SEMPAE

Trèves

GROUPE RENAULT

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Nonlinear and time-dependent behaviour of compressed melamine foam: application to pyramidal asperities in a surface roughness model

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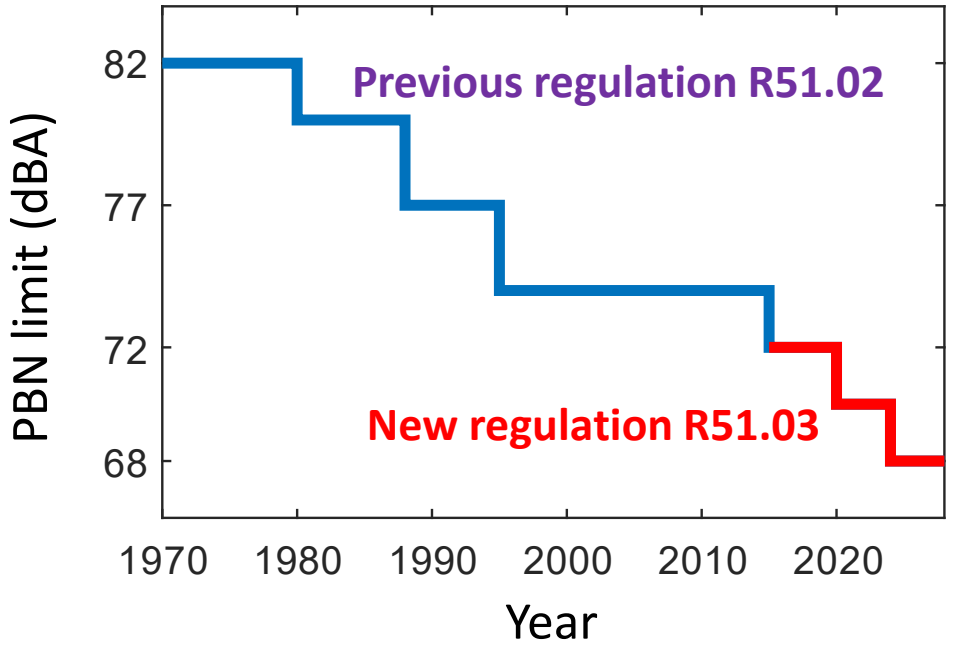
07/11/2023

Porous acoustic screens with partial contact

Road noise is big source of complaints
European regulation is lowering pass-by noise limit



Porous acoustic screens with partial contact

Completed project: EcOBEx (2014-2017)

EcOBEx

Porous acoustic screens with partial contact

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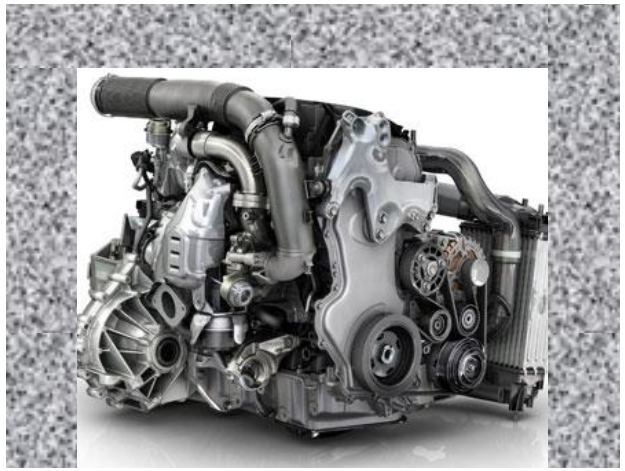
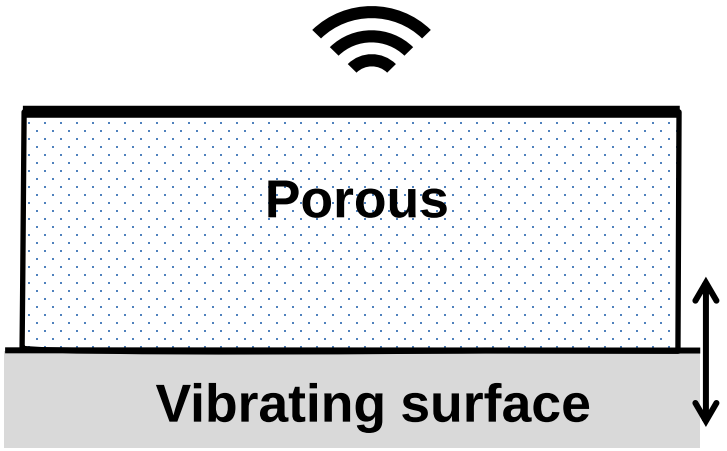
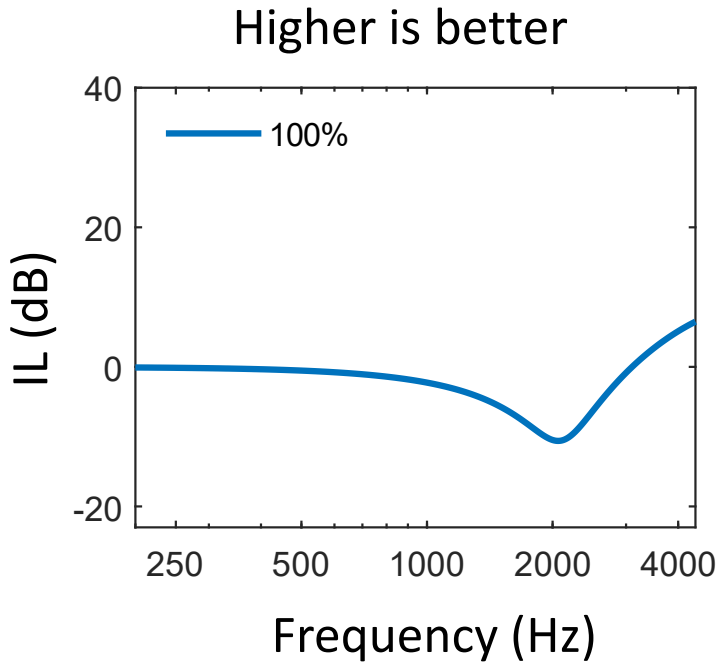
Current project: SEMPAE (2020-2023)



Porous acoustic screens with partial contact

Strong effect of screen mechanical properties
Partial contact yields better decoupling





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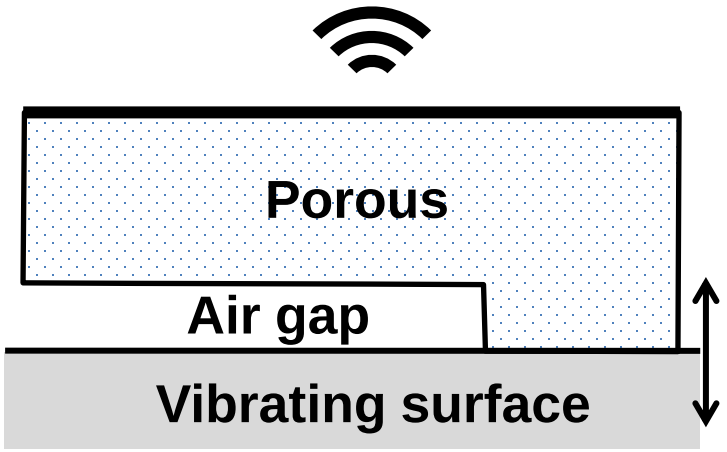
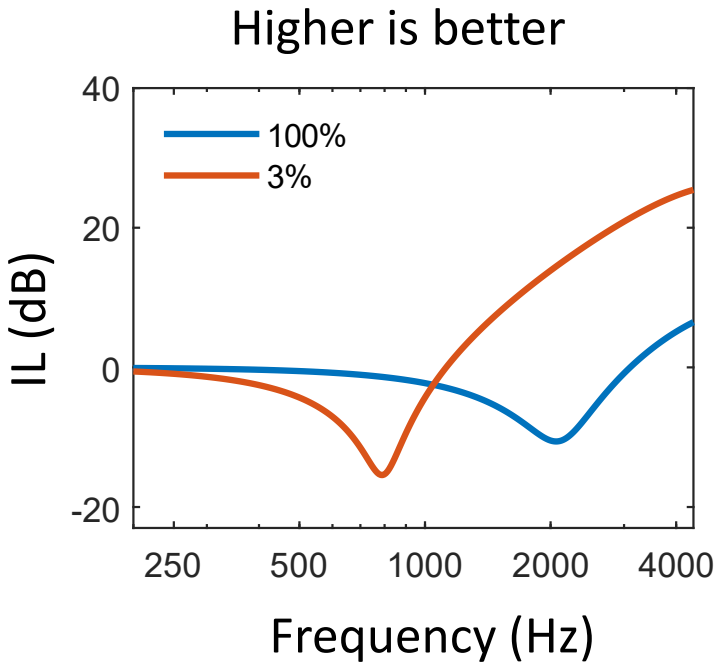
Partial contact yields better decoupling
Modelled with PTMM (Verdière, 2013)





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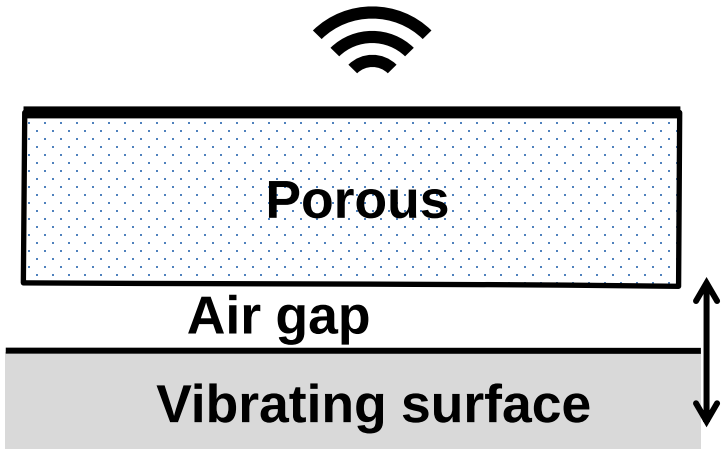
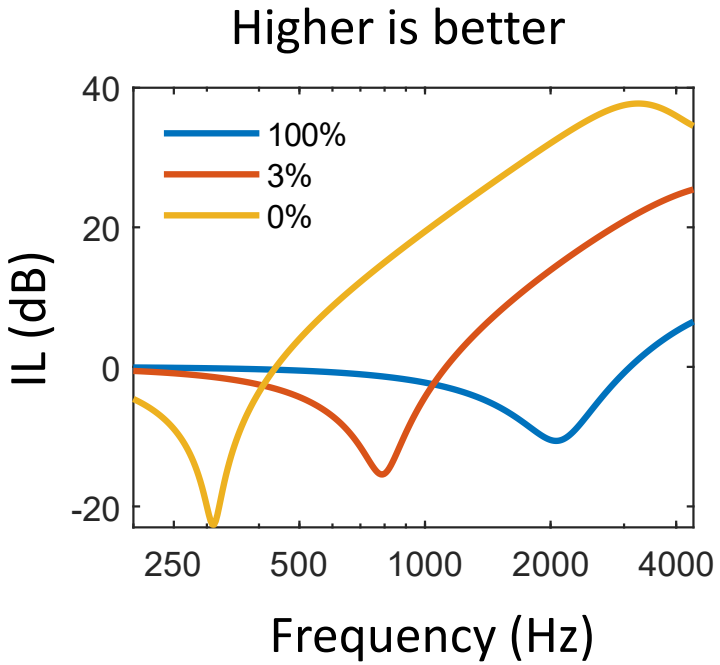




Porous acoustic screens with partial contact

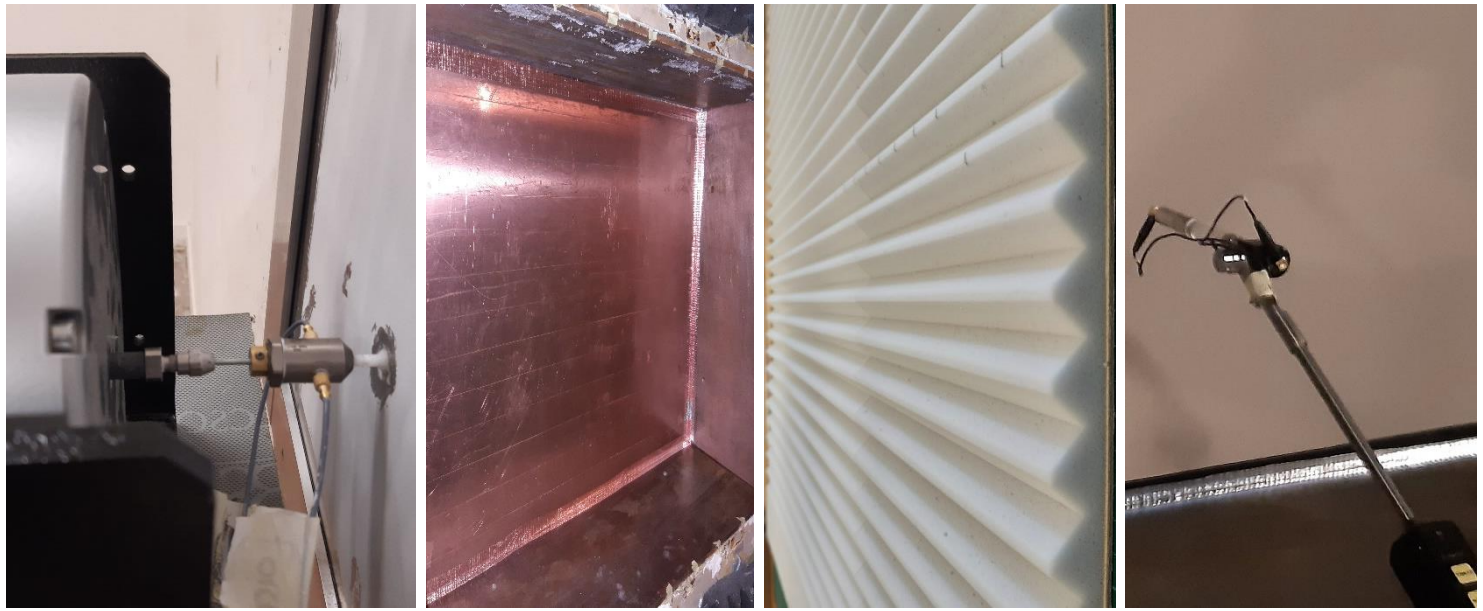
Experimental results of partial contact

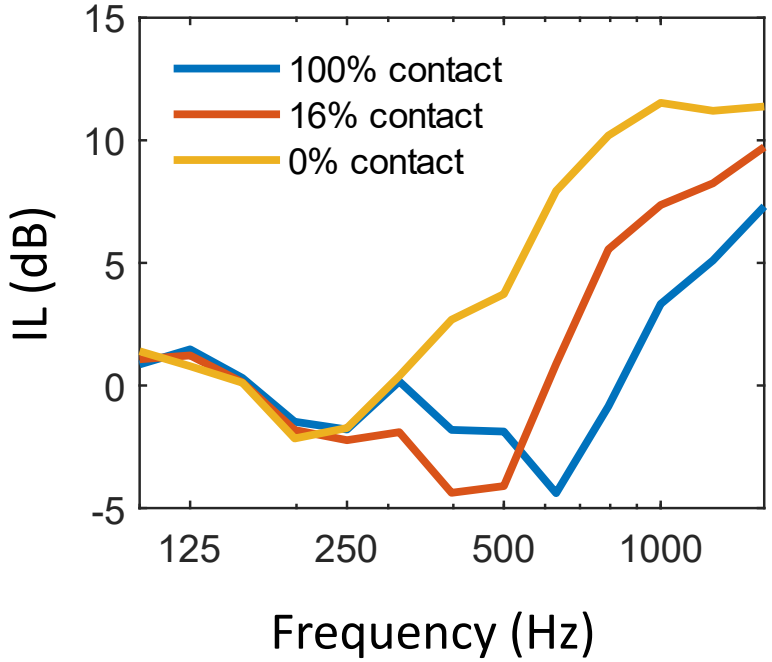
Shaker:
Injected power

Plate

Porous screen
+ heavy layer

Intensity probe:
Radiated power

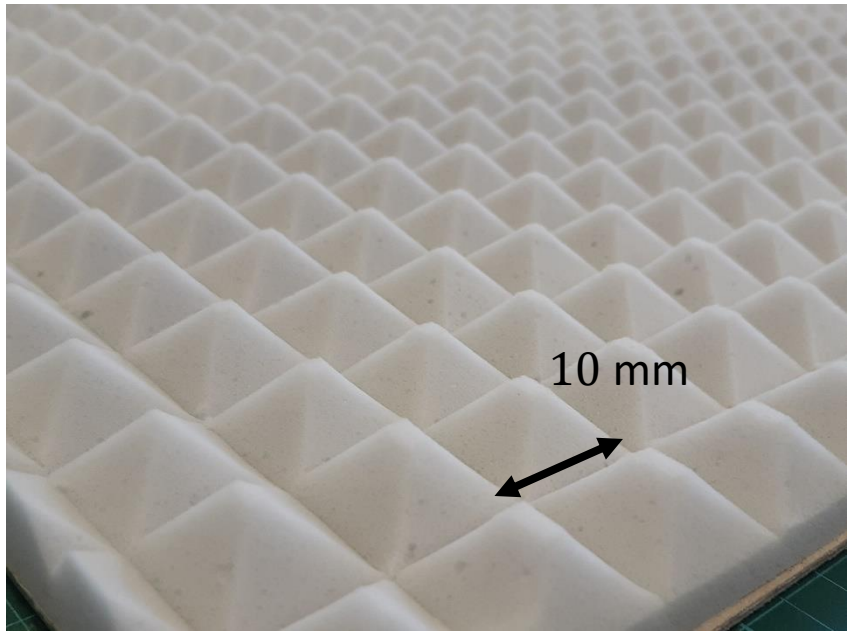


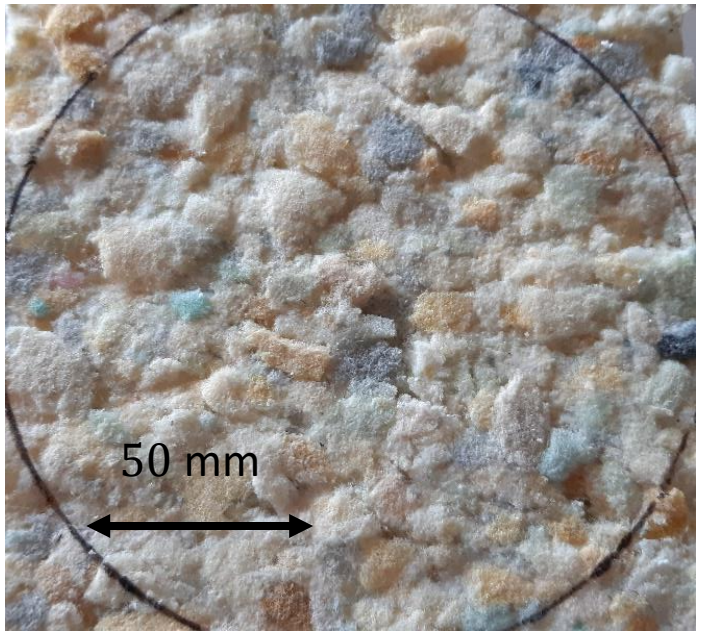


Porous acoustic screens with partial contact

The contact region between the engine and the porous screen should be modelled

1) How much contact when compressed ?
2) What is the compression stiffness?





Porous acoustic screens with partial contact

Modelling a rough surface

Porous acoustic screens with partial contact

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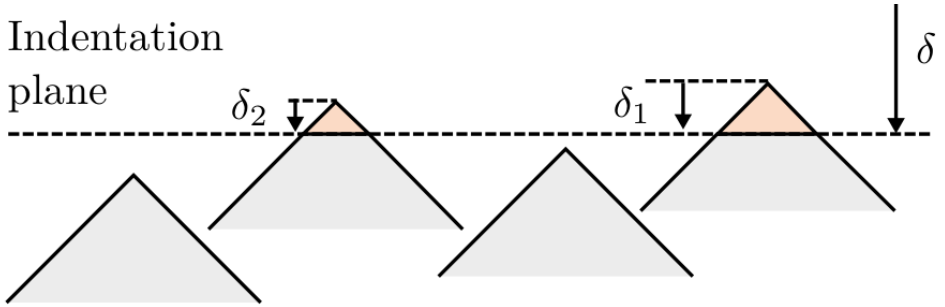

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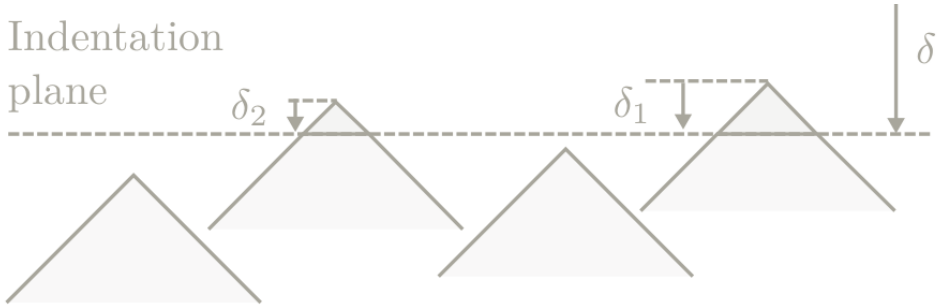

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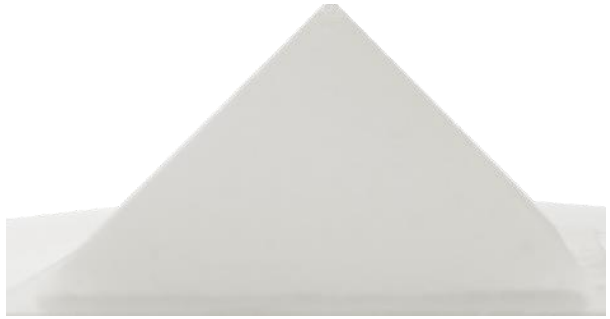

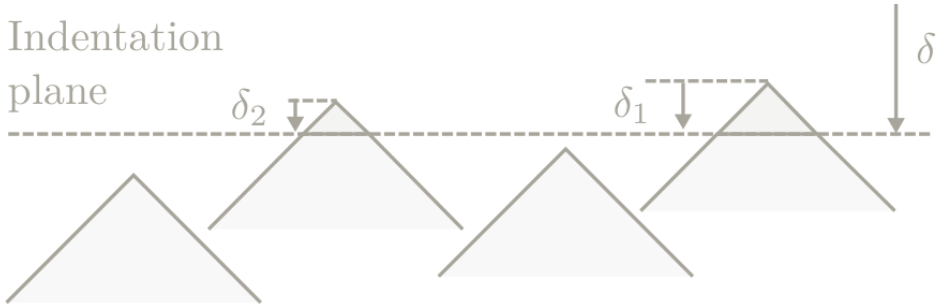

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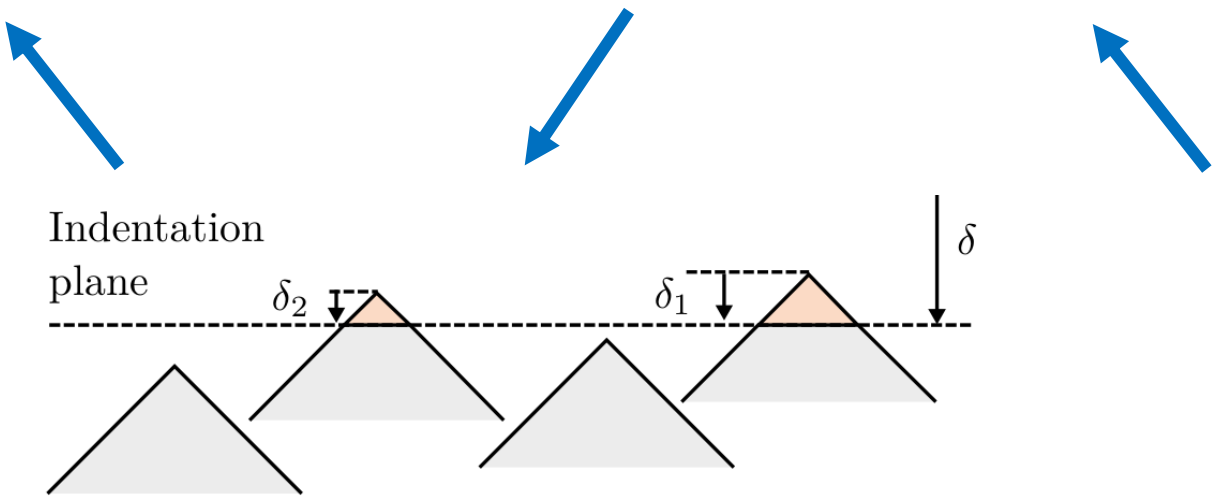

Plan

1) **Intrinsic material behaviour**

2) Pyramid compression

Modelling material behaviour: nonlinearity

Porous microstructural material
Known to behave non linearly
Modelled with a hyperelastic model

Modelling material behaviour: nonlinearity

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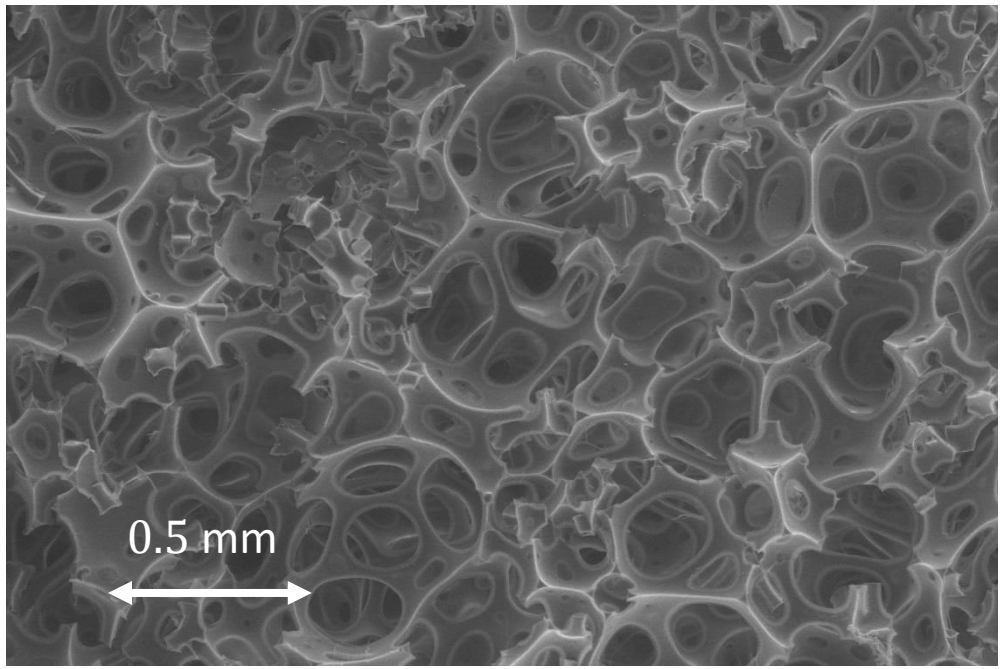

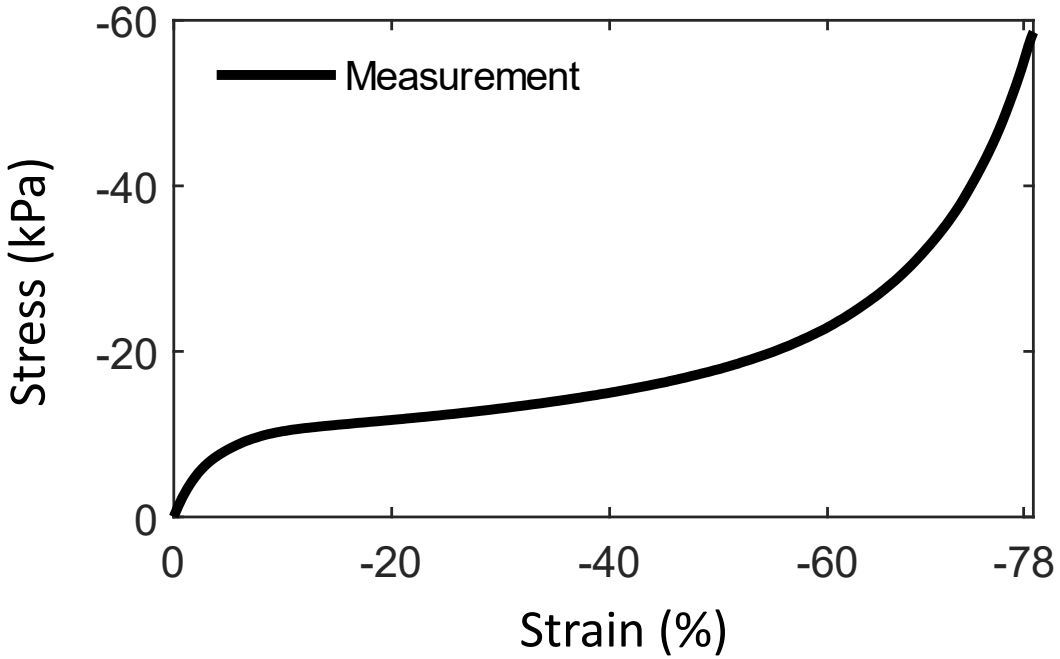

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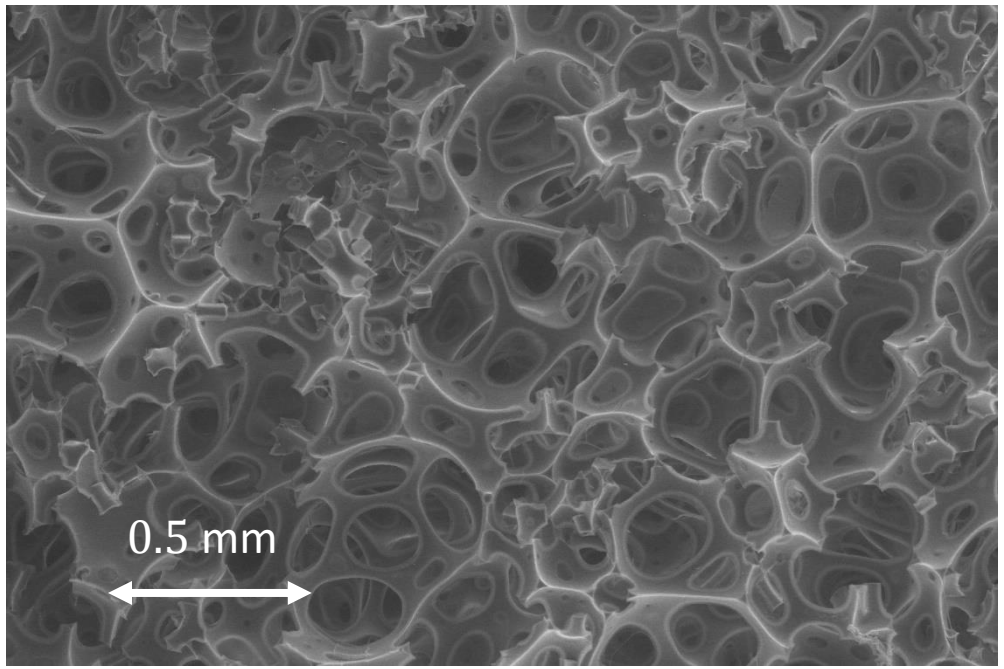
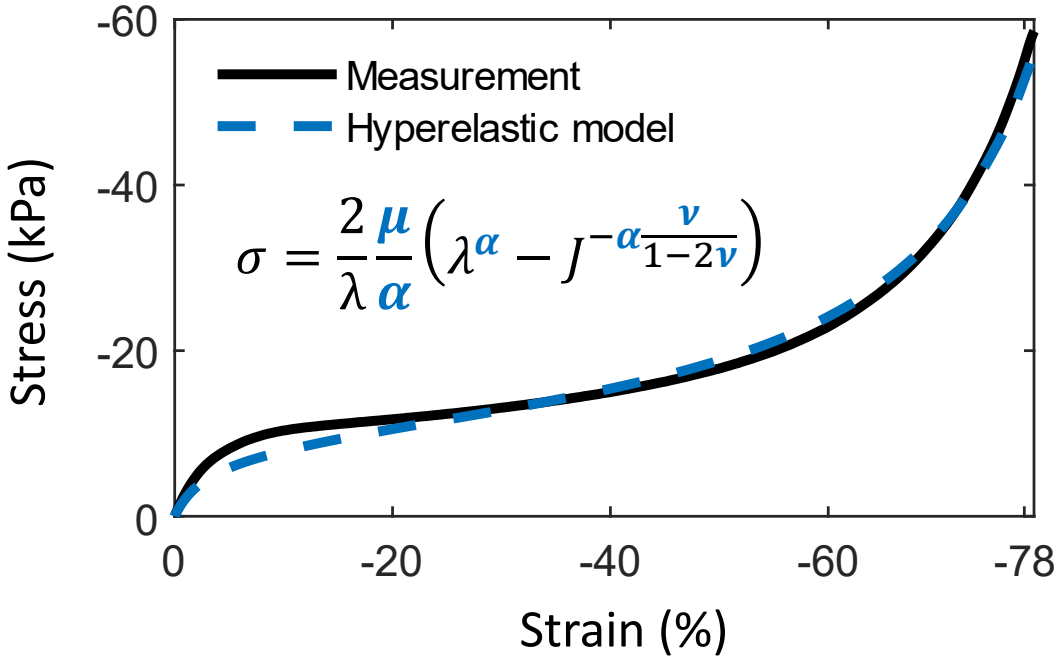
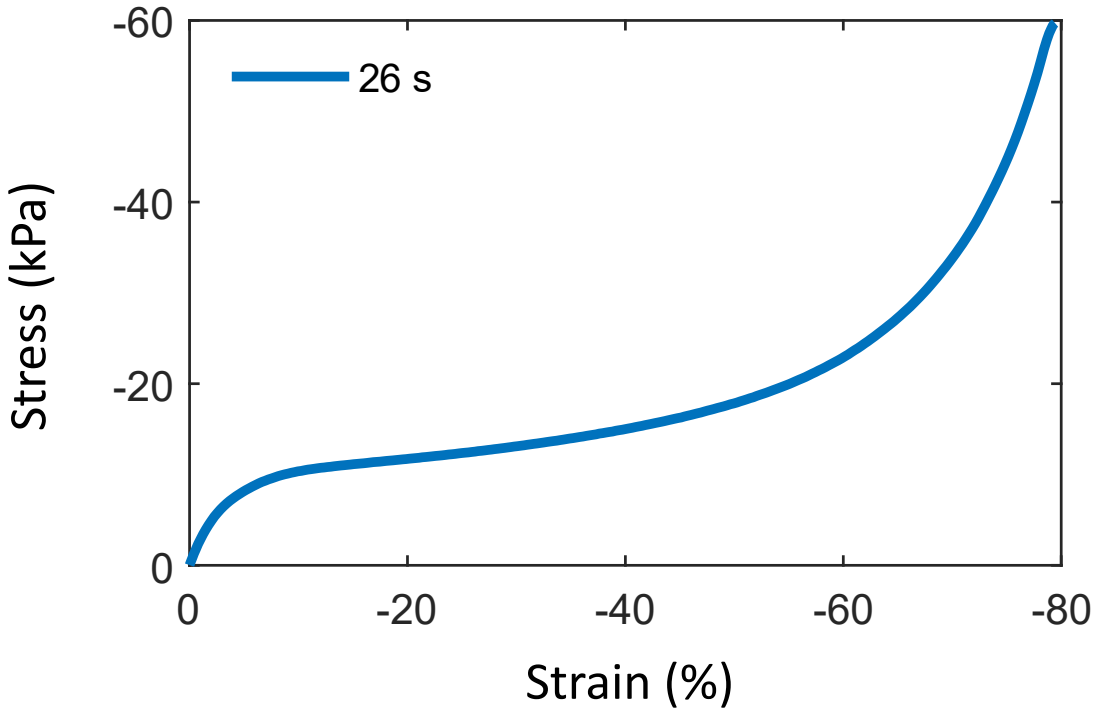




Modelling material behaviour: relaxation

Time-dependence of measurements due to relaxation

Can the instant response be obtained?



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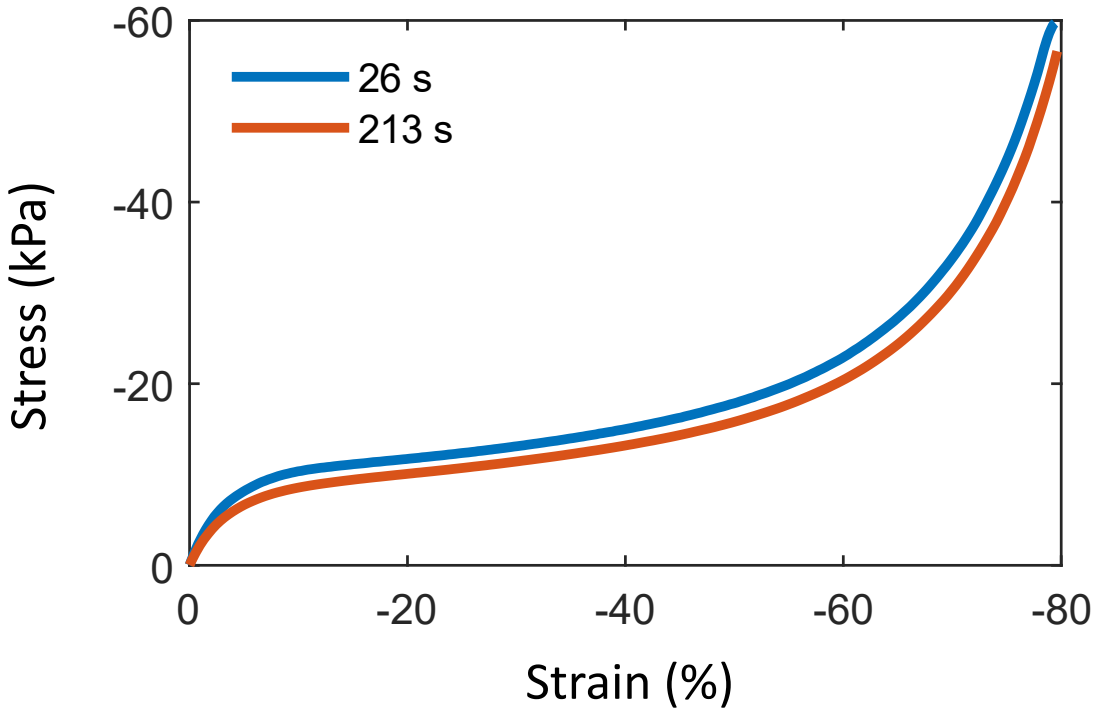

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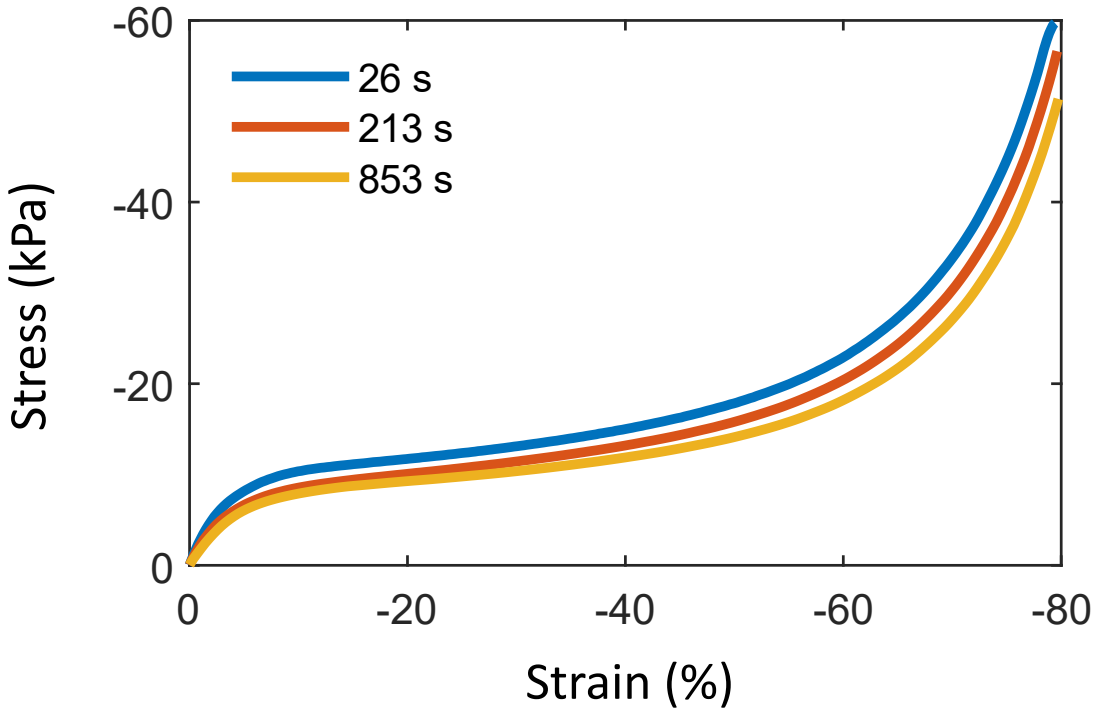

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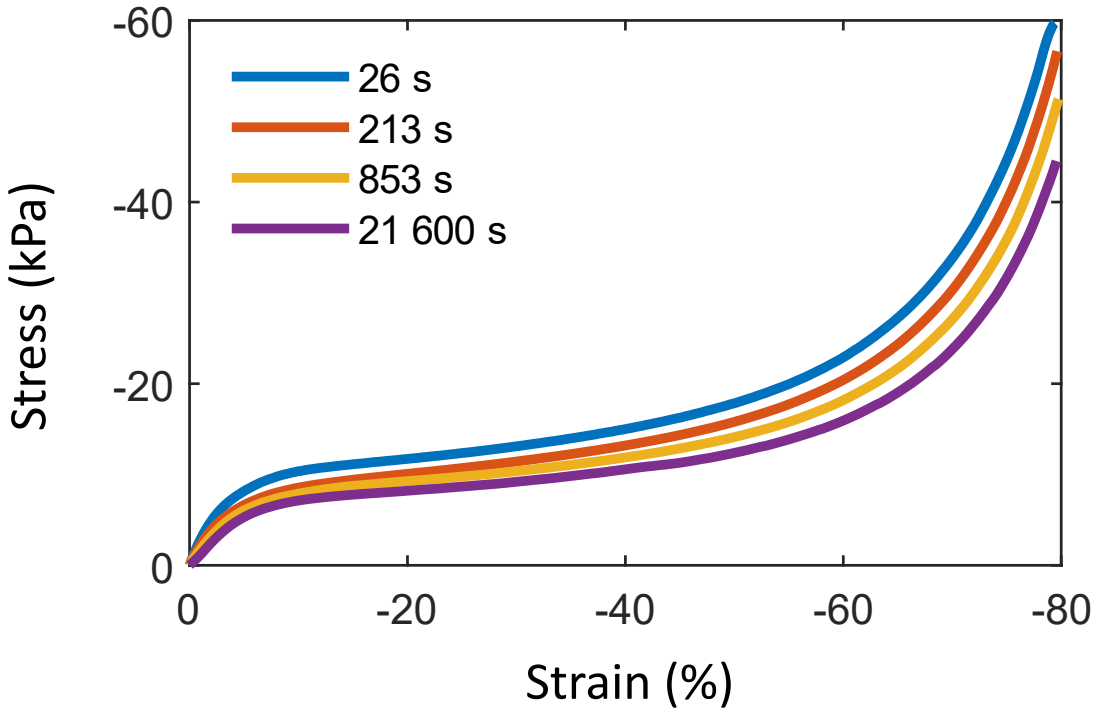
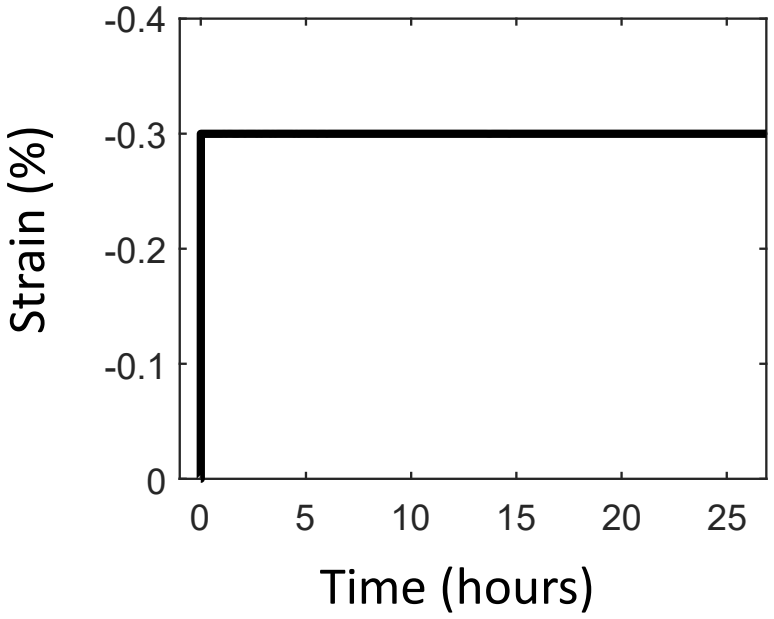
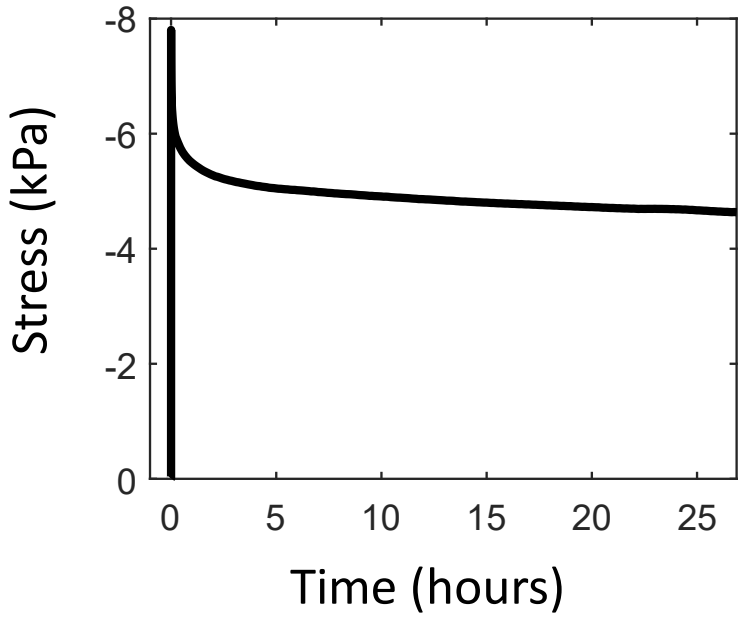
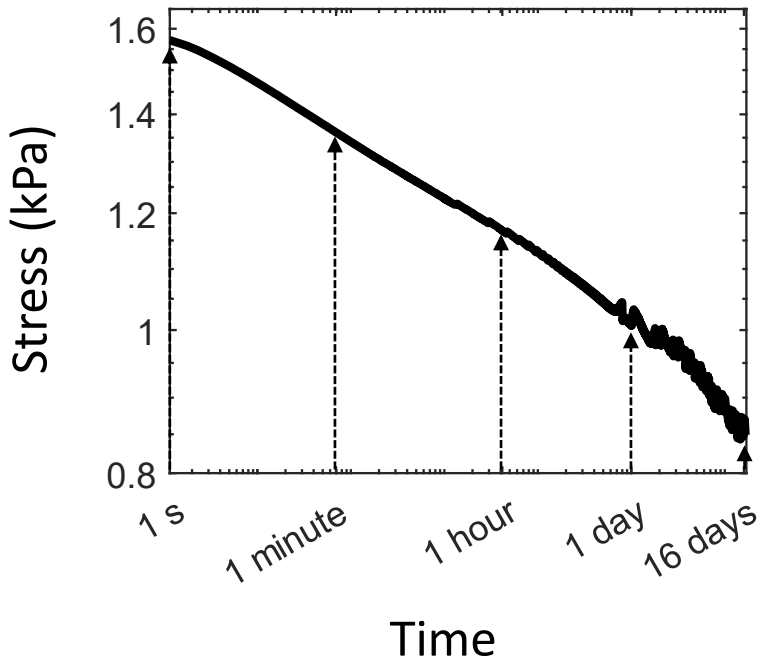


Modelling material behaviour: relaxation

Over long durations, relaxation leads to large variations
How can it be modelled?







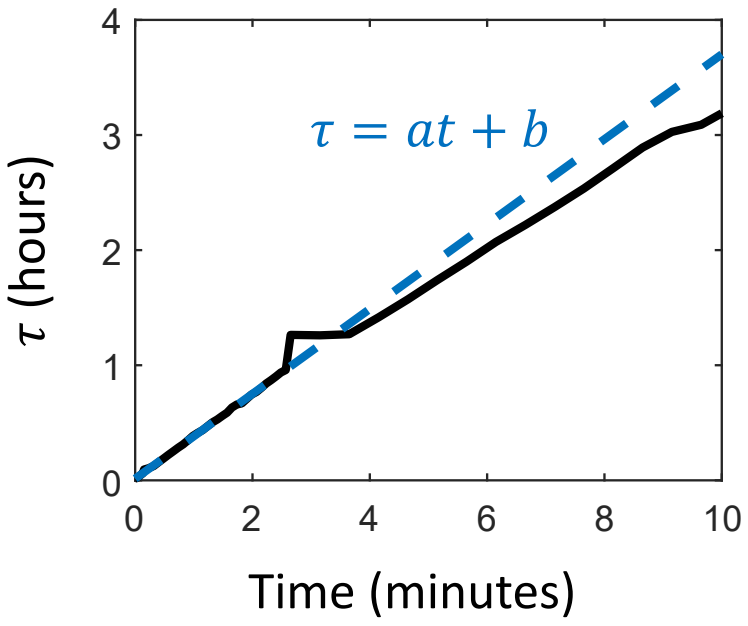
- 5 minutes: 20 % difference
- 24 hours: 40 % difference

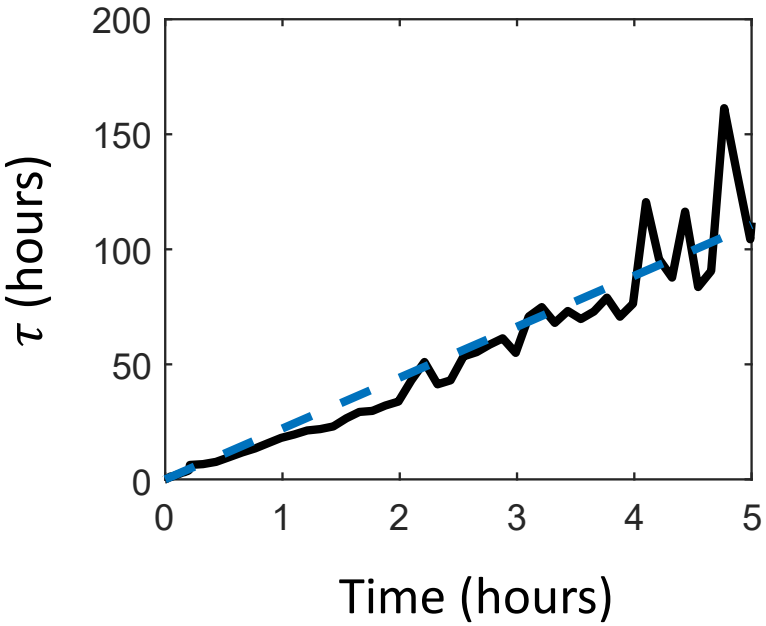
Modelling material behaviour: relaxation

At constant strain, relaxation time τ increases linearly with time

Relaxation time :

$$\tau = \frac{-F}{\dot{F}}$$

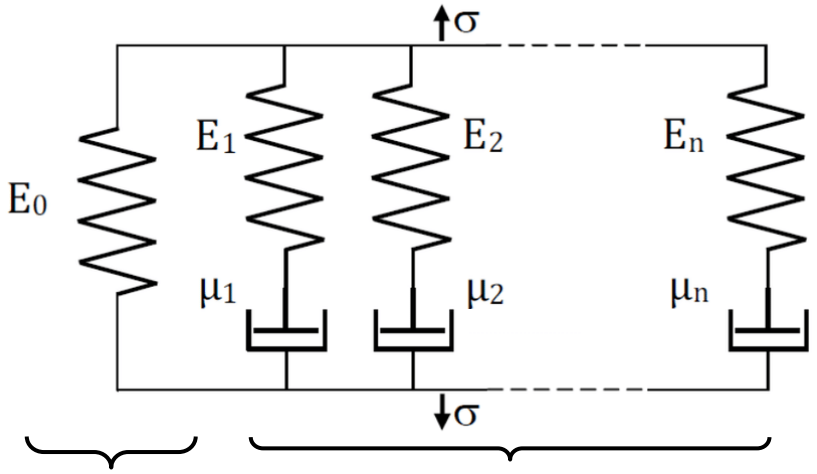




Modelling material behaviour: relaxation

Different relaxation times could be modelled with generalized Maxwell model

Generalized Maxwell model



Static stress E_0 $\boldsymbol{N}$ **relaxation times** $\boldsymbol{\tau_i = \frac{\mu_i}{E_i}}$

Modelling material behaviour: relaxation

However the behaviour is more reminiscent of an aging phenomenon

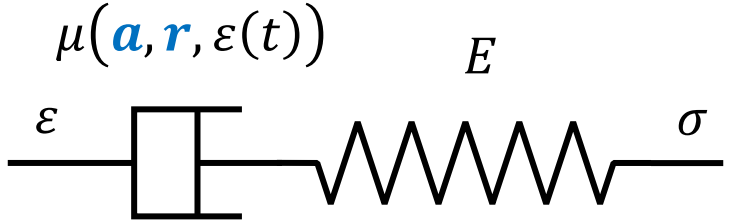
$$= \frac{1}{\tau}$$

$$\begin{cases} \dot{\sigma} = -f\sigma + E\dot{\varepsilon} \\ \dot{f} = -\boldsymbol{a}f^2 + \boldsymbol{r}\dot{\varepsilon}^2 \end{cases}$$

Aging: when $\dot{\varepsilon} = 0$,
τ increases with slope a

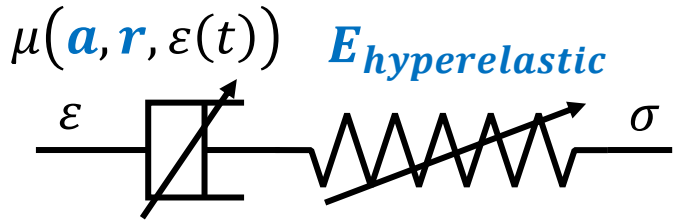
Rejuvenation: when
$\dot{\varepsilon} \neq 0$, τ decreases

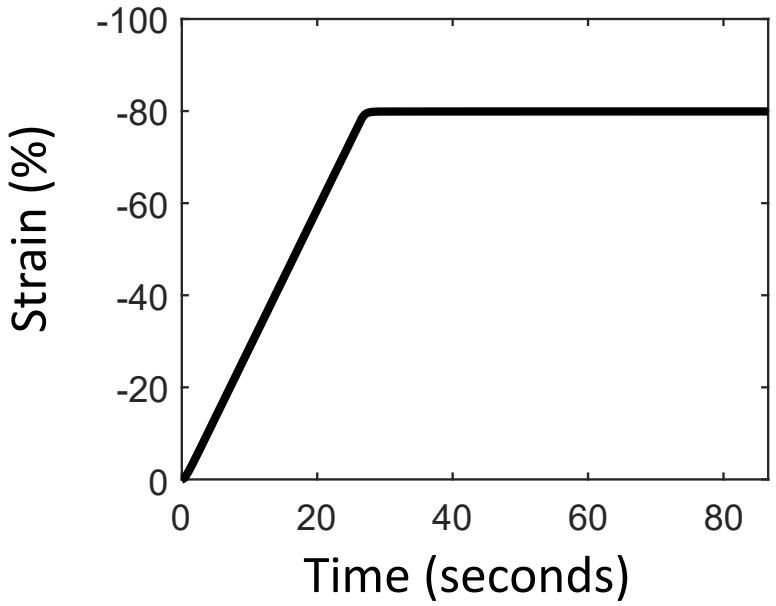
Aging model

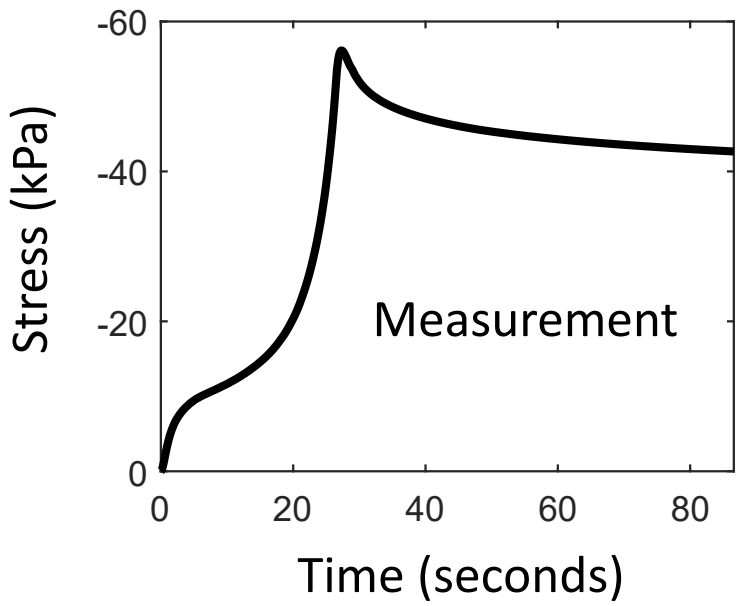


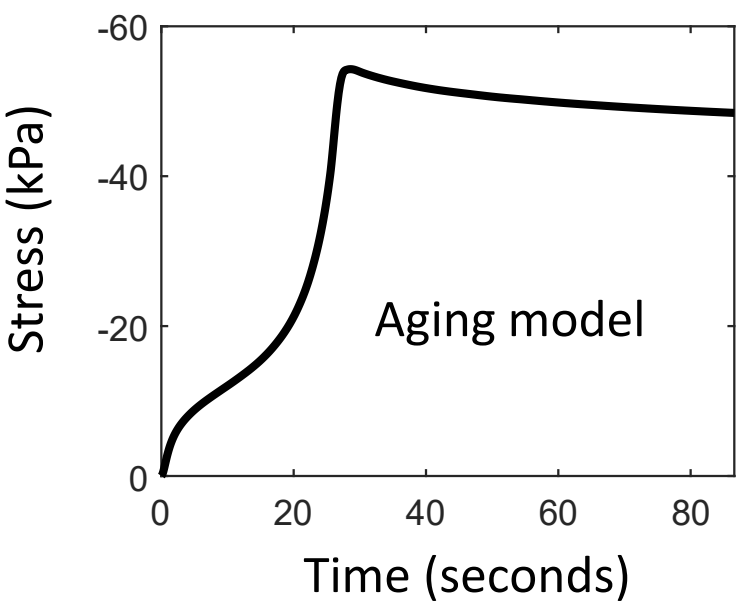
Modelling full material behaviour

Aging model combining nonlinearity and relaxation
Can predict response at any time



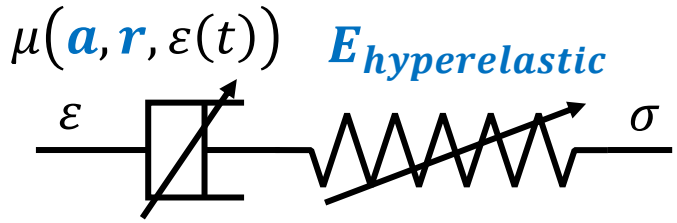


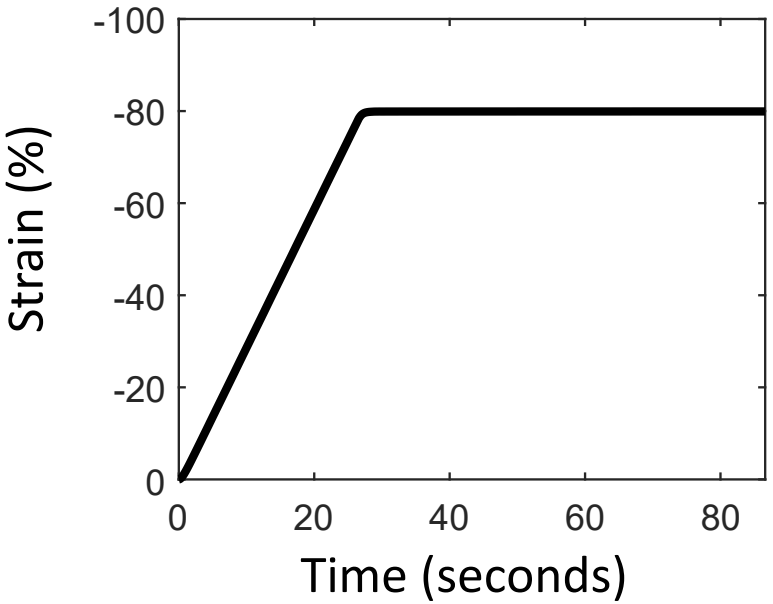


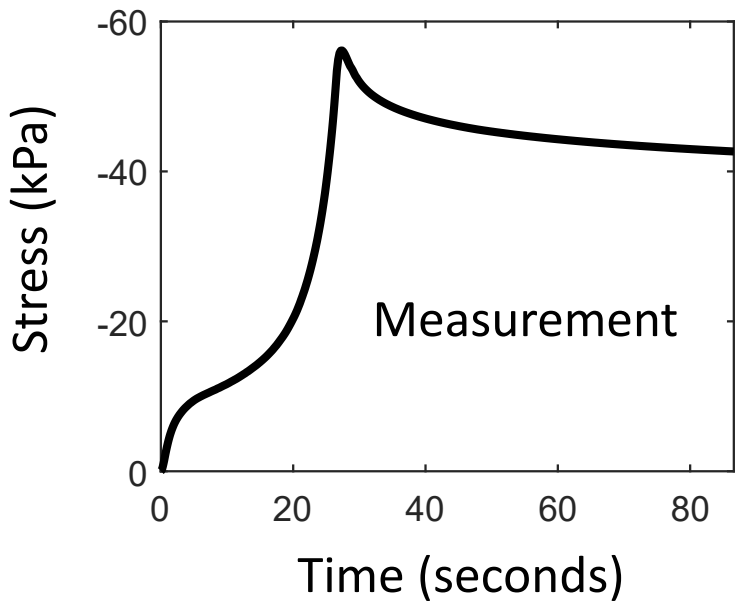


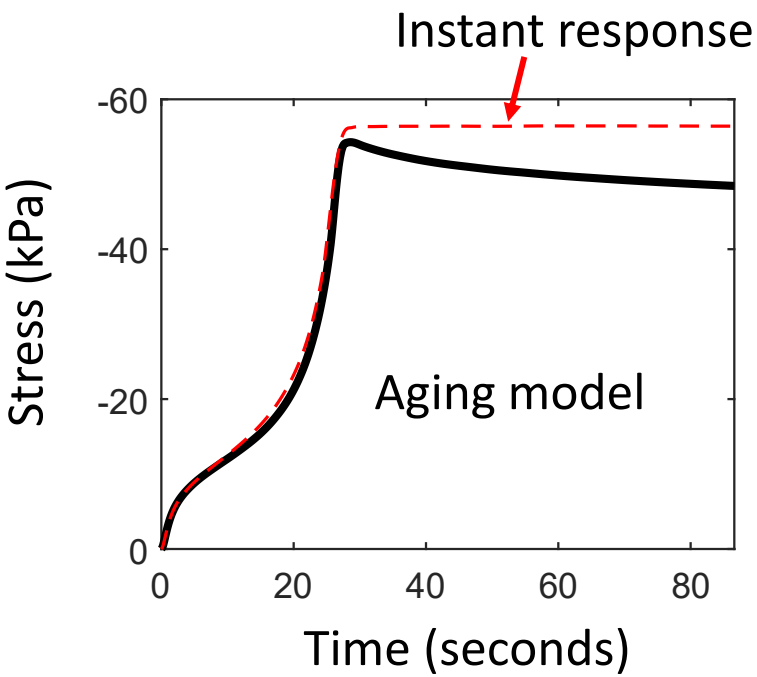
Modelling full material behaviour

Aging model combining nonlinearity and relaxation
Can predict response at any time
Measure instant response if quick enough









Plan

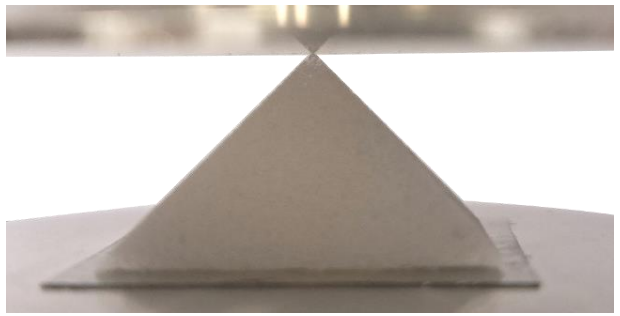
1) Intrinsic material behaviour

2) **Pyramid compression**

Behaviour of an asperity

Measurements on pyramidal asperities of melamine foam
Numerical FEM model
Analytical expectation

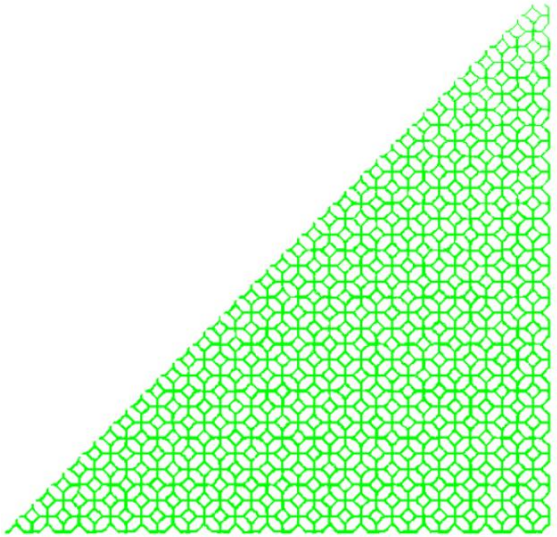
1) Experiment



2) Analytical

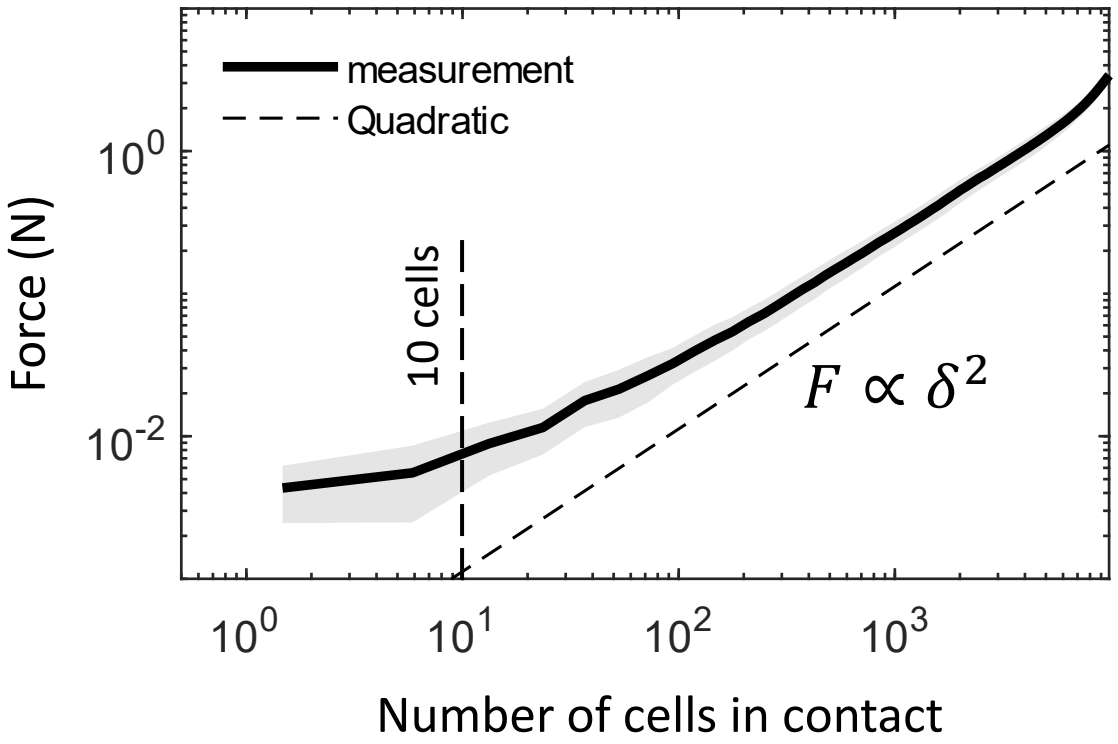
$$F \propto \delta^2$$

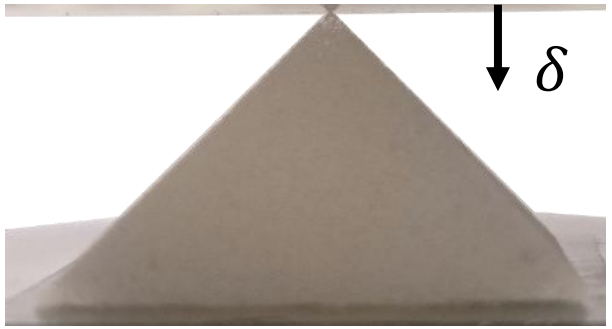
3) FEM models



Behaviour of an asperity

Experimental results similar to quadratic tendency!
Works $\gtrsim$ 10 cells in contact

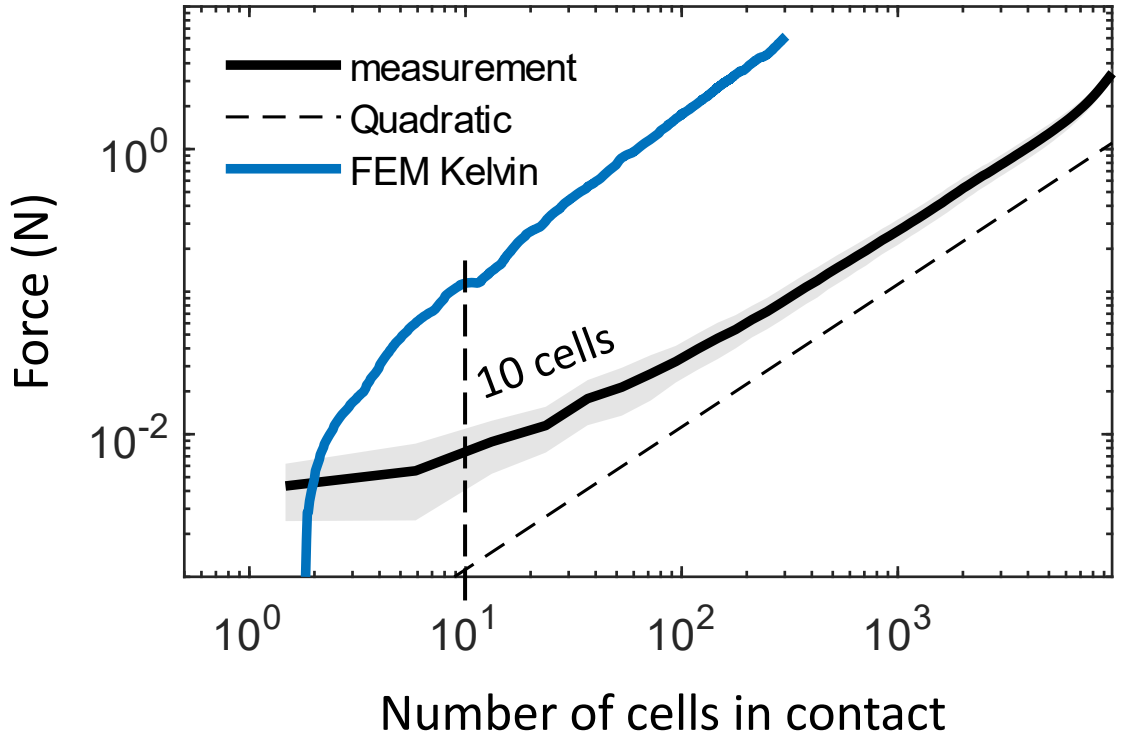




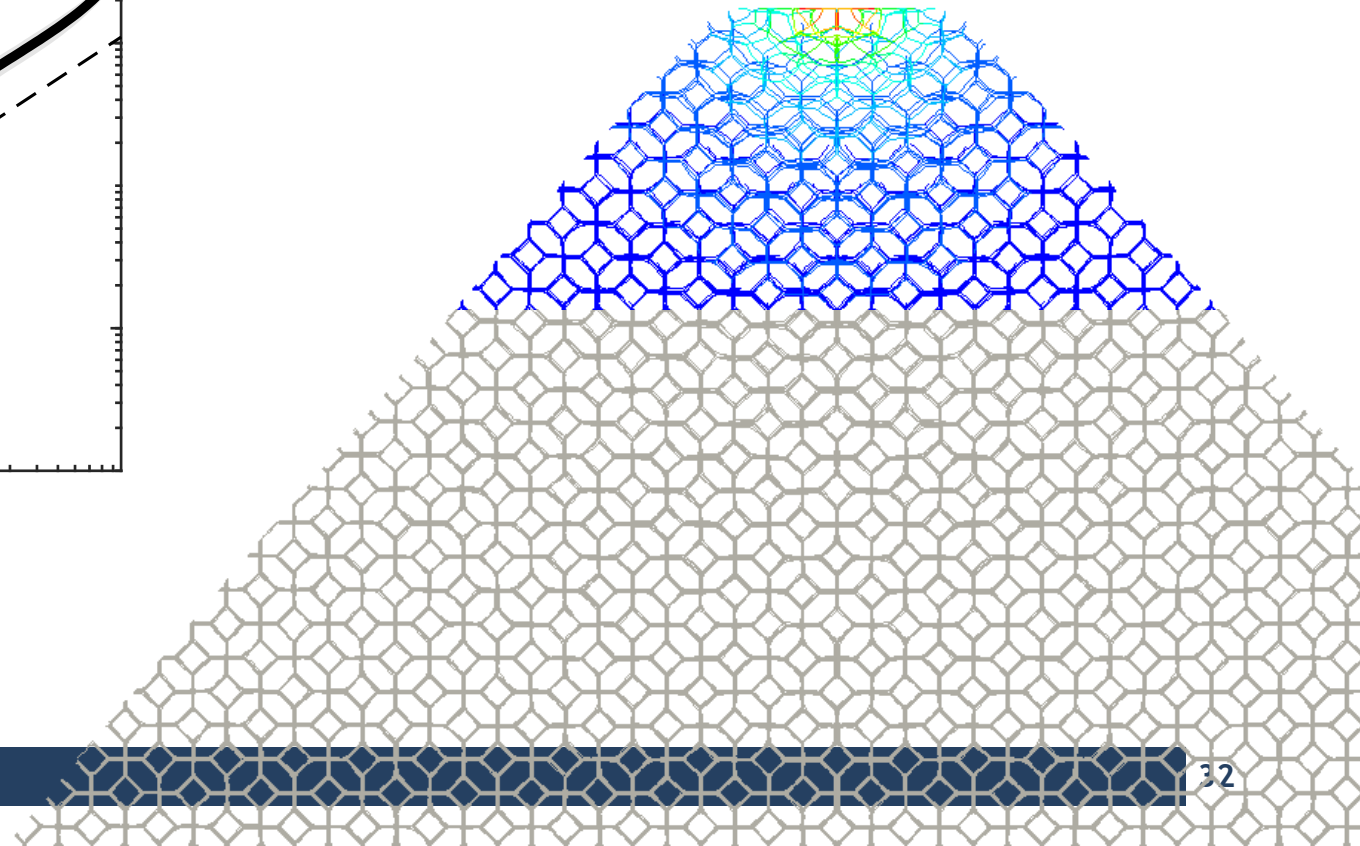
Behaviour of an asperity

Comparison with FEM model

- Quadratic tendency ≳ 10 cells in contact

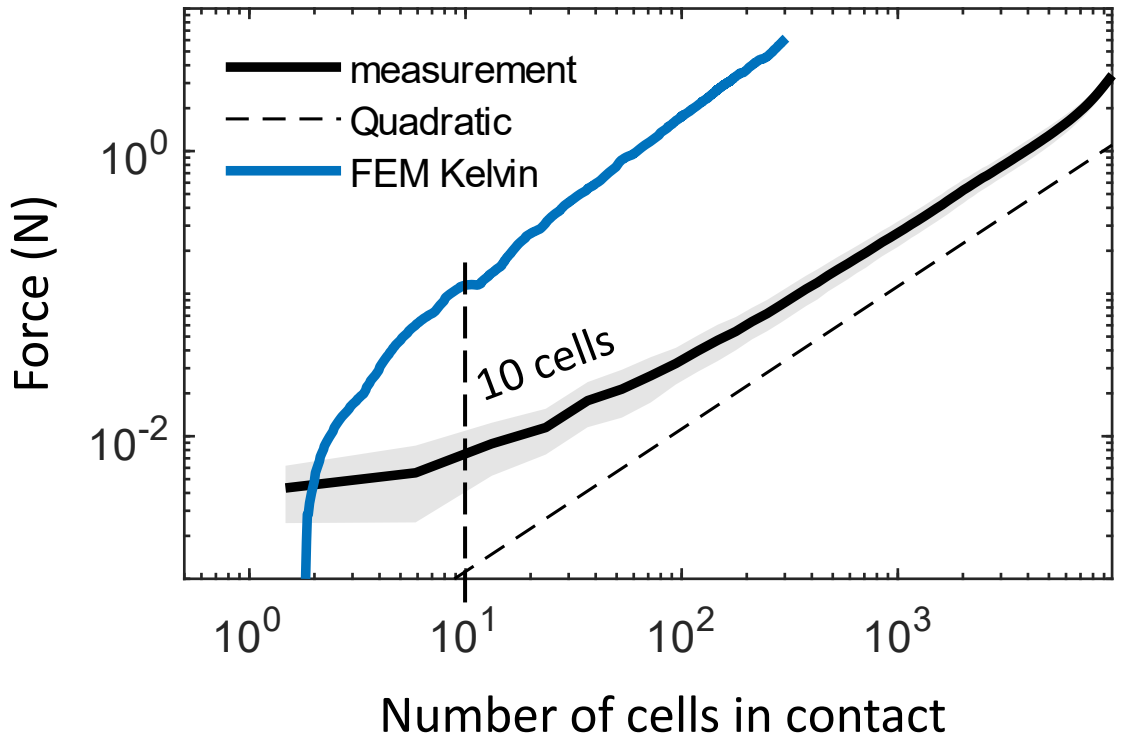


12 cells in contact : nearly continuous

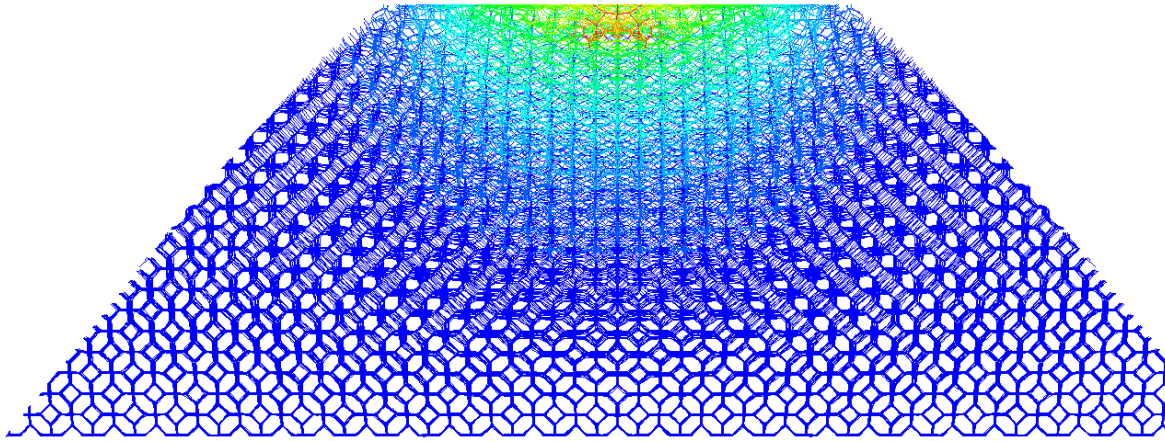


Comparison with FEM model

- Quadratic tendency $\gtrsim$ 10 cells in contact



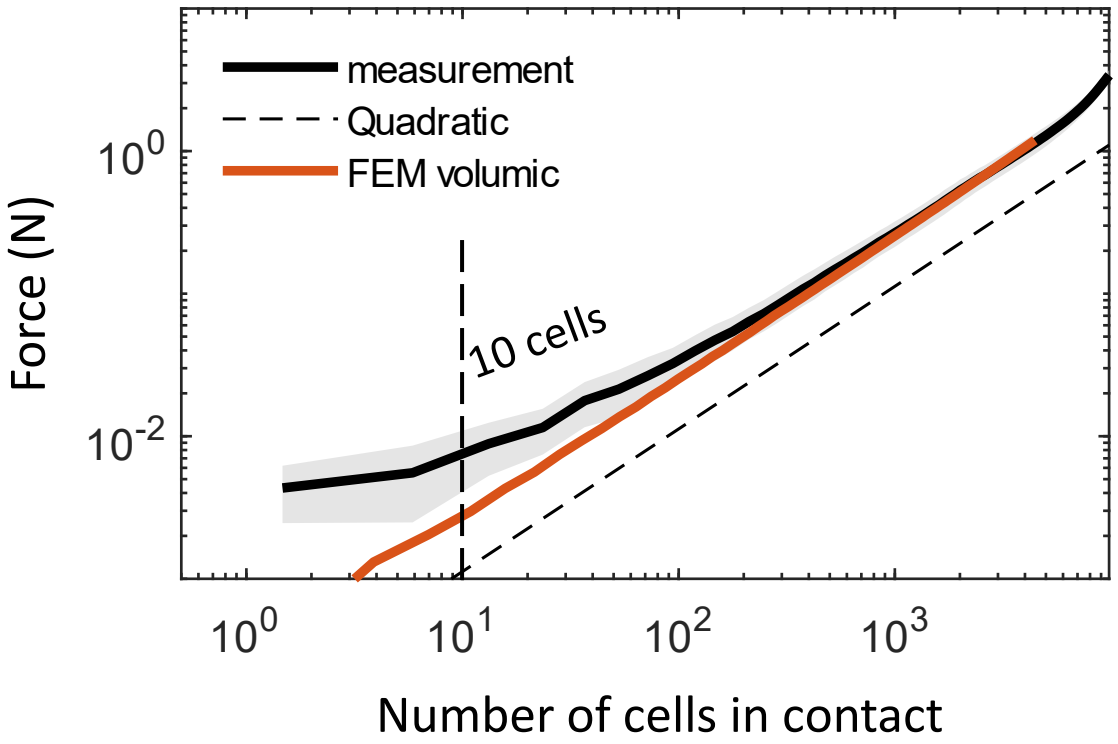
194 cells in contact: continuous

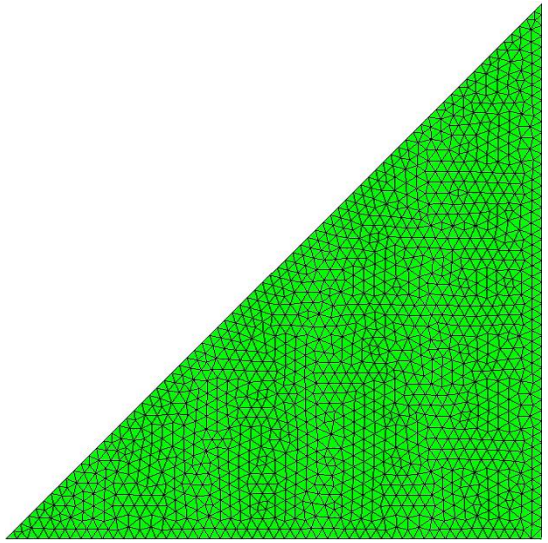


Behaviour of an asperity

Continuous hyperelastic FEM model predicts prefactor

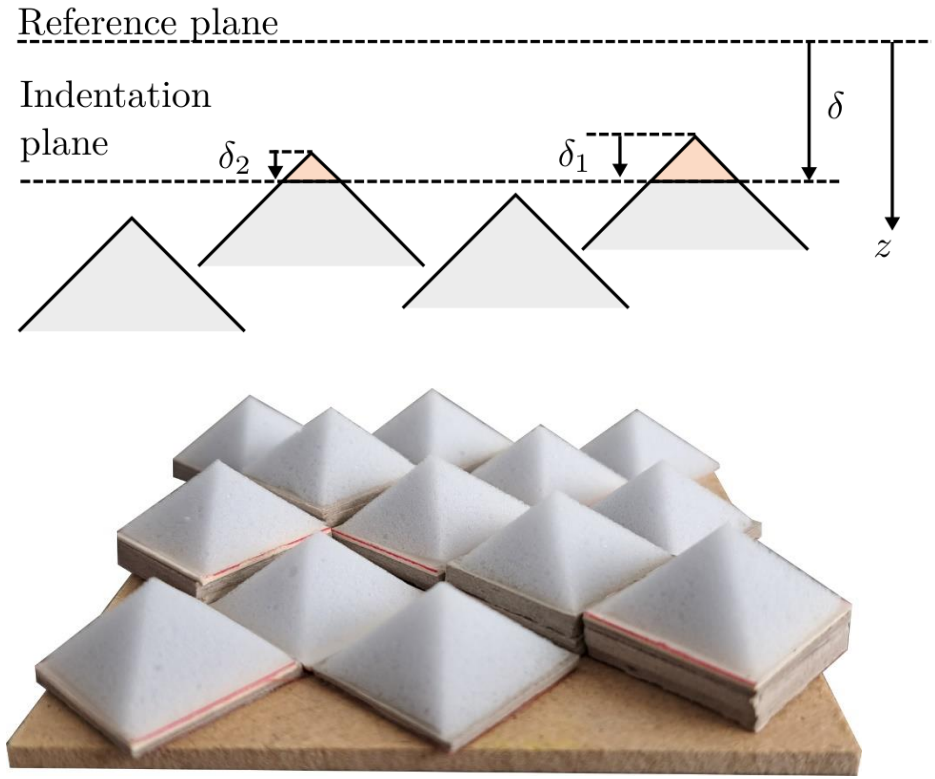
$$F \propto \boldsymbol{E}\, \delta^2$$

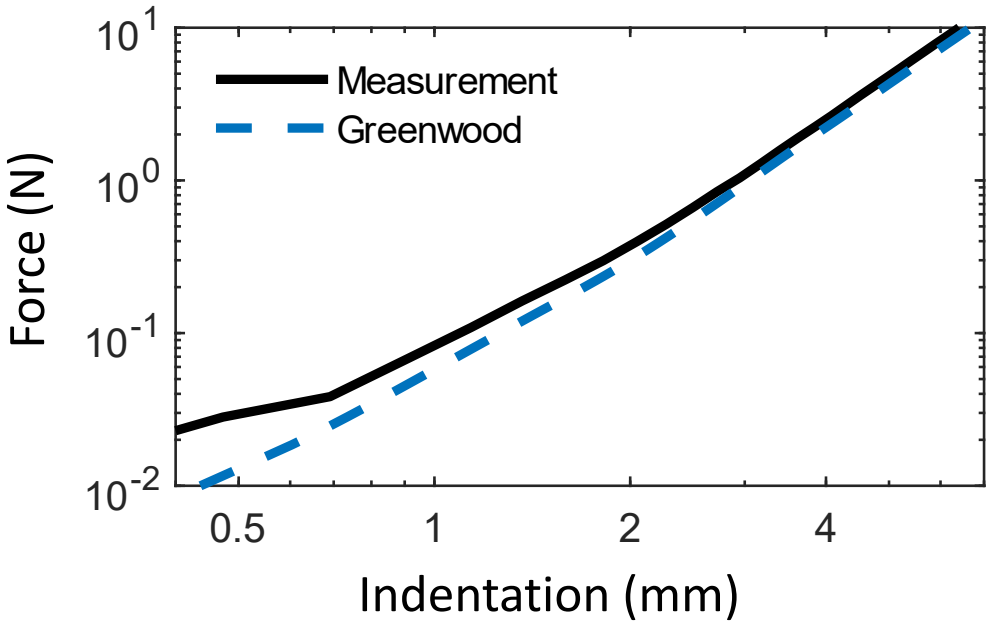




Application to a surface of several asperitise

- A surface of several pyramids was created and modelled
- Asperity height distribution: quasi-uniform
- Greenwood surface roughness model was used

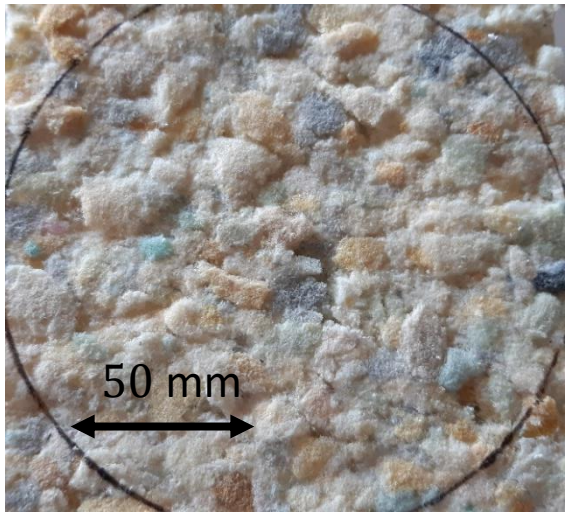


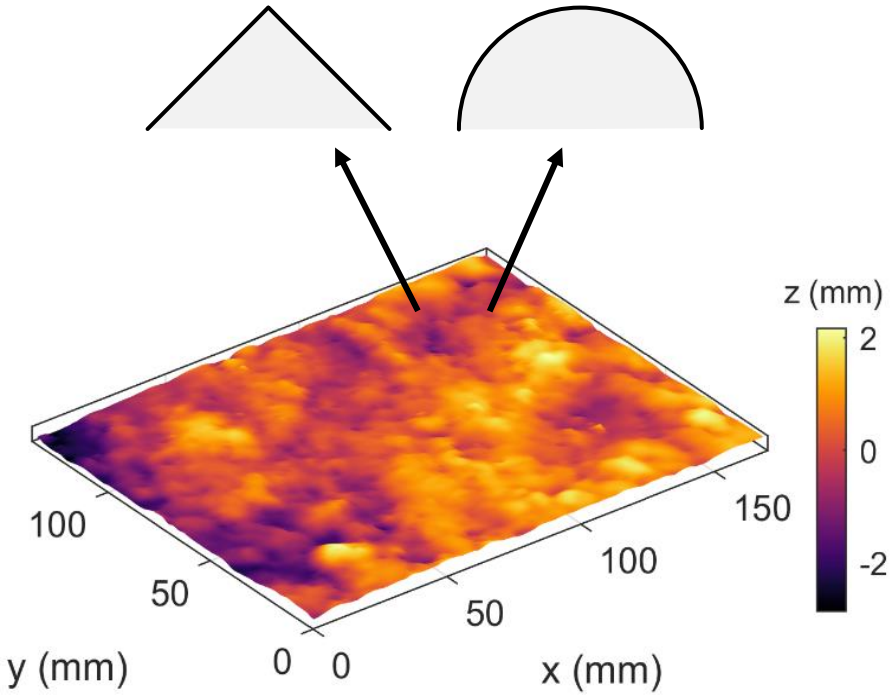


Outlook

Application to a real material

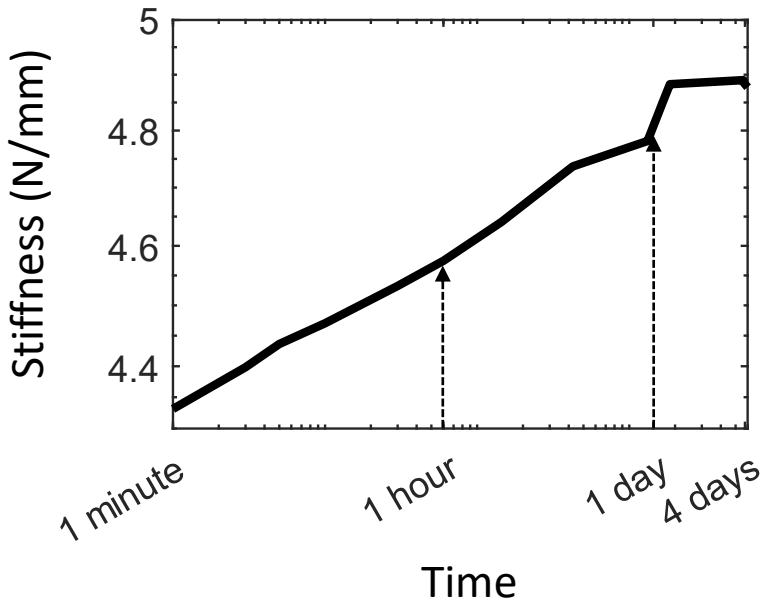
- A 3D scan could be analysed to compute asperity info
- Transition to bulk behaviour can be predicted
- Study impact of Poisson effect?

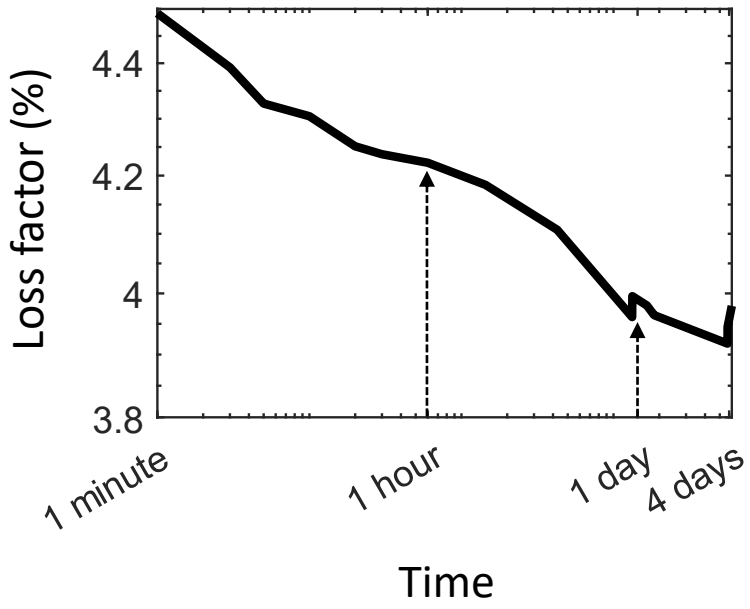




Outlook

Effect of relaxation on dynamic behaviour should be examined





QMA measurements (20-200 Hz)

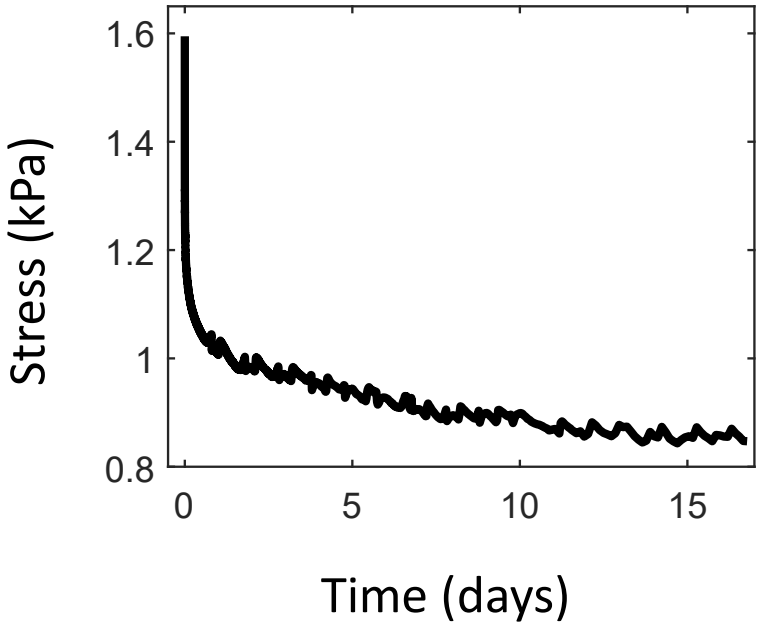
Difference after

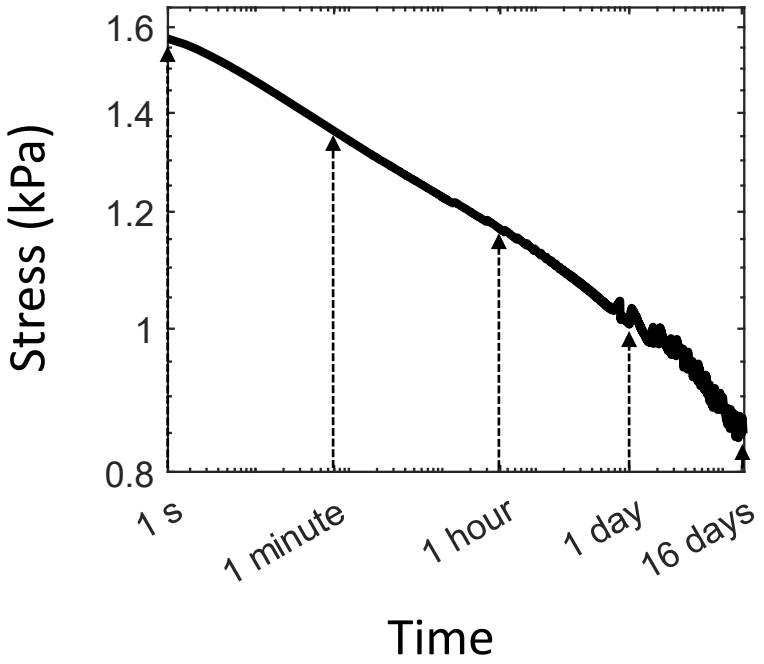
- 30 minutes: 5%
- 24 hours: 10%

Thank you

Modelling material behaviour: relaxation

Relaxation continues at very long durations

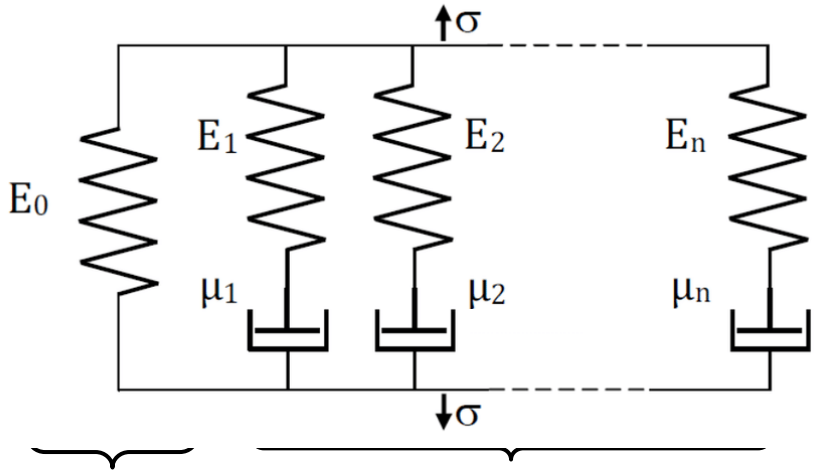




Modelling material behaviour: relaxation

Relaxation could be modelled with generalized Maxwell model

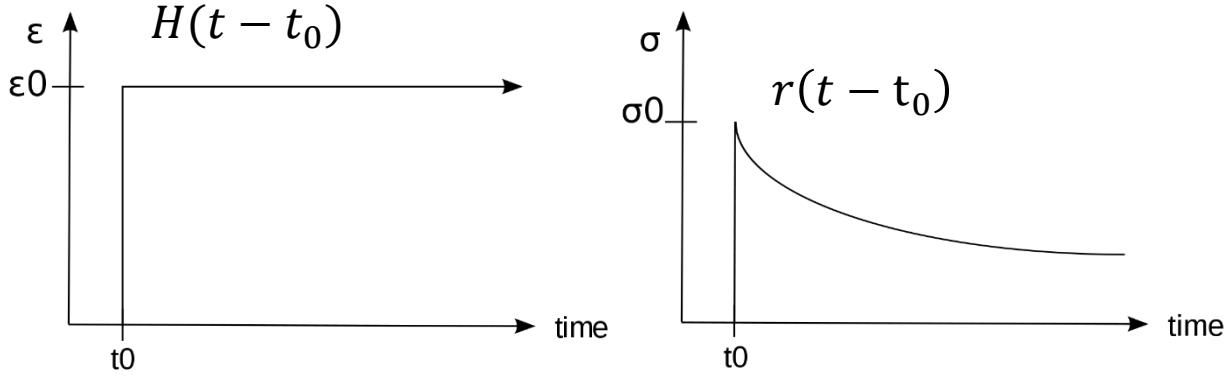
Generalized Maxwell model



Static stress E_0 N decay times $\tau_i = \frac{\eta_i}{E_i}$

Stress response to a Heaviside step strain $r(t)$:

$$r(t) = E_0 H(t) + \sum_{i=1}^{N} E_i e^{-\frac{t}{\tau_i}} H(t)$$



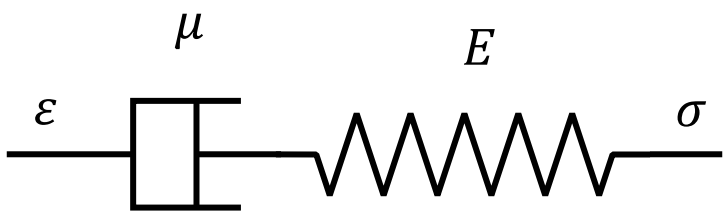
Modelling material behaviour: relaxation

However the behaviour is more reminiscent of an aging phenomenon

$$\frac{1}{\tau}$$

$$\dot{\sigma} = -\frac{E}{\mu}\sigma + E\dot{\varepsilon}$$

Maxwell model



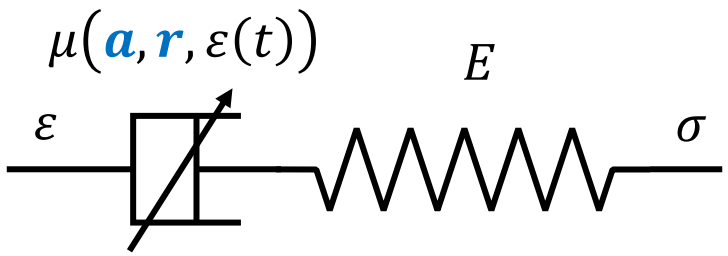
Modelling material behaviour: relaxation

However the behaviour is more reminiscent of an aging phenomenon

$$\frac{1}{\tau}$$

$$\begin{cases} \dot{\sigma} = -f\sigma + E\dot{\varepsilon} \\ \dot{f} = -\boldsymbol{a}f^2 + \boldsymbol{r}\dot{\varepsilon}^2 \end{cases}$$

Aging model



Aging: when $\dot{\varepsilon} = 0$, $\tau = \frac{1}{f}$ increases with slope a

Rejuvenation: when $\dot{\varepsilon} \neq 0$, $\tau = \frac{1}{f}$ decreases

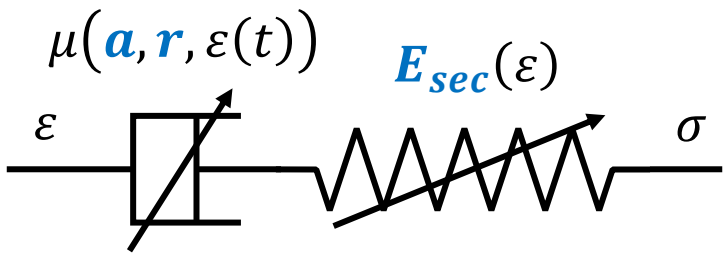
Modelling material behaviour: relaxation

However the behaviour is more reminiscent of an aging phenomenon

$\frac{1}{\tau}$ Strain-dependant modulus

$$\begin{cases} \dot{\sigma} = -f\sigma + \boldsymbol{E_{sec}(\varepsilon)}\dot{\varepsilon} \\ \dot{f} = -\boldsymbol{a}f^2 + \boldsymbol{r}\dot{\varepsilon}^2 \end{cases}$$

Nonlinear modulus



Aging: when $\dot{\varepsilon} = 0$, $\tau = \frac{1}{f}$ increases with slope a

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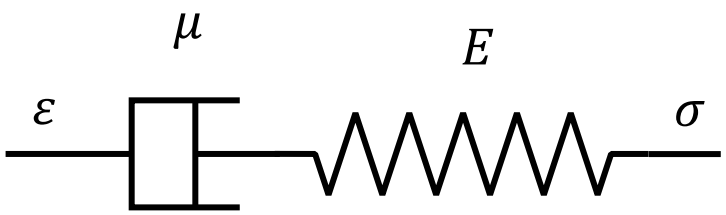
Modelling material behaviour: relaxation

However the behaviour is more reminiscent of an aging phenomenon

$$= \frac{1}{\tau}$$

$$\dot{\sigma} = -\frac{E}{\mu}\sigma + E\dot{\varepsilon}$$

Maxwell model

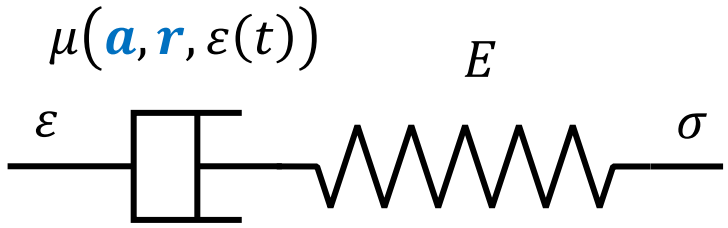


$$= \frac{1}{\tau}$$

$$\begin{cases} \dot{\sigma} = -f\sigma + E\dot{\varepsilon} \\ \dot{f} = -\boldsymbol{a}f^2 + \boldsymbol{r}\dot{\varepsilon}^2 \end{cases}$$

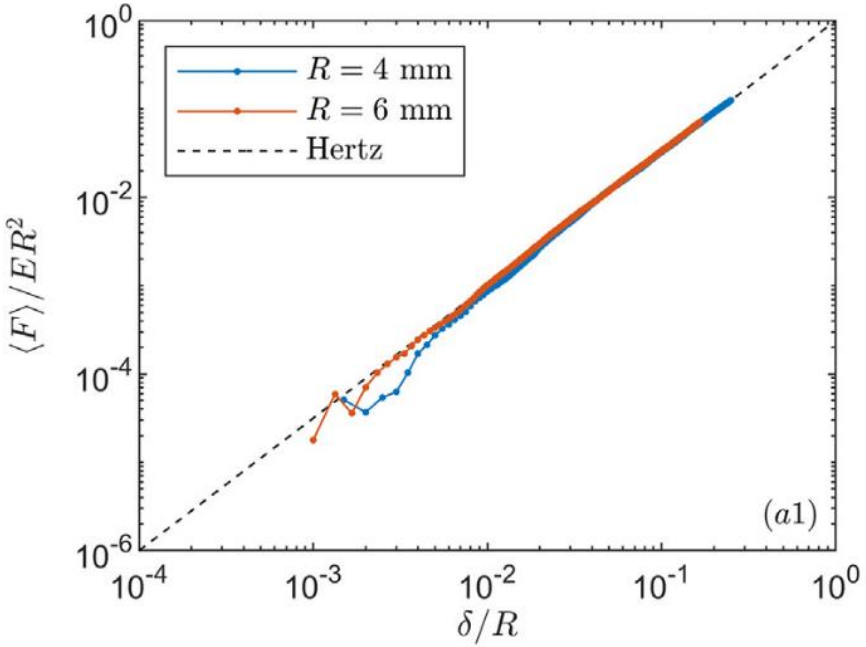
Aging Rejuvenation

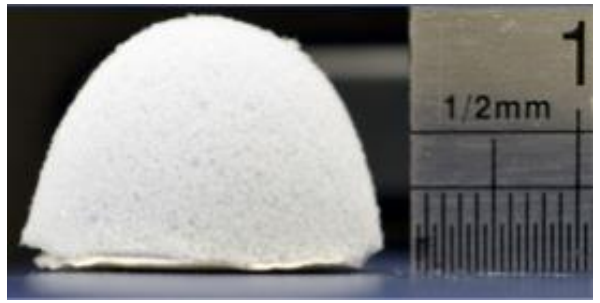
Aging model



Behaviour of an asperity

A sphere of foam follows Hertz' law (previous work: Hentati, 2020)





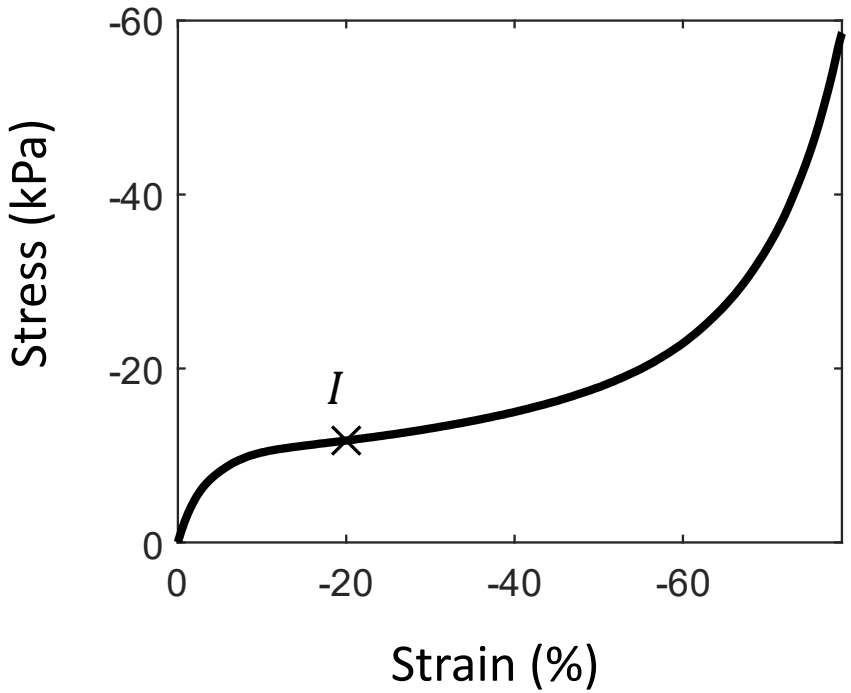
$$F \propto ER^{\frac{1}{2}}\delta^{\frac{3}{2}}$$

Behaviour of an asperity

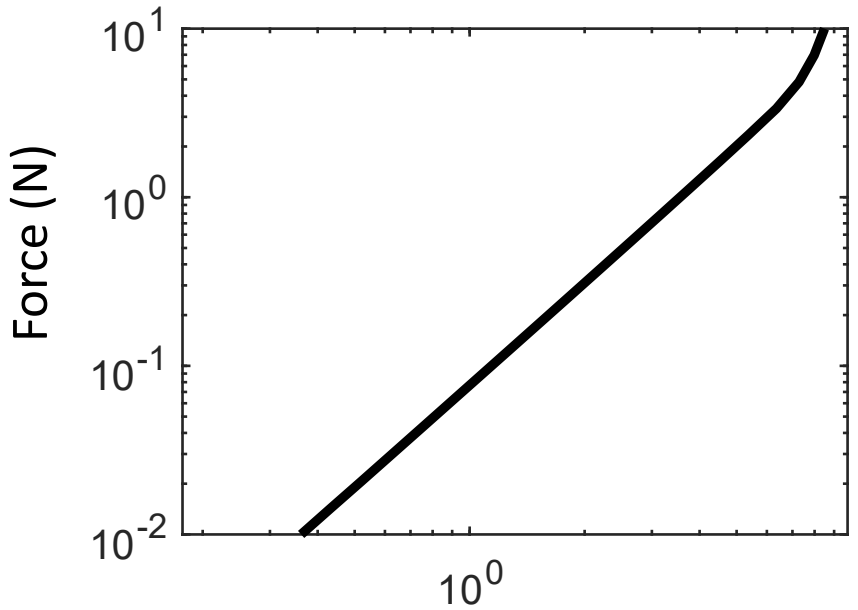
Analytical approximation with a single modulus
Which modulus should be taken?

$$F \propto \boldsymbol{E}\, \delta^2$$

Hyperelastic stress / strain response



Predicted pyramid force



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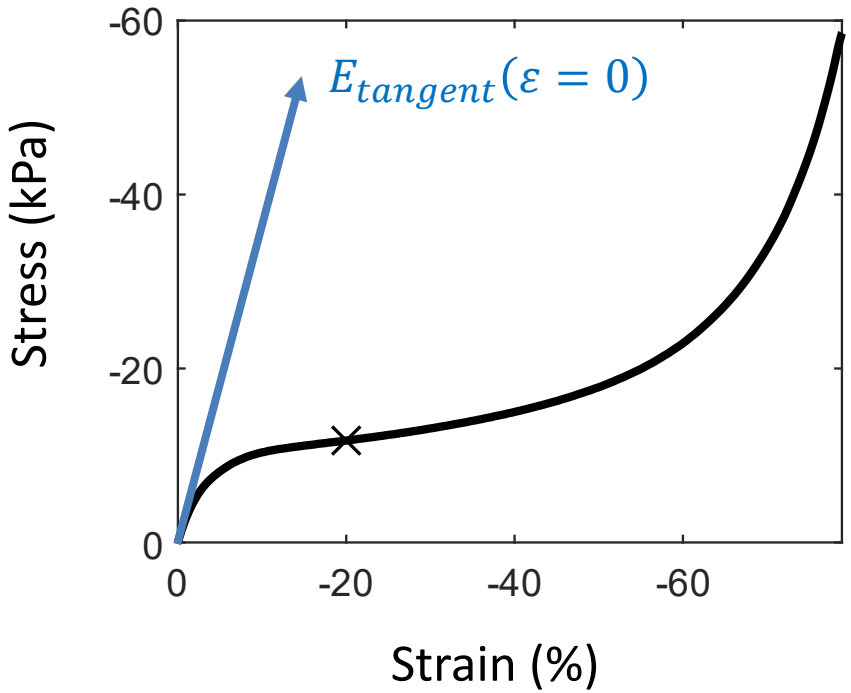
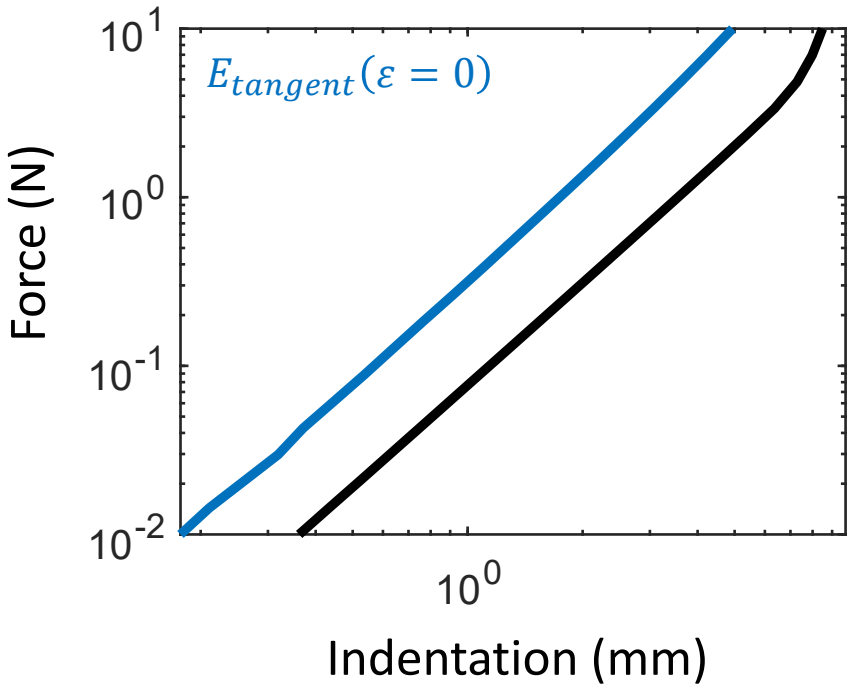


Predicted pyramid force



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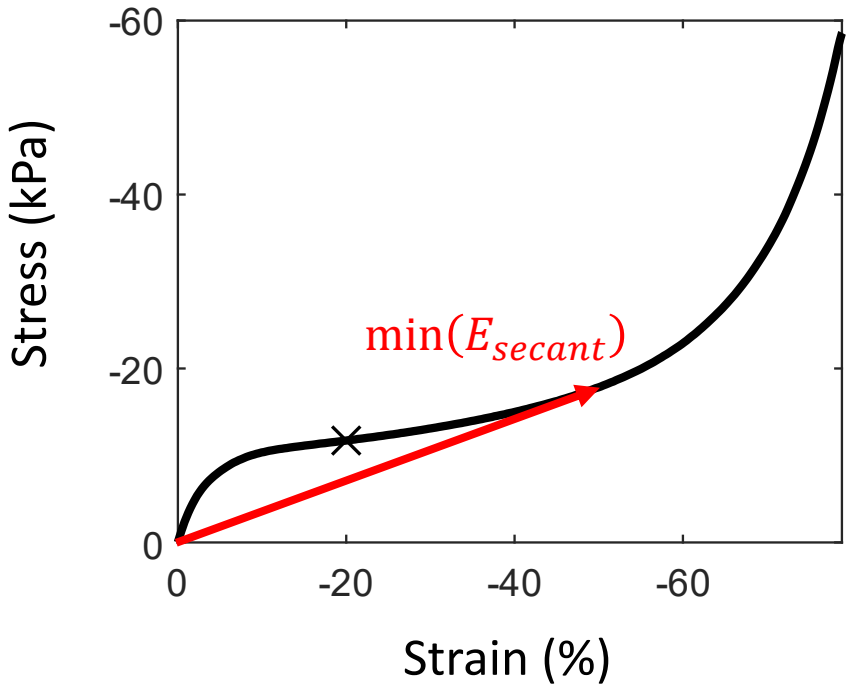
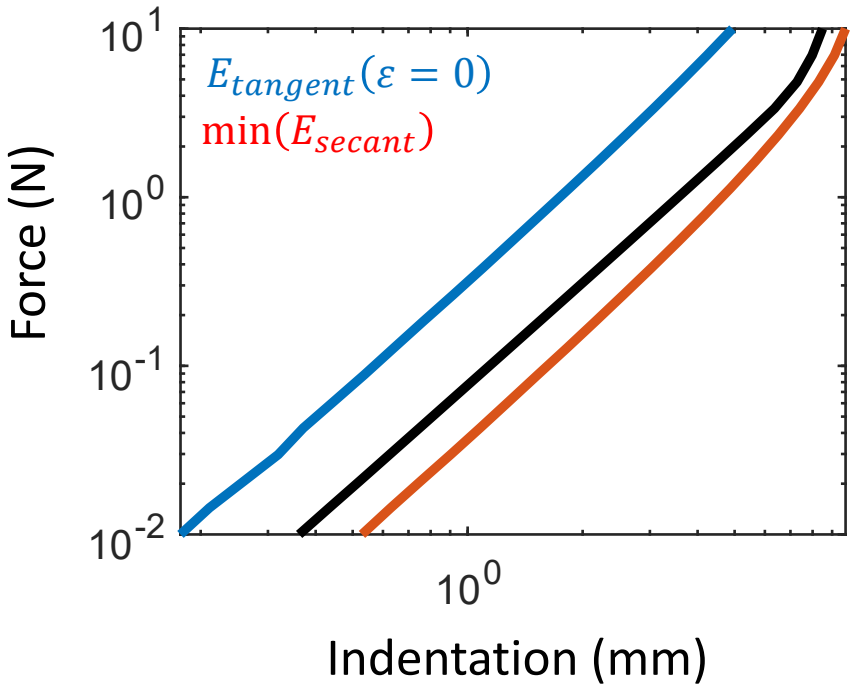


Predicted pyramid force



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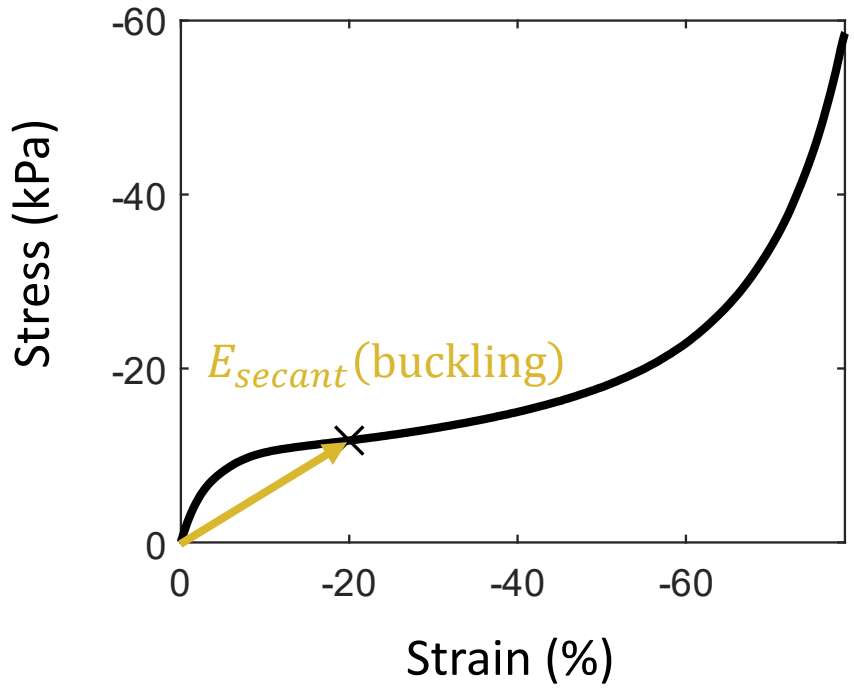
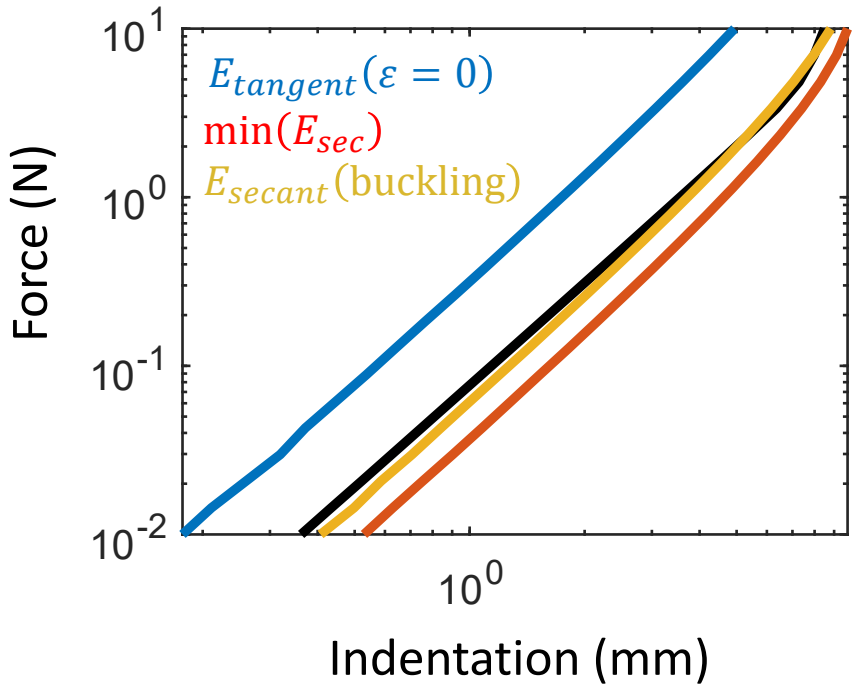
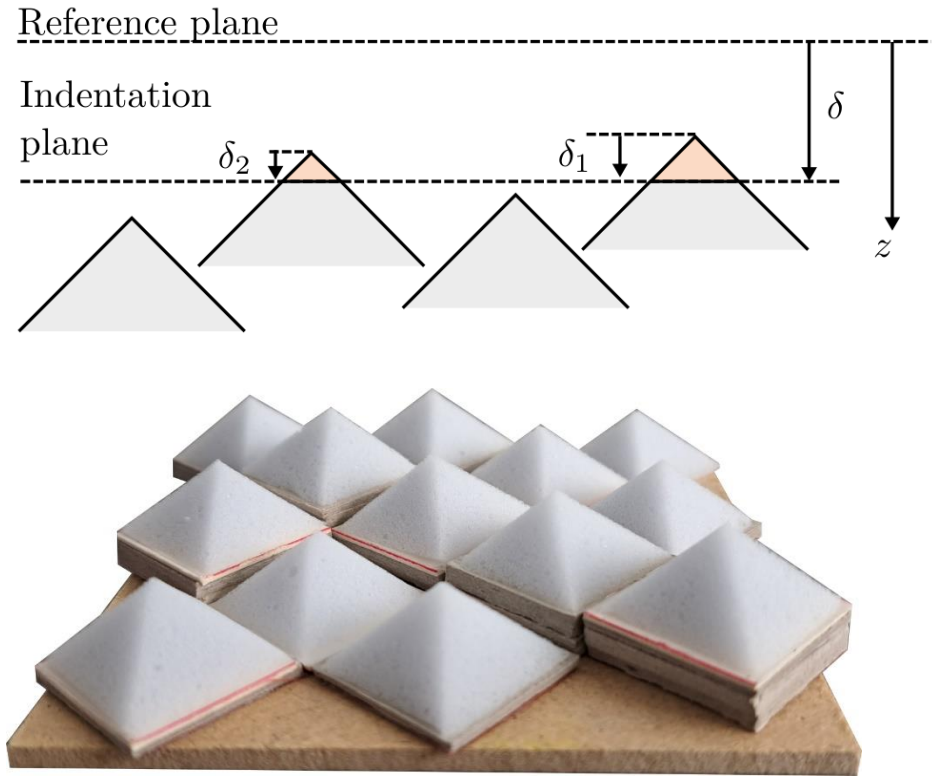


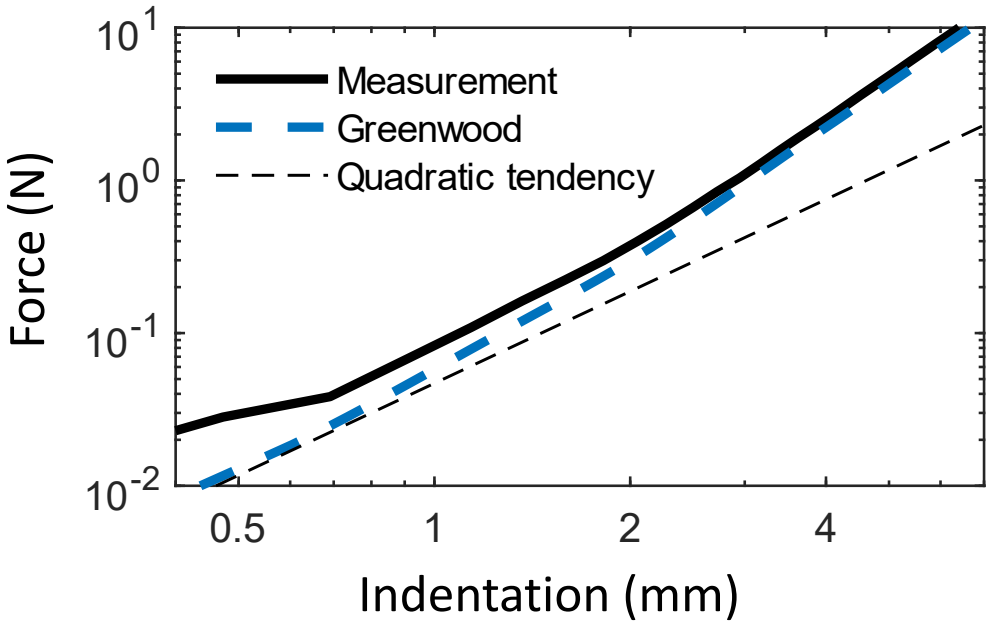
Predicted pyramid force



Application to a surface of several asperitise

A surface of several pyramids was created and modelled
Quasi-uniform asperity height distribution
Greenwood surface roughness model





Outlook

Measurements on radiating plate
Measurements on real engine casing