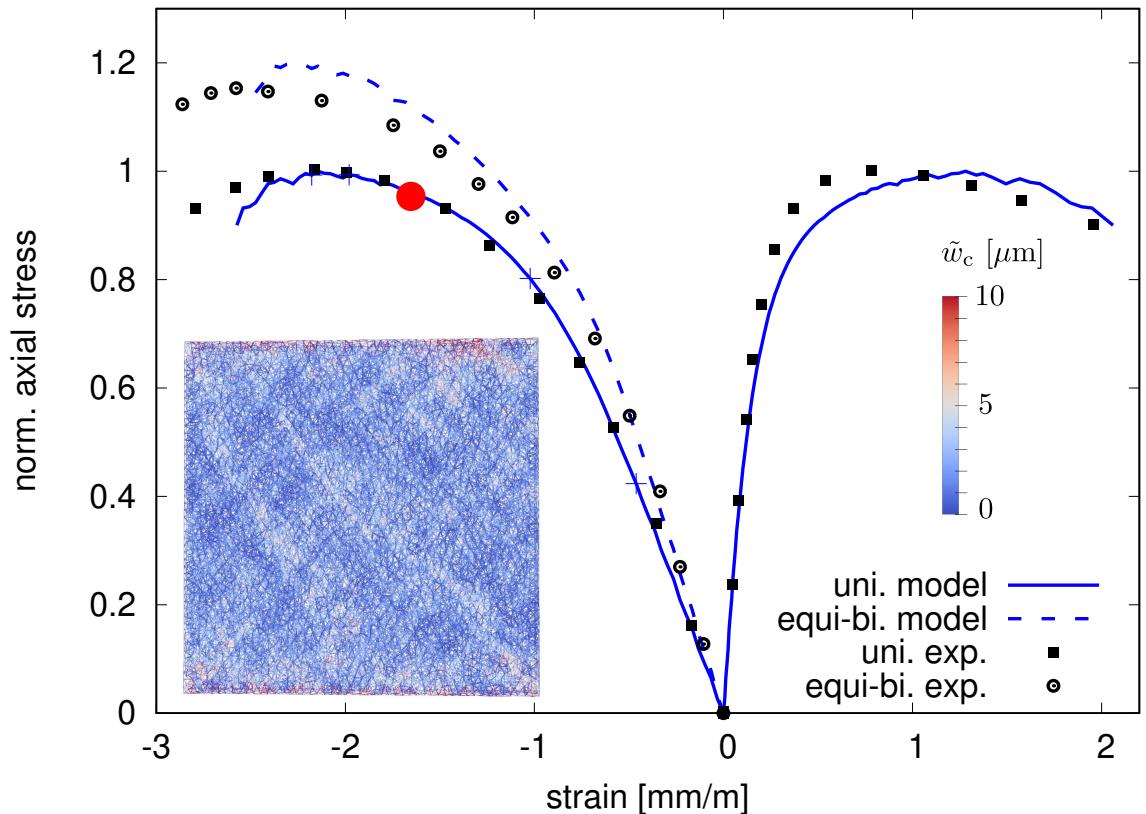
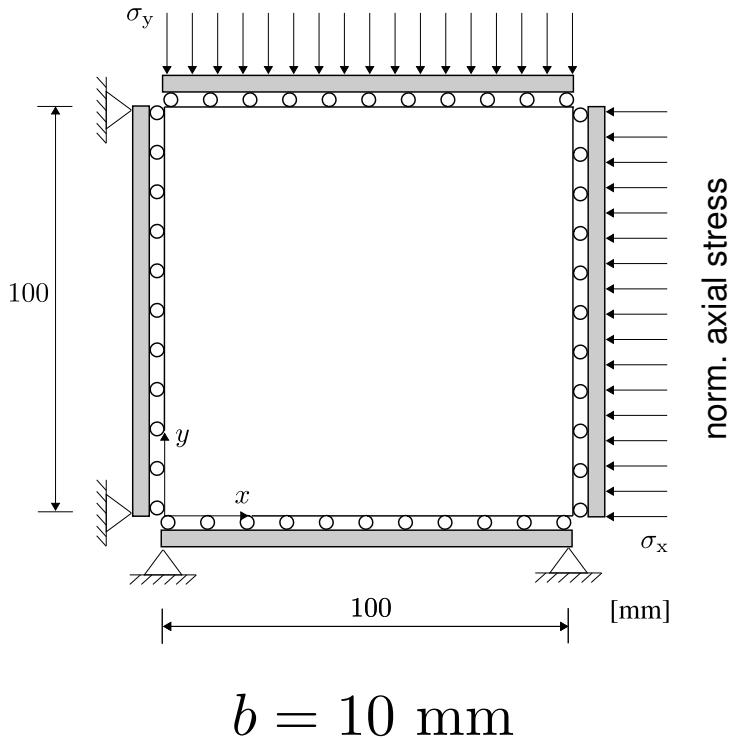


3D explicit

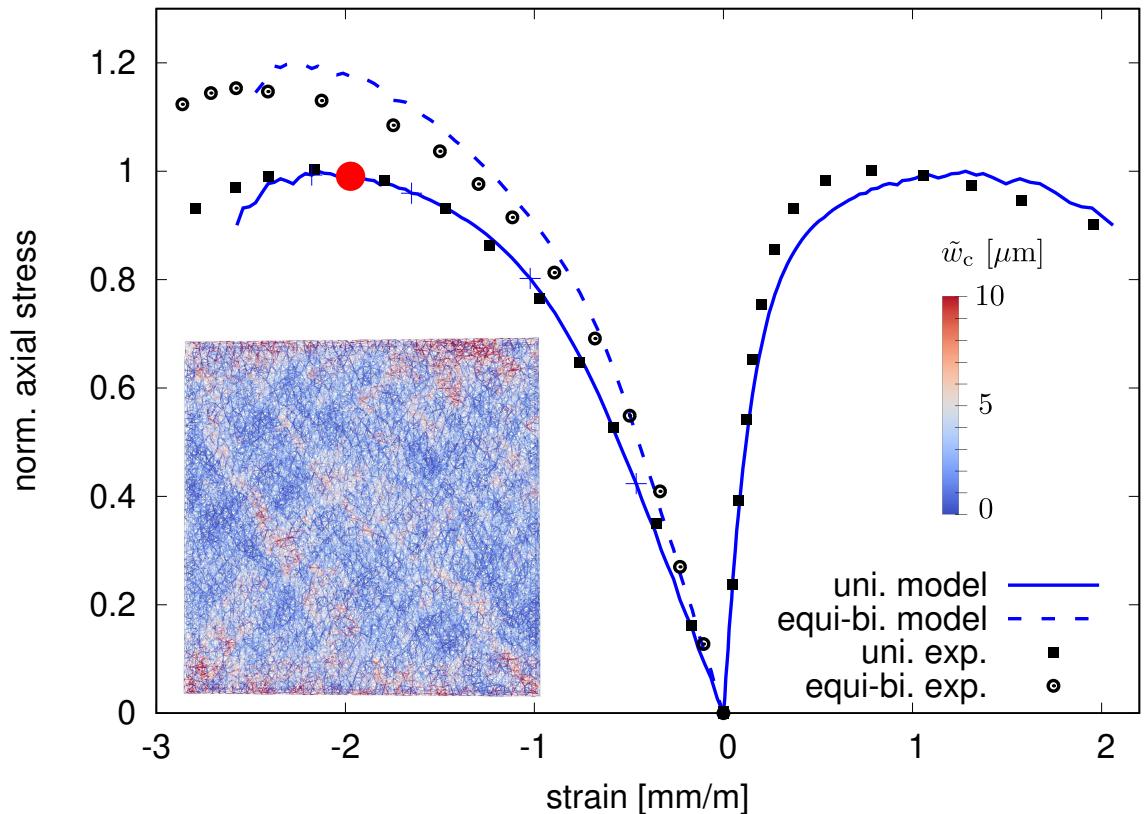
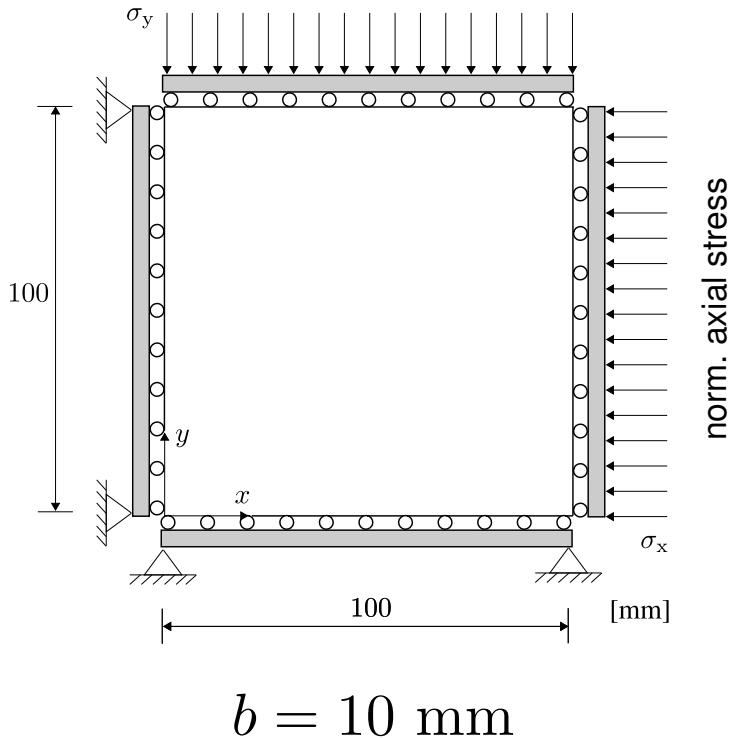
Uni- and biaxial compression



