Modelling the behaviour of plastics for design under impact

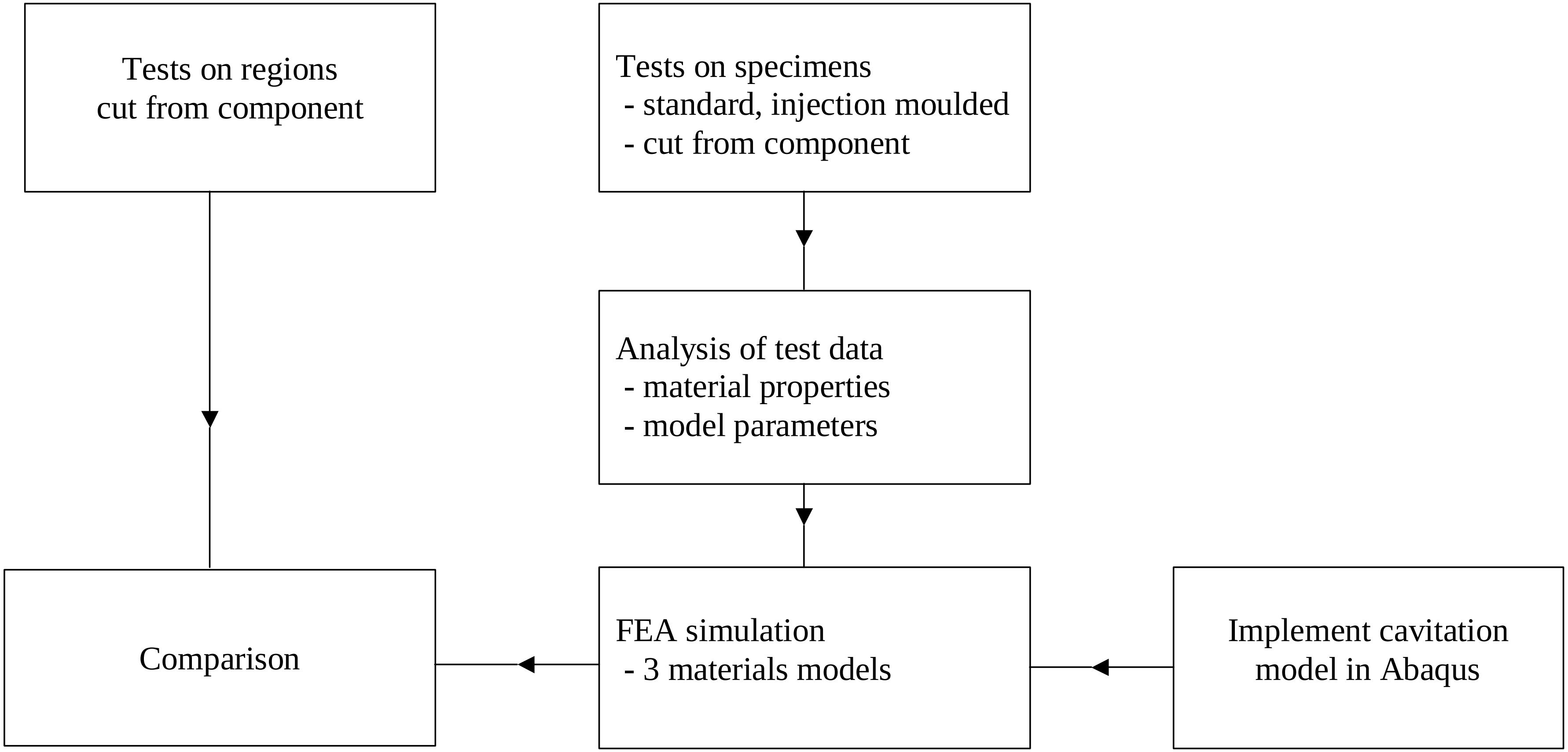
G. Dean and L. Crocker

MPP IAG Meeting 6 October 2004

Land Rover door trim