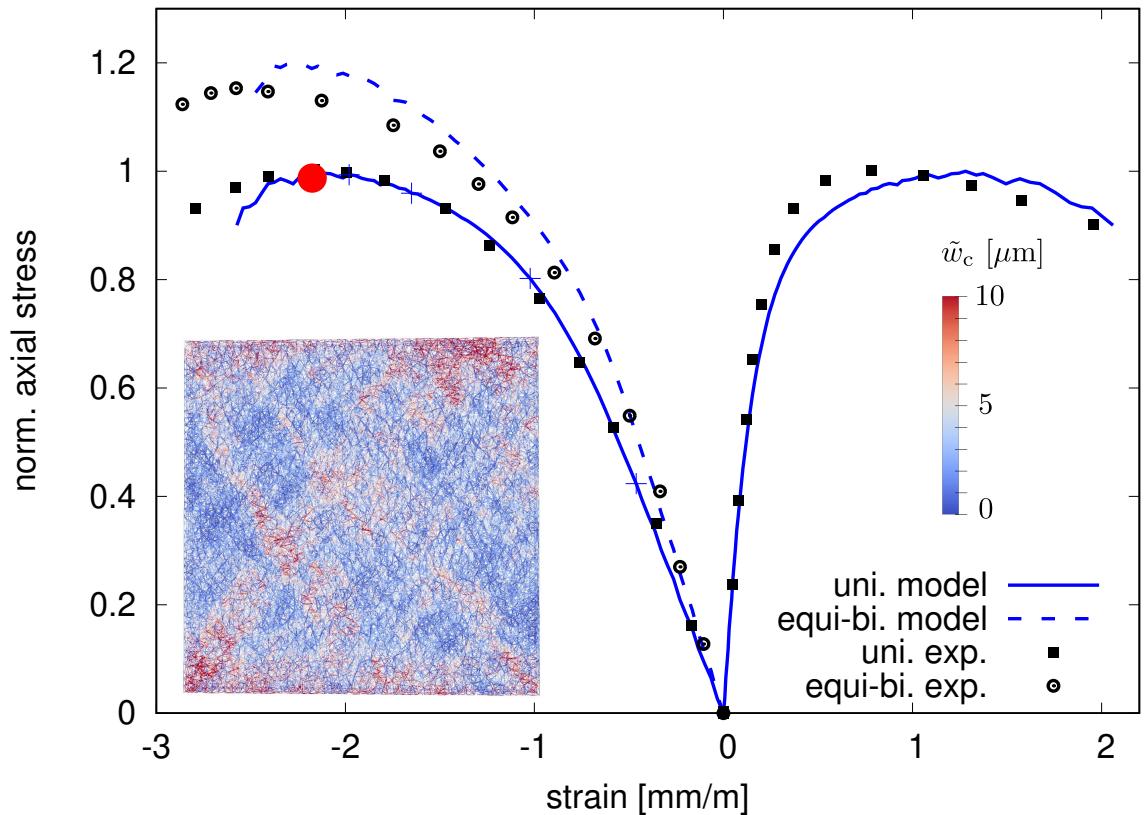
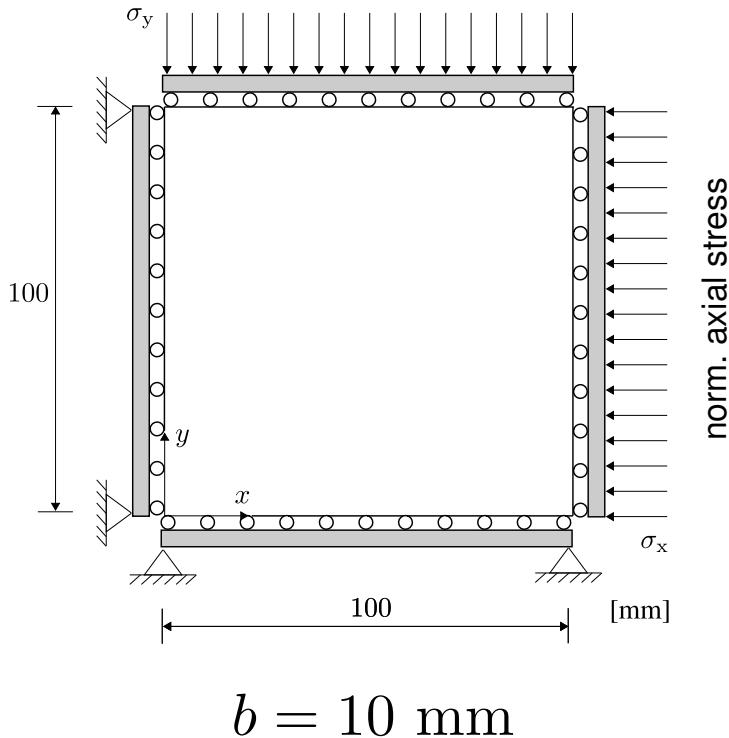
Uni- and biaxial compression



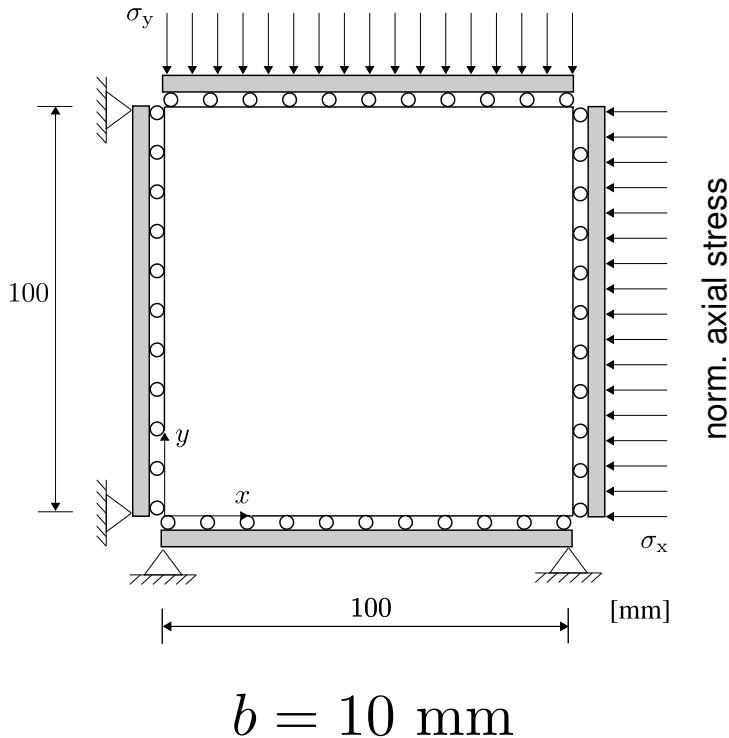
Uni- and biaxial compression



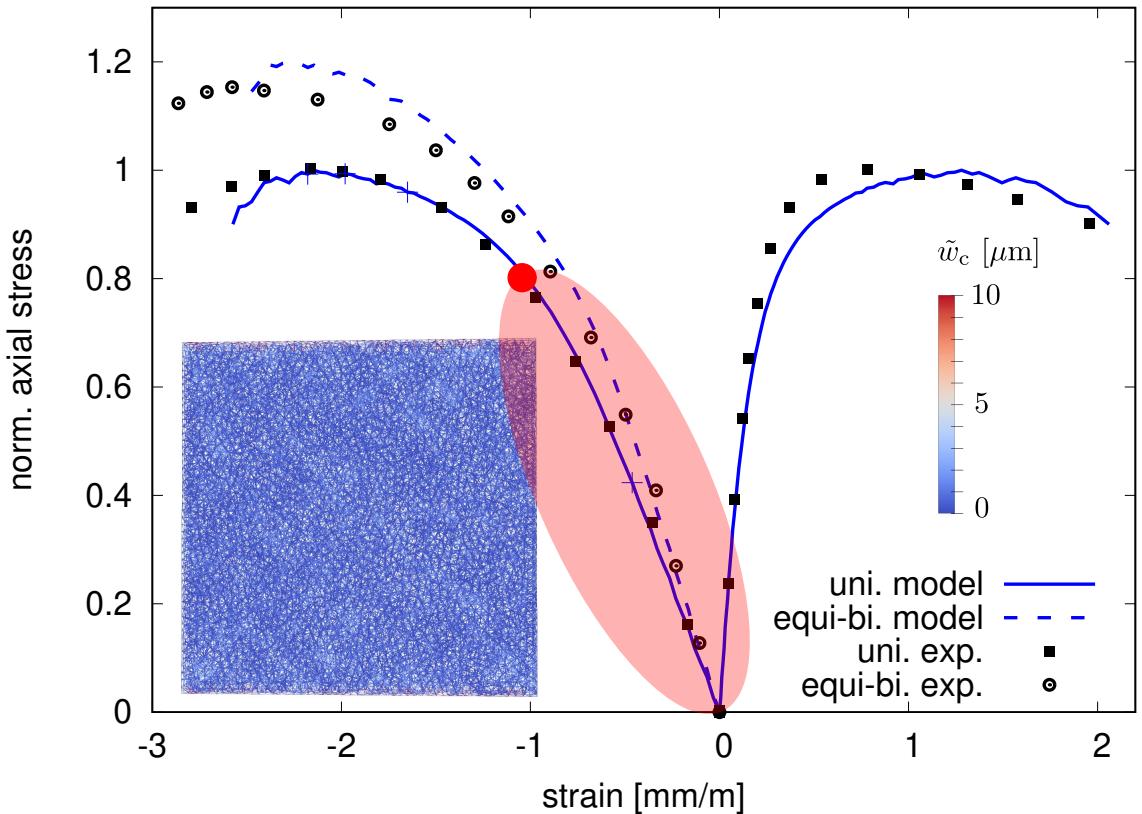
Uni- and biaxial compression



Uni- and biaxial compression



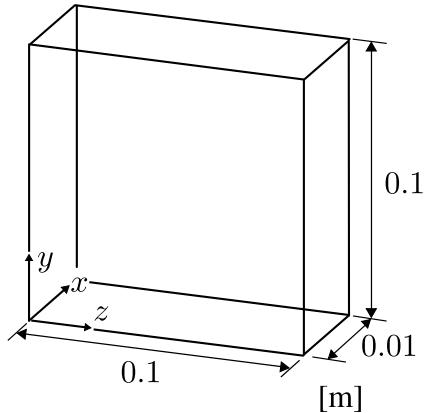
Ref: Kupfer et al. (1969)



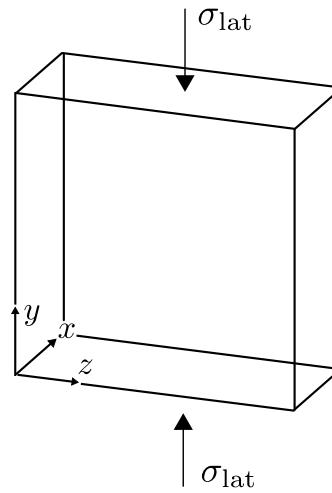
Analysis of fracture process zone

Geometry and loading setups

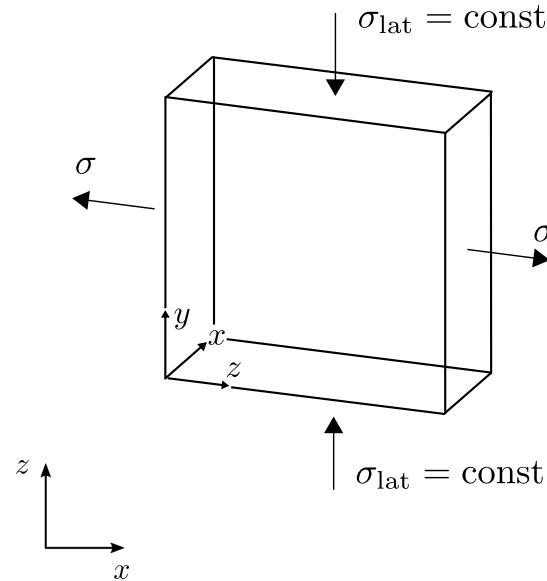
Periodic cell



Step 1

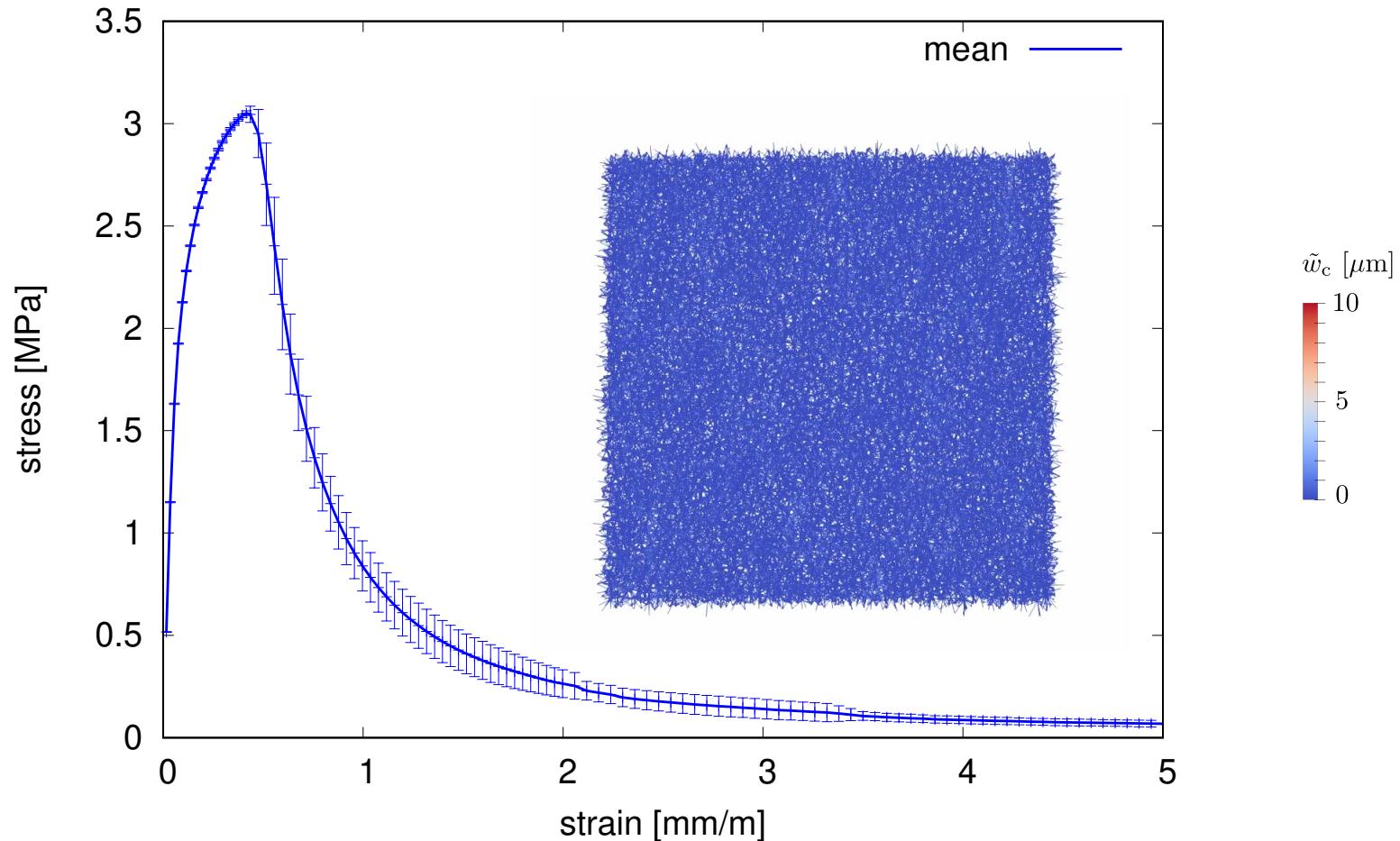


Step 2

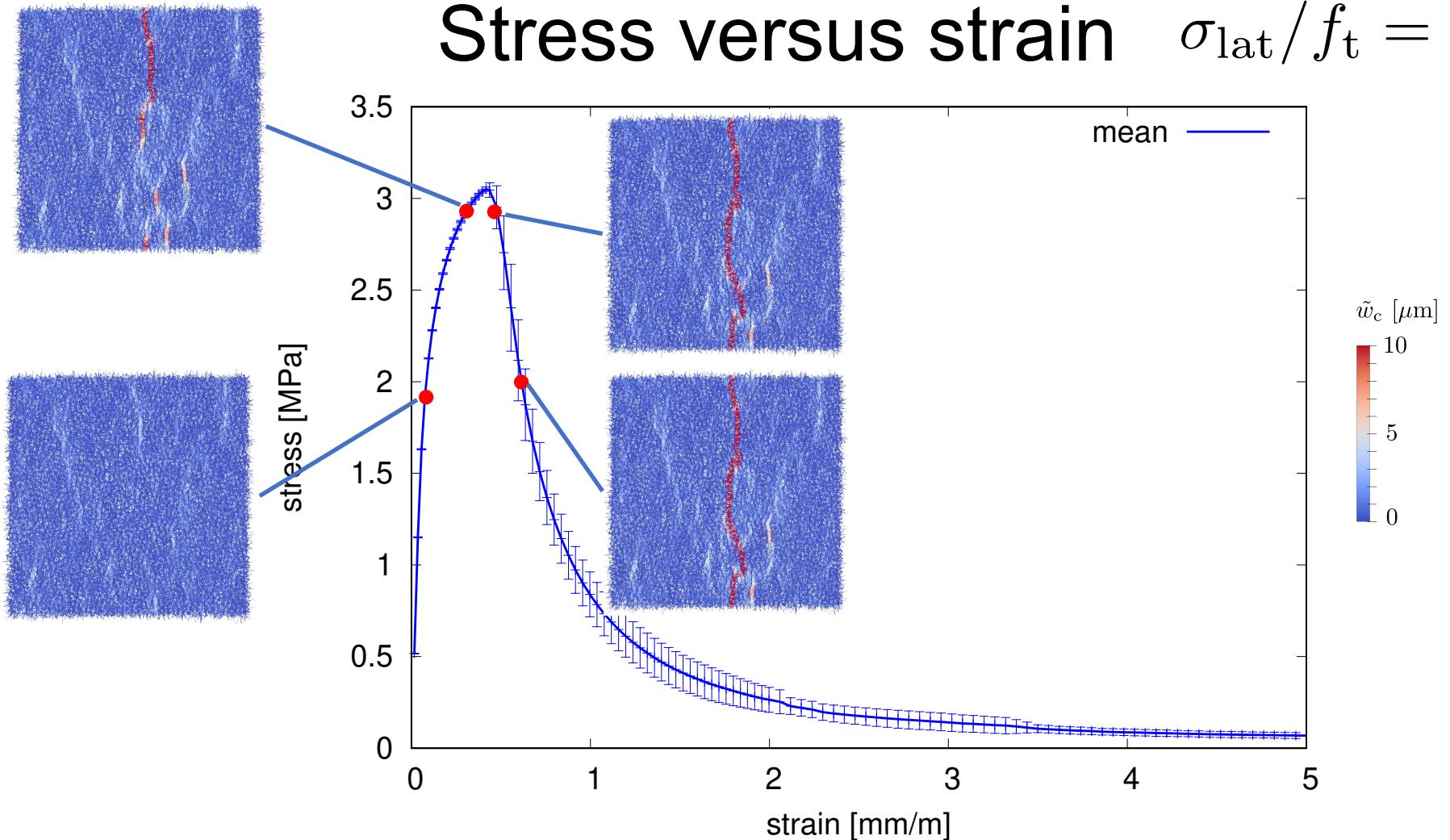


10 random analyses for
each confinement case

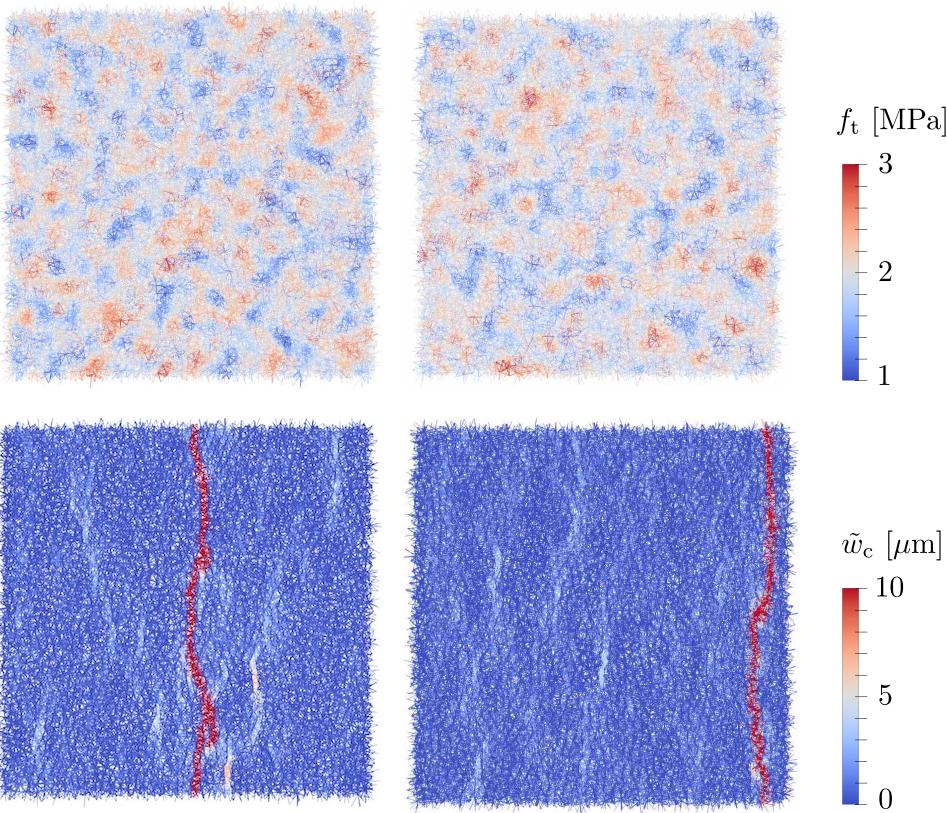
Stress versus strain $\sigma_{\text{lat}}/f_t = 0$



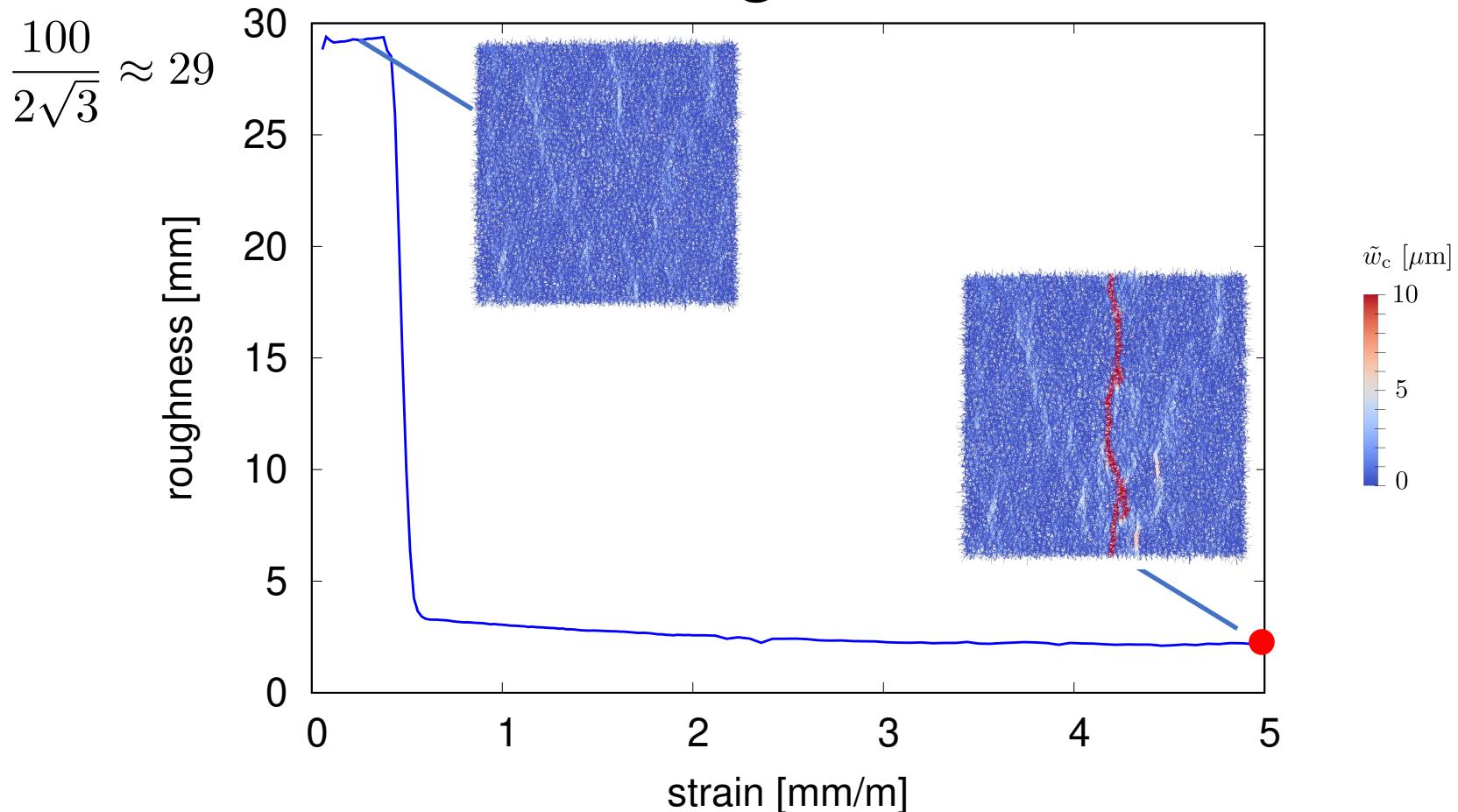
Stress versus strain $\sigma_{\text{lat}}/f_t = 0$



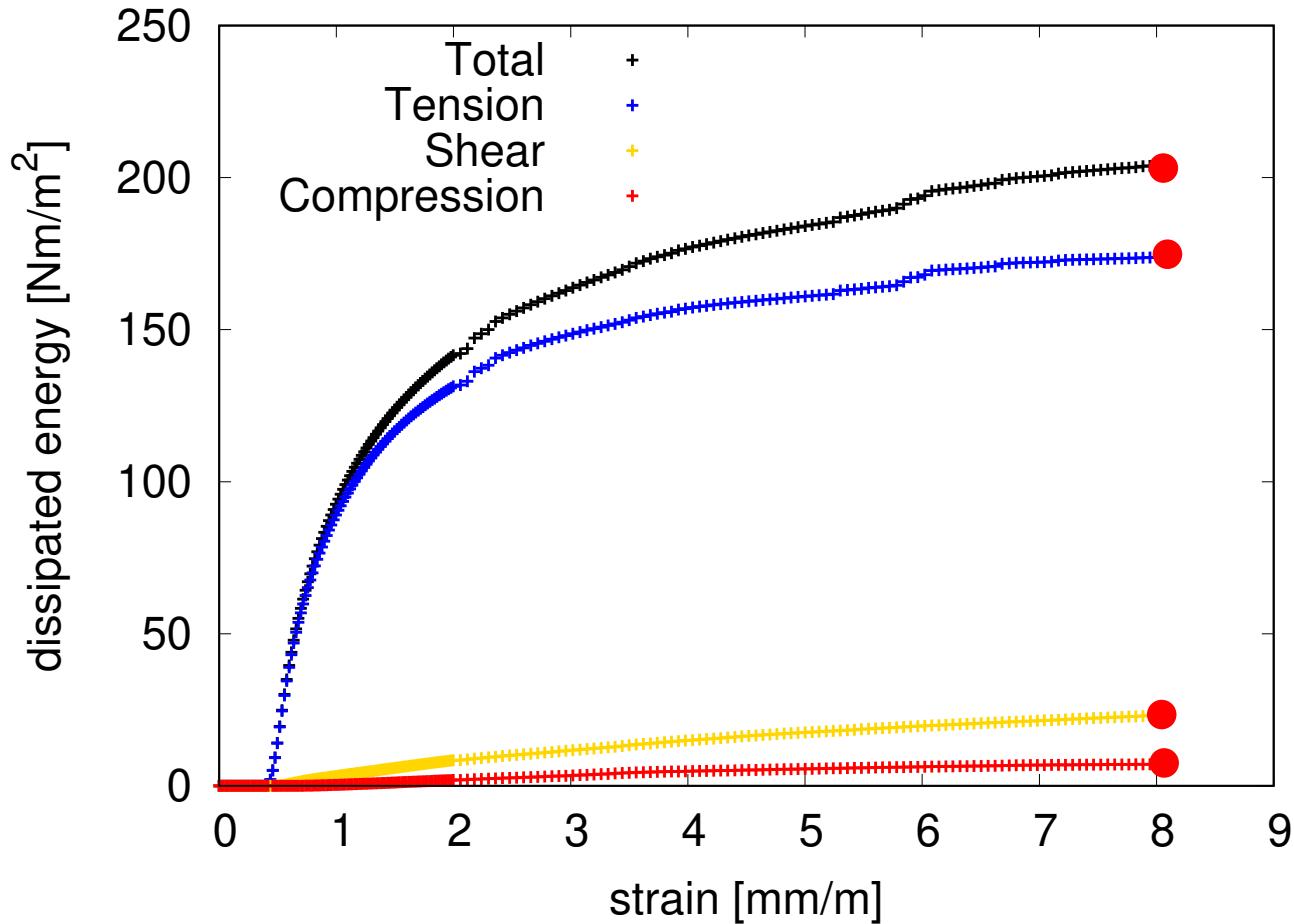
Fracture patterns



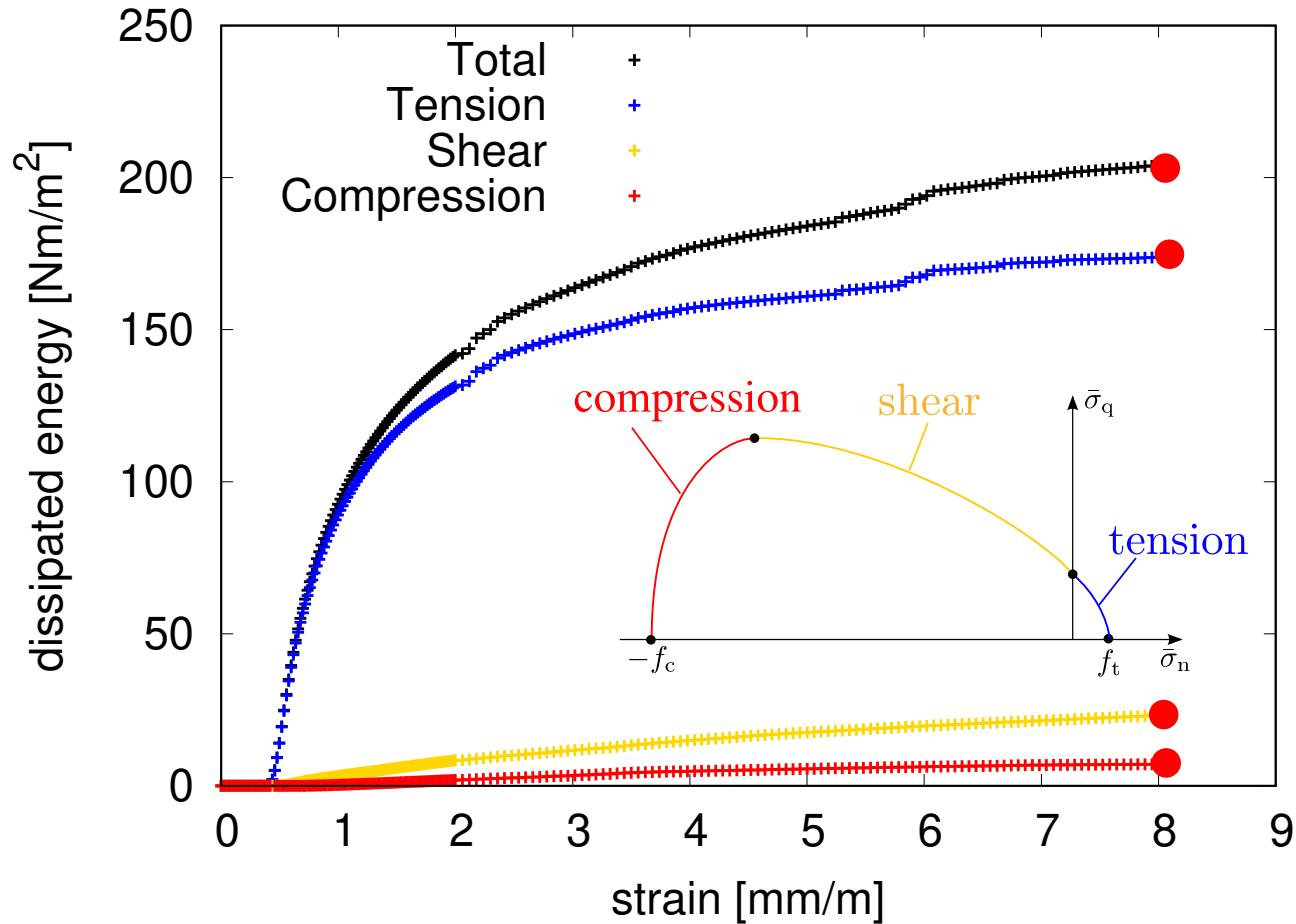
Roughness



Dissipation



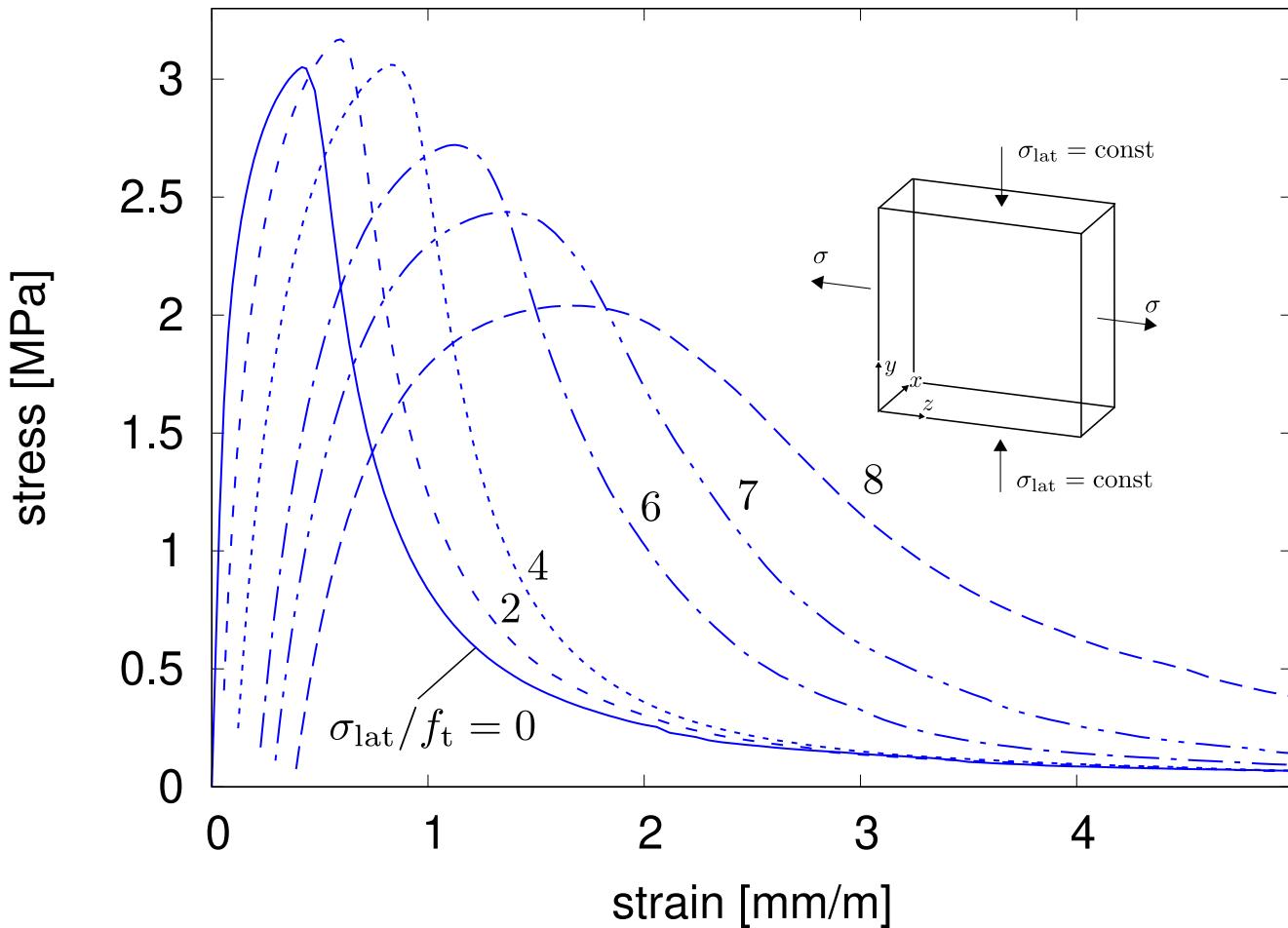
Dissipation



What is the reason for the increase in fracture energy due compression parallel to the crack?

Possible explanations: more friction, wider FPZ

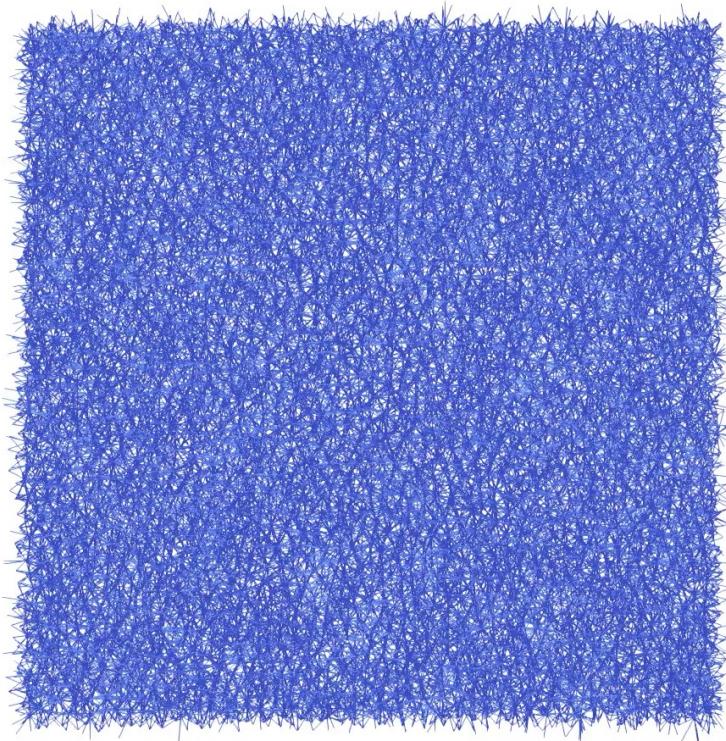
Stress versus strain for step 2



Incremental-
iterative analysis

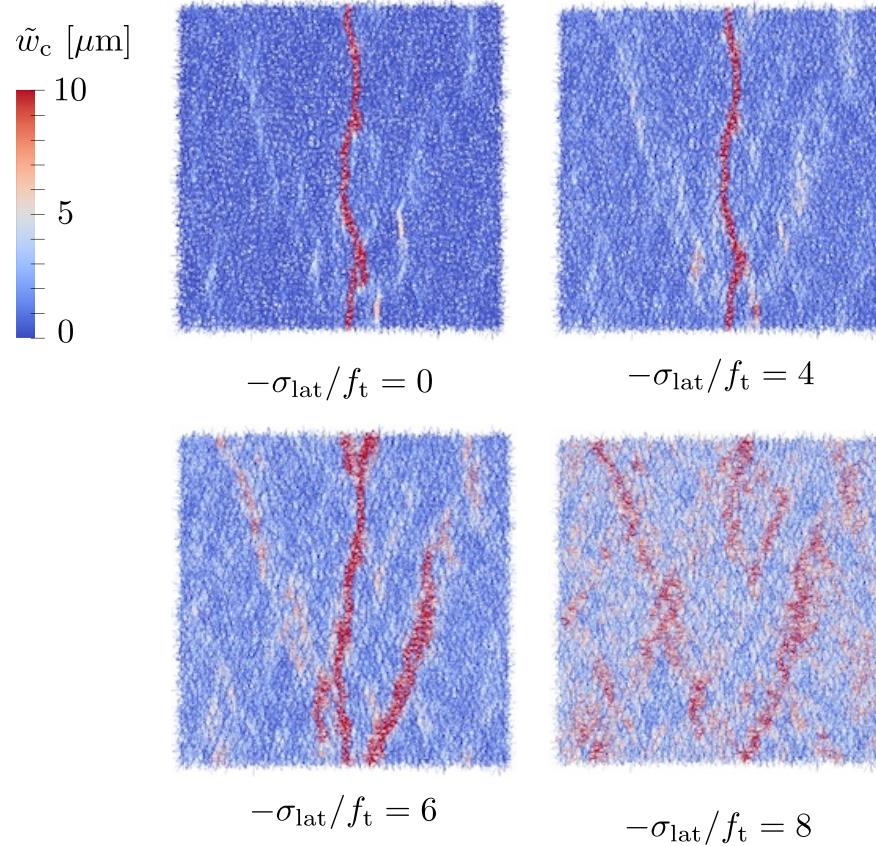
Average of 10
analyses

Fracture patterns

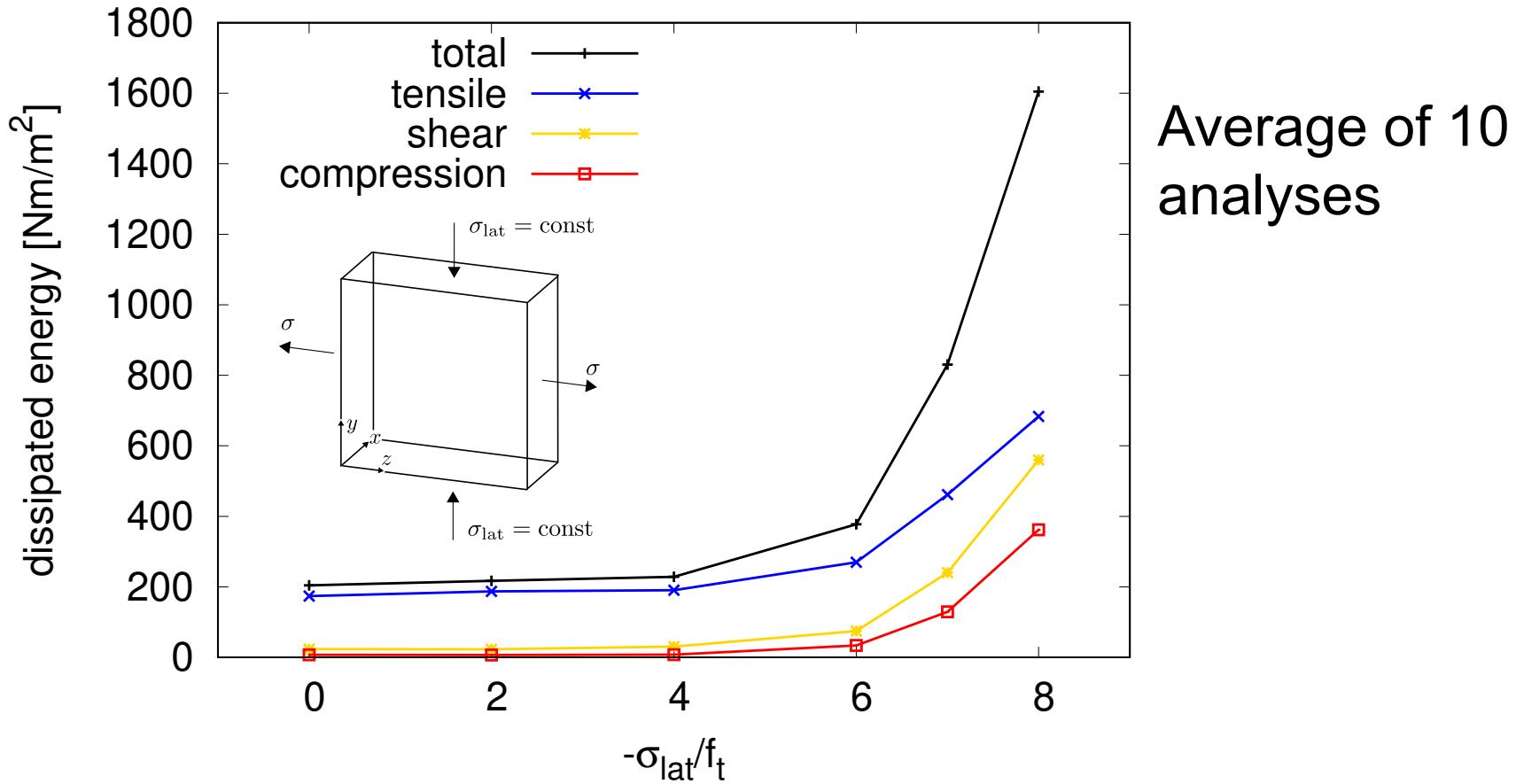


$$\sigma_{\text{lat}} / f_t = 6$$

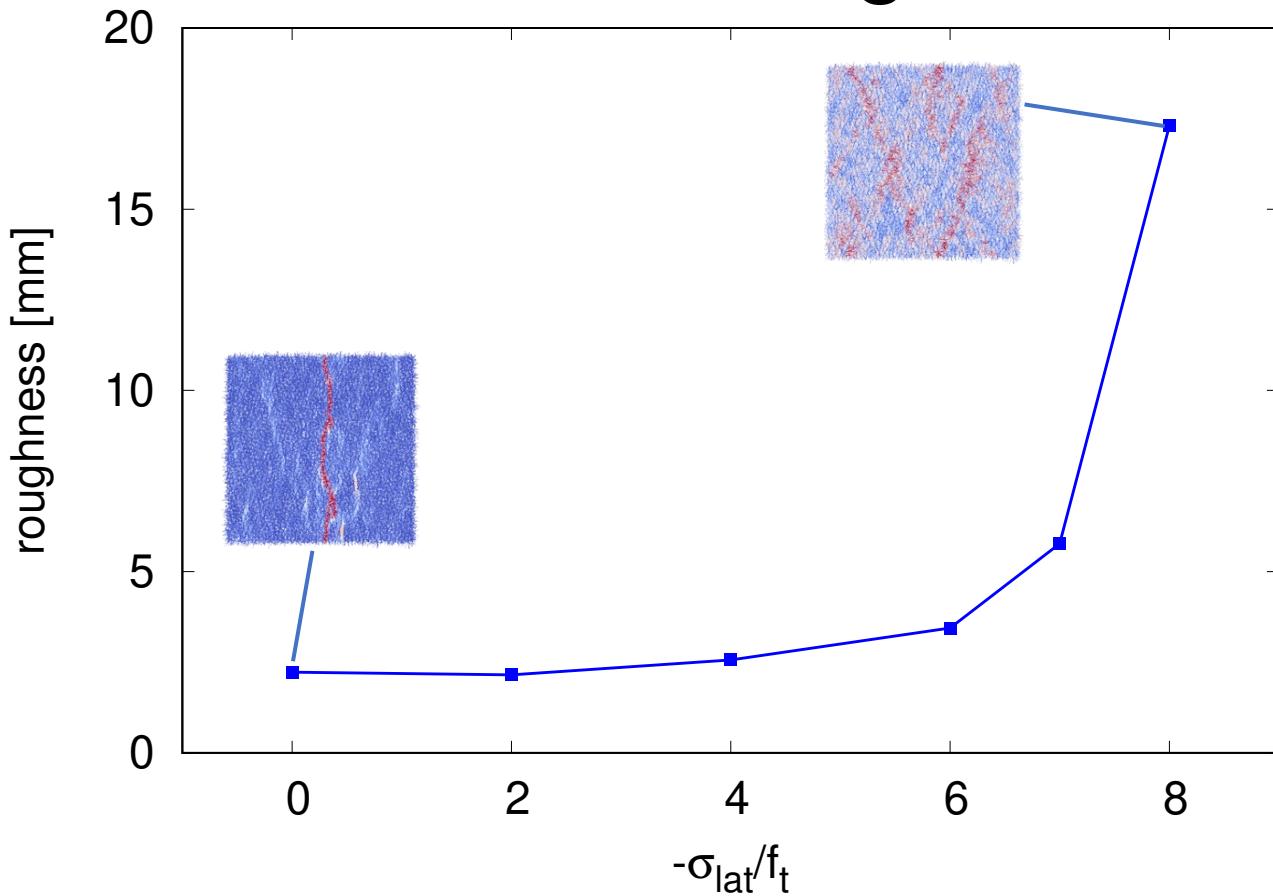
Fracture patterns



Post-peak dissipated energy



Roughness



Average of 10 analyses

$$\Delta h = \sqrt{\sum_{i=1}^N w_i (z_i - \bar{z})^2}$$

Conclusions

Compressive stress parallel to the crack has a strong effect on dissipated energy.

Ratio of shear to tension dissipation increases slightly with increasing compressive stress.

Roughness increases strongly with increasing compressive stress.

All simulations were performed with
OOFEM (<http://www.oofem.org>)



University
of Glasgow

A wide-angle photograph of a sunset or sunrise over a city skyline. The sky is filled with horizontal clouds, transitioning from deep orange and yellow near the horizon to a darker blue-grey at the top. In the foreground, dark silhouettes of trees and buildings are visible against the bright sky. A prominent, tall, spired tower, likely the University of Glasgow's main building, stands on the right side of the frame, its silhouette sharp against the warm colors of the sky.

Thank you for listening

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   @UofGlasgow