Loading stages and selected regions

Project MPP7.9 Main tasks



Tests on regions
cut from component

Tests on specimens
- standard, injection moulded
- cut from component

Analysis of test data
- material properties
- model parameters

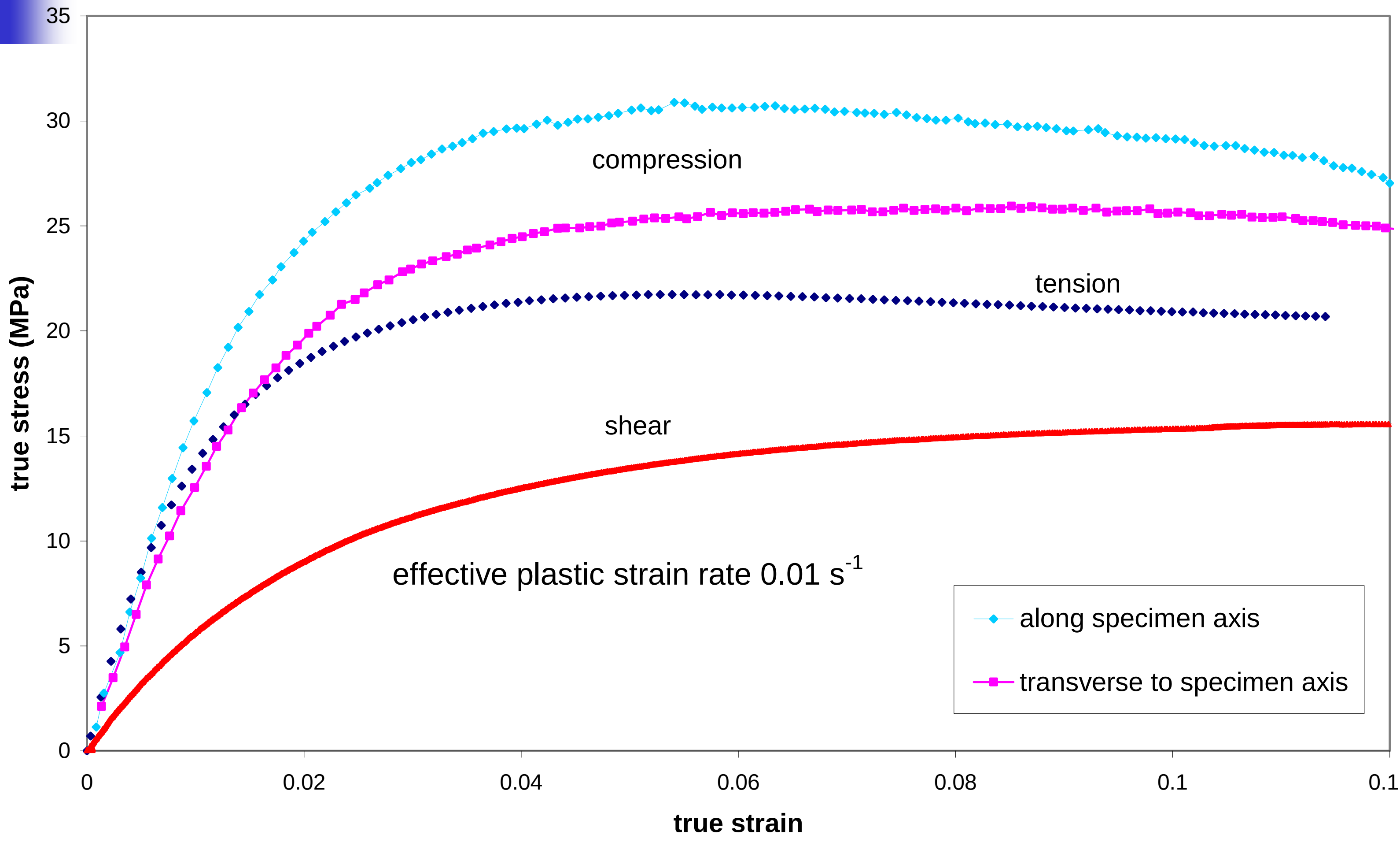
FEA simulation
- 3 materials models

Implement cavitation
model in Abaqus

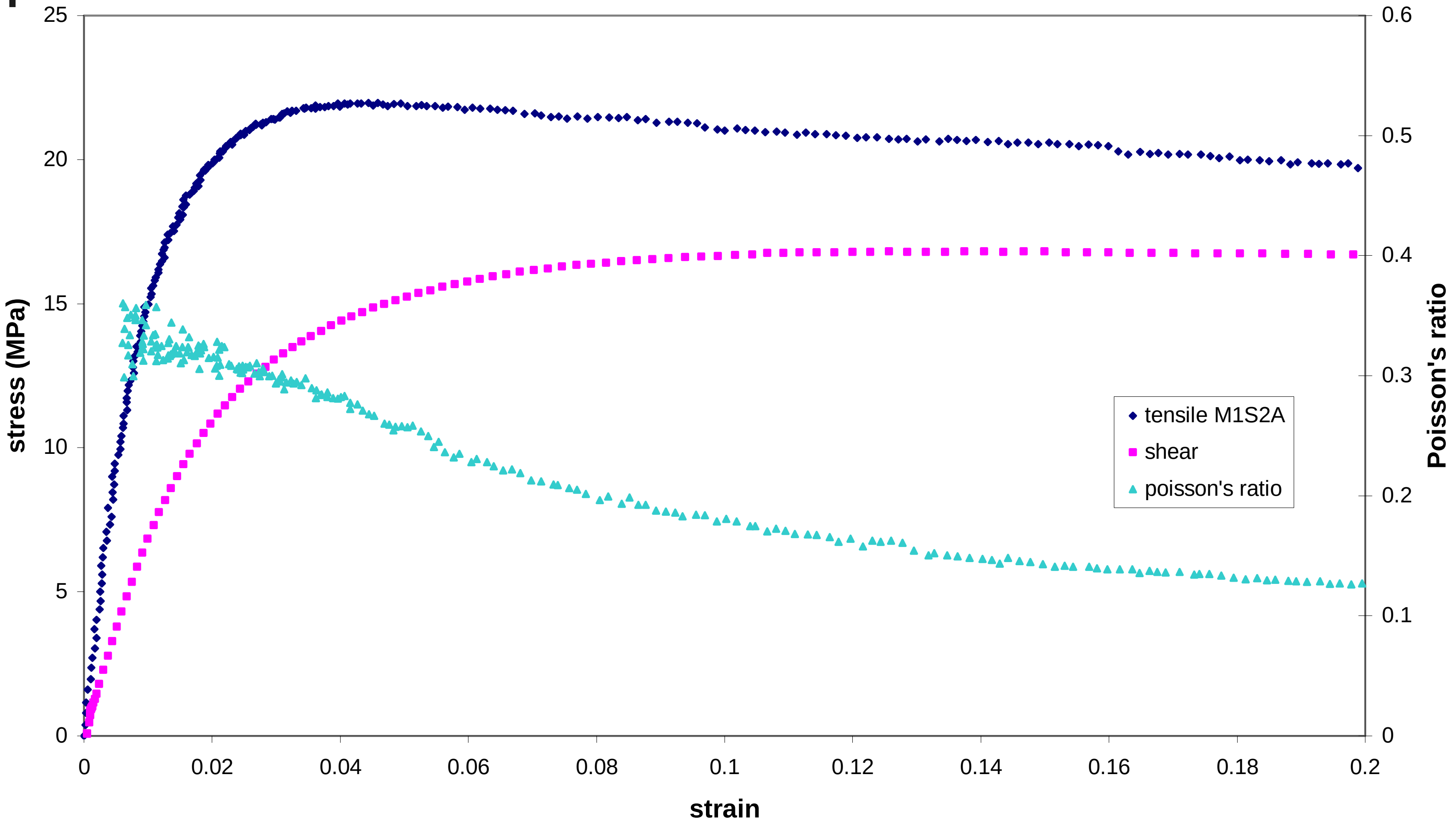
Comparison

Stress-strain curves for Dow polymer

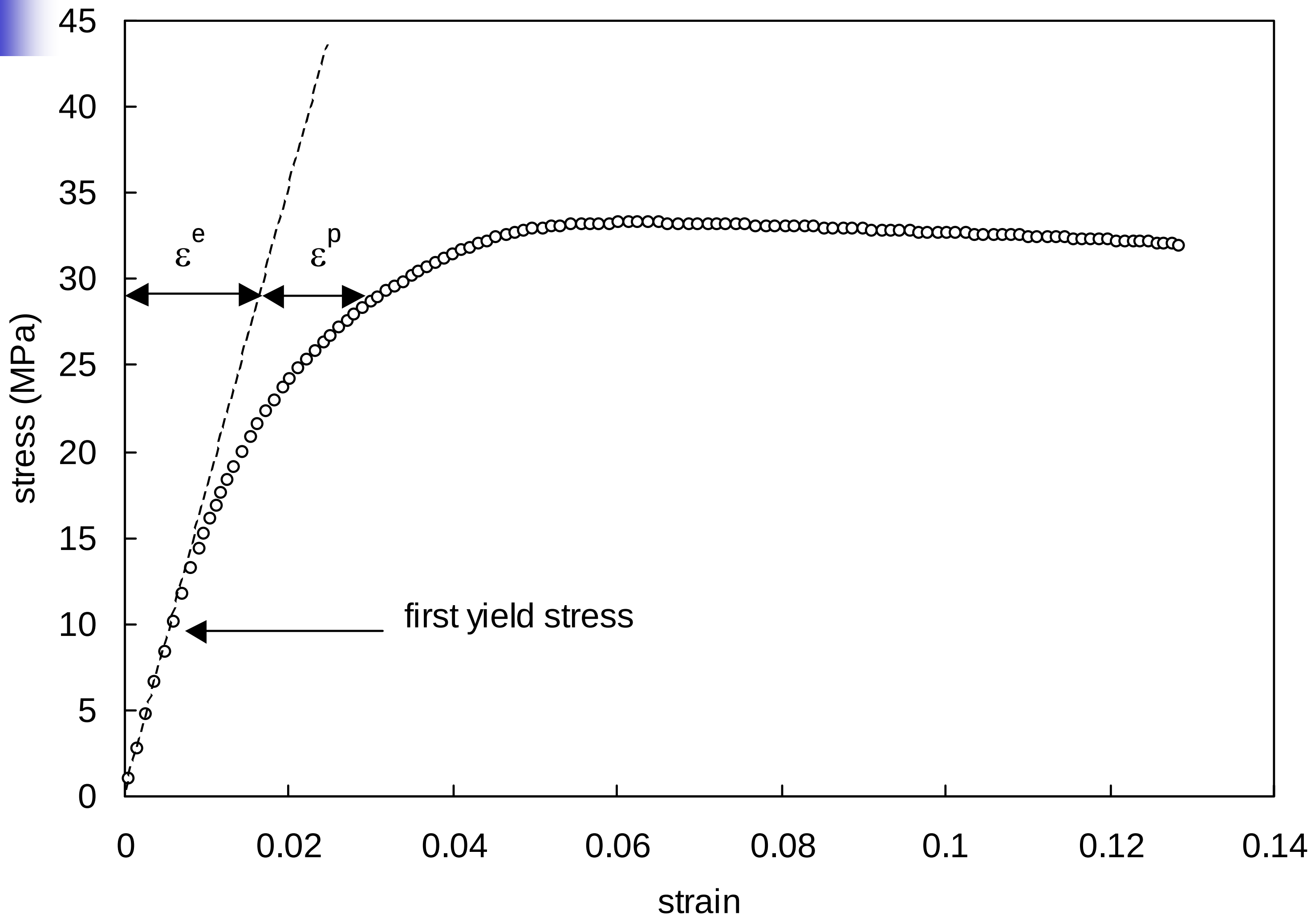
- injection moulded specimens



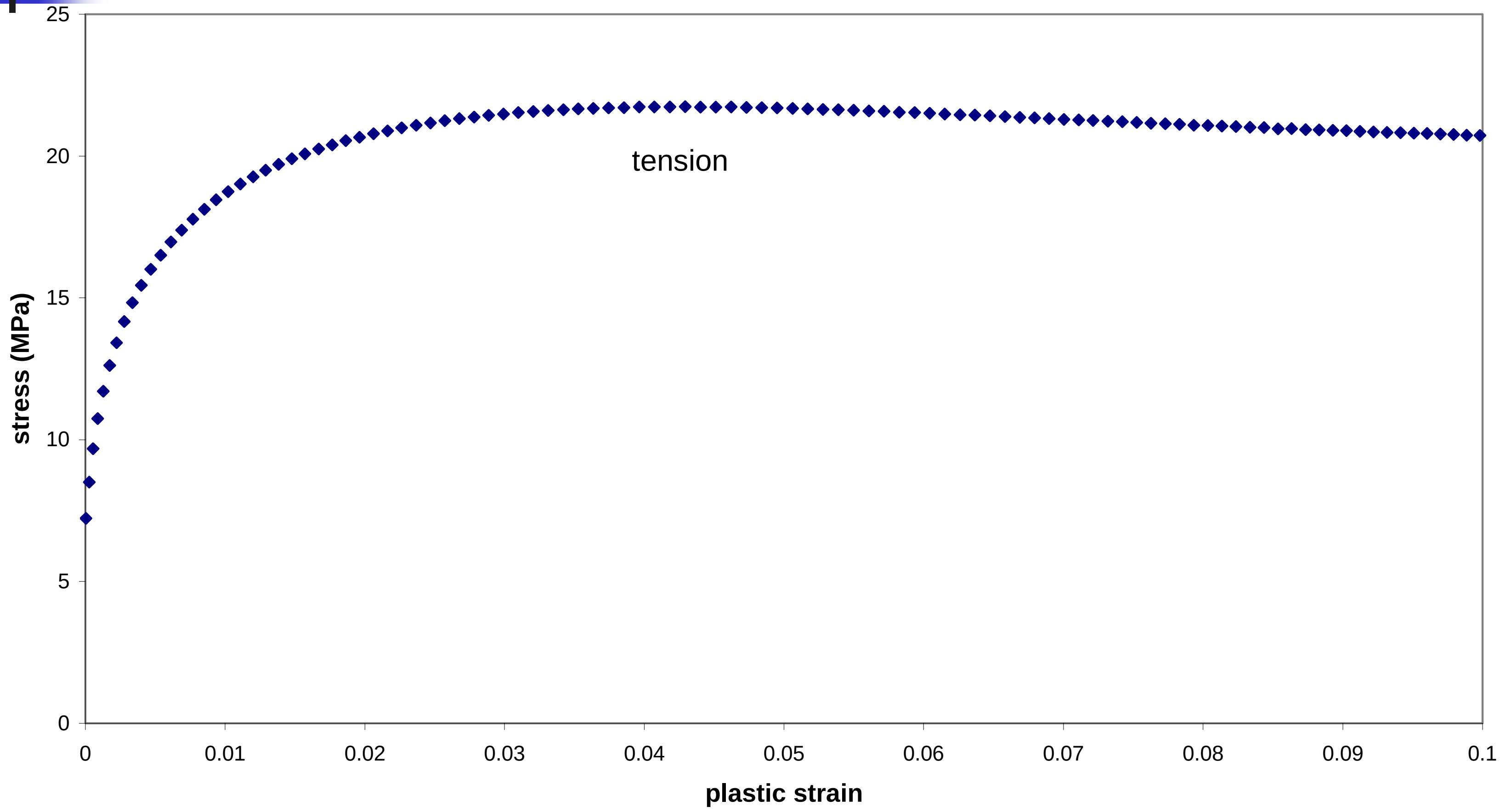
Results for specimens cut from door trim



Elastic-plastic models



Tensile hardening curve



Plastic behaviour

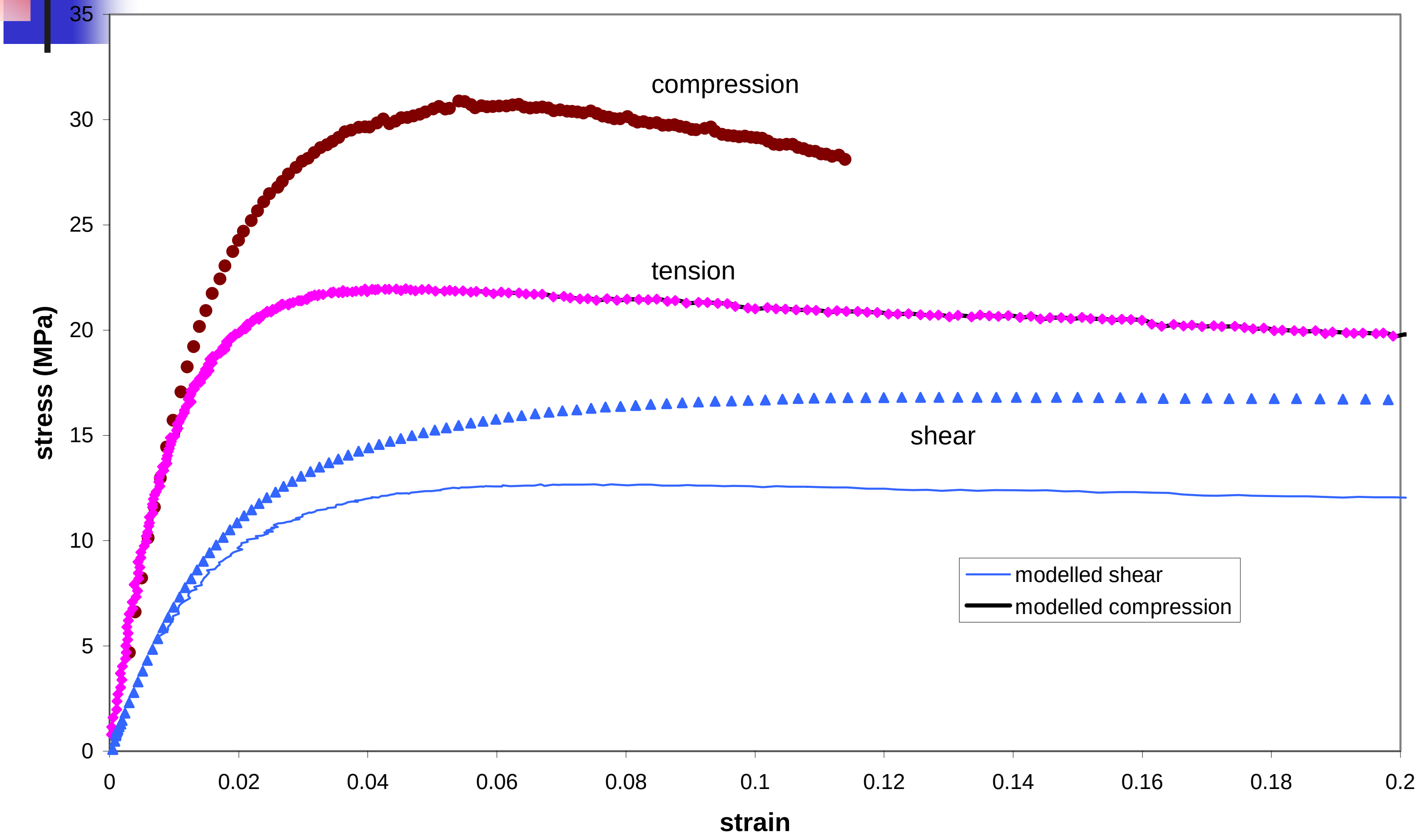
- Stresses are related by a yield criterion
  - Simplest criterion is von Mises

$$\sigma_e = \sigma_T(\varepsilon^p)$$

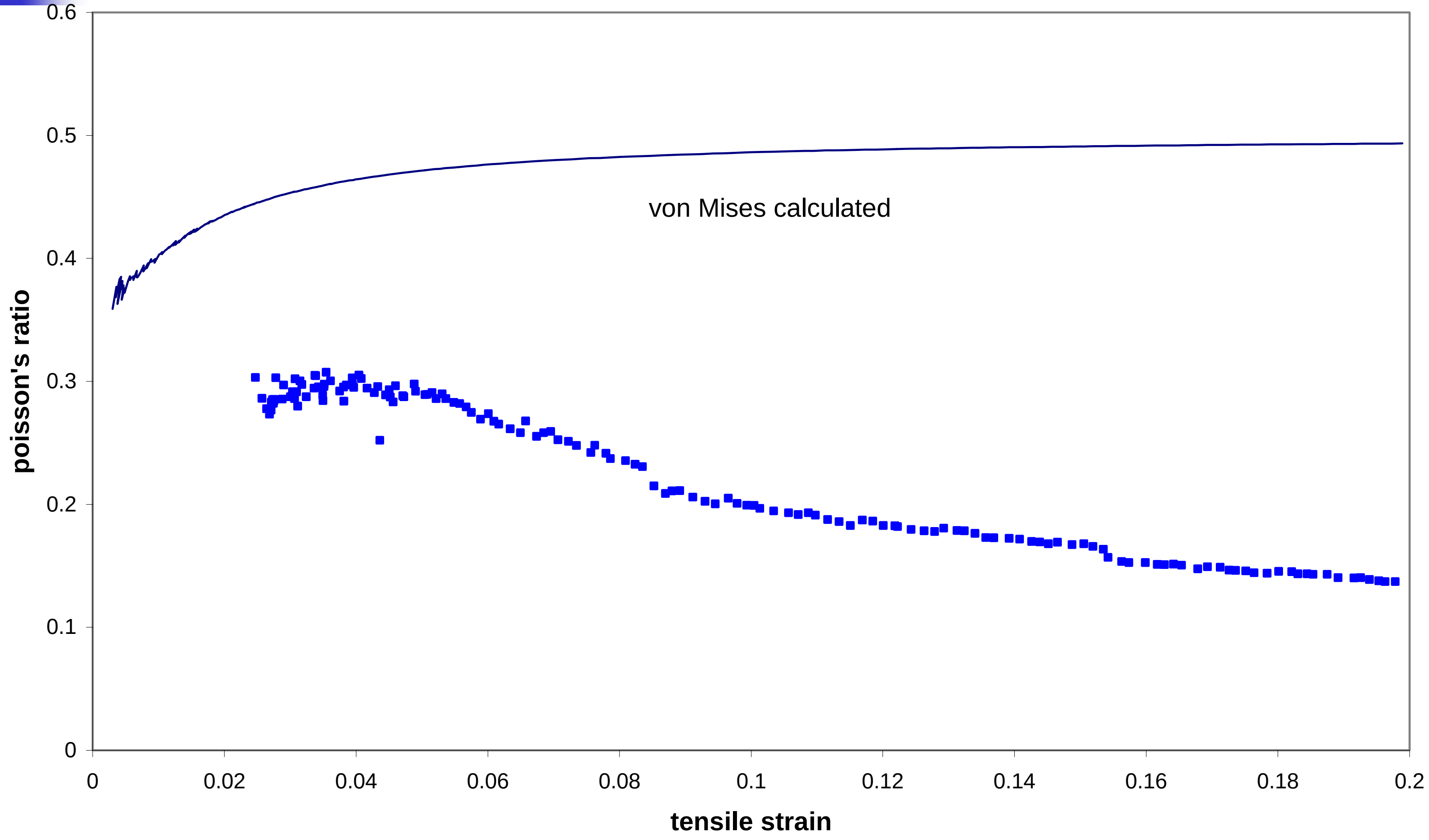
  - σ_e is the effective shear stress

$$\sigma_e^{\,2} = \left[\frac{1}{2}(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]$$

Predictions using the von Mises model



Prediction of Poisson’s ratio



A more accurate yield criterion

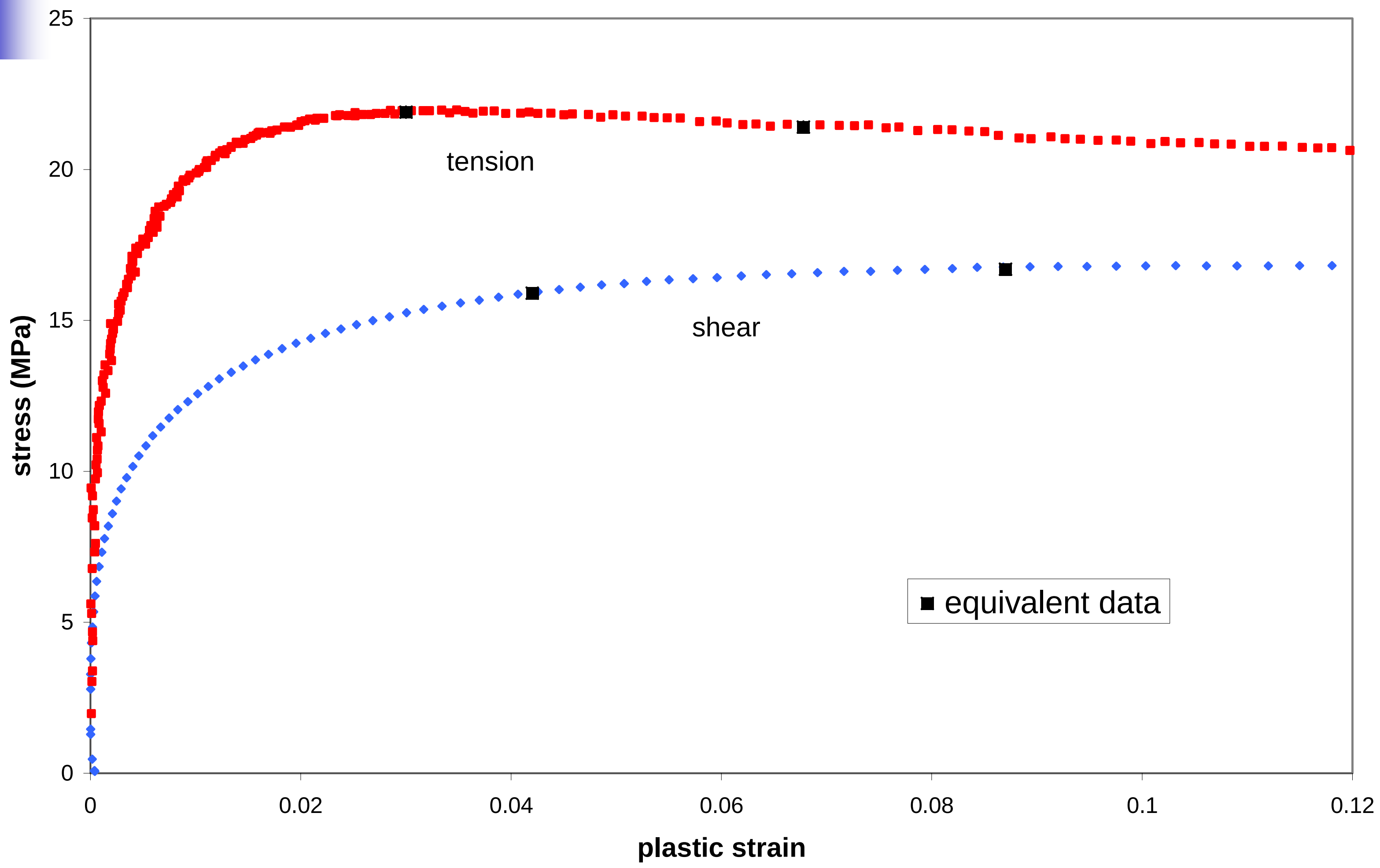
- Yielding in plastics is sensitive to the hydrostatic component of stress

$$\sigma_e = (1 + \frac{\mu}{3})\sigma_T - \mu\sigma_m$$

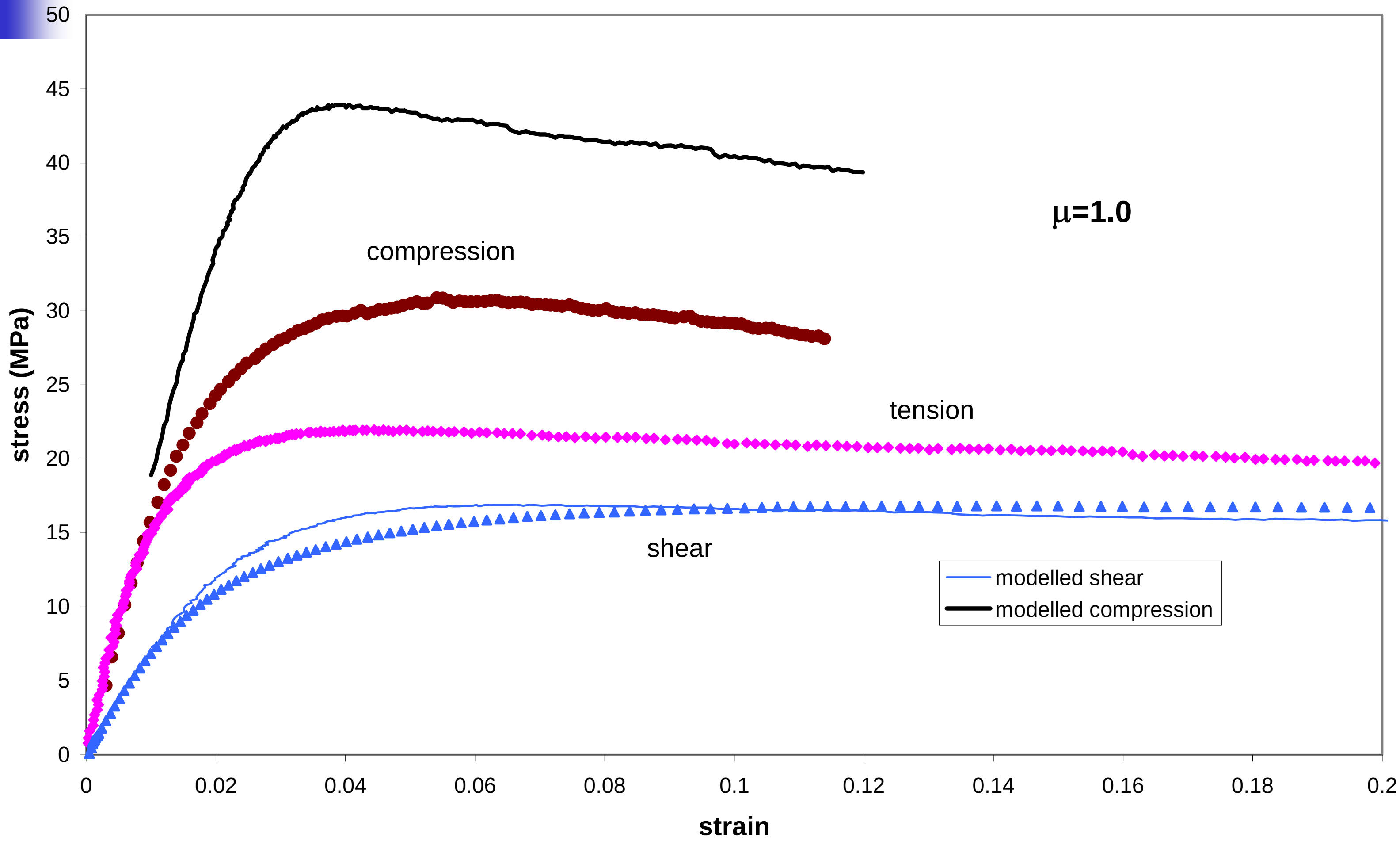
- μ is a material parameter
  - σ_m is the hydrostatic stress

$$\sigma_m = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3)$$

Determination of the parameter μ



Predictions using the Drucker-Prager model



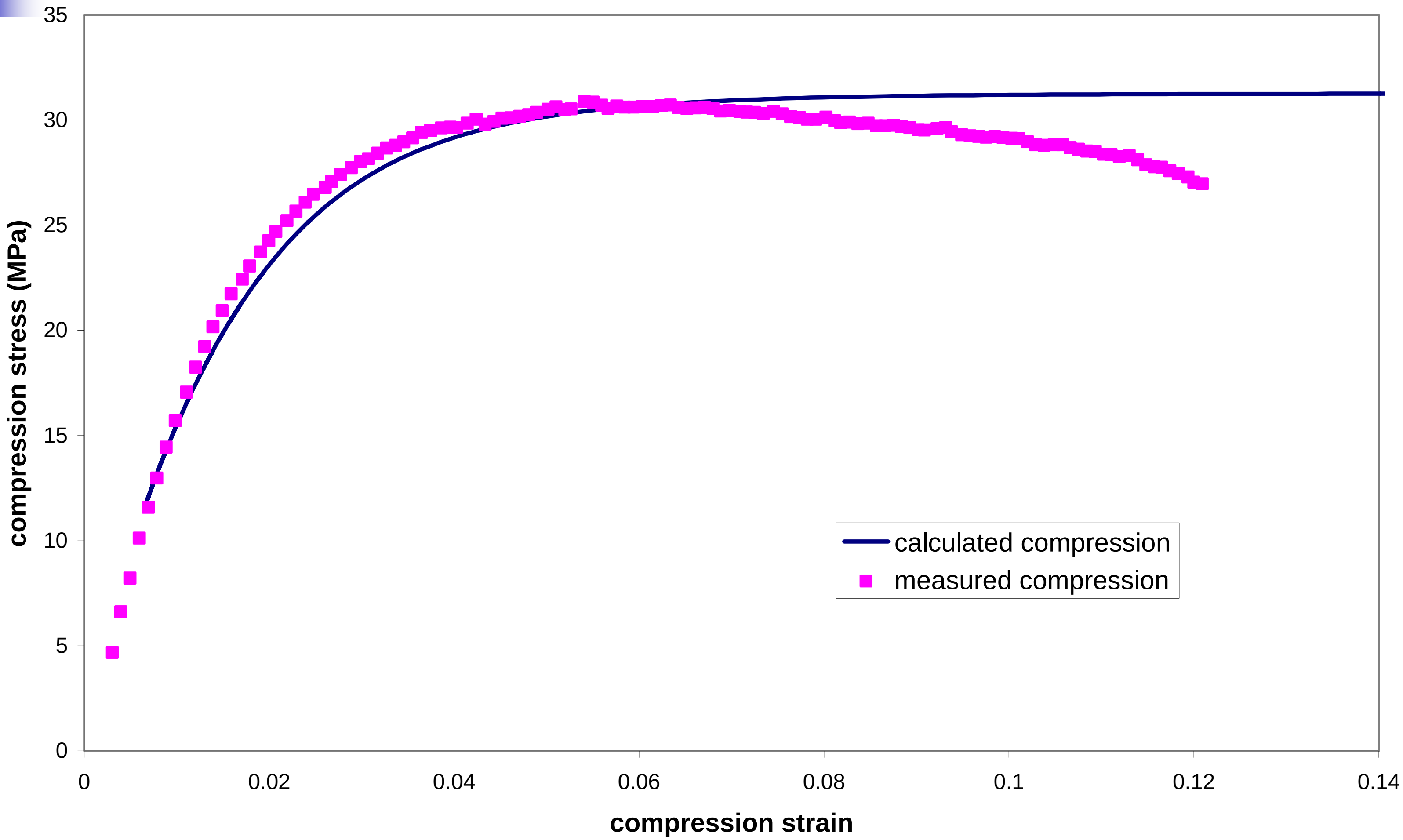
An elastic-plastic model with cavitation

- Under stress states with a hydrostatic component, cavities form in the polymer
- These promote yielding in the regions between cavities
- The yield criterion depends on cavity volume fraction
  - Expressed in terms of the shear hardening curve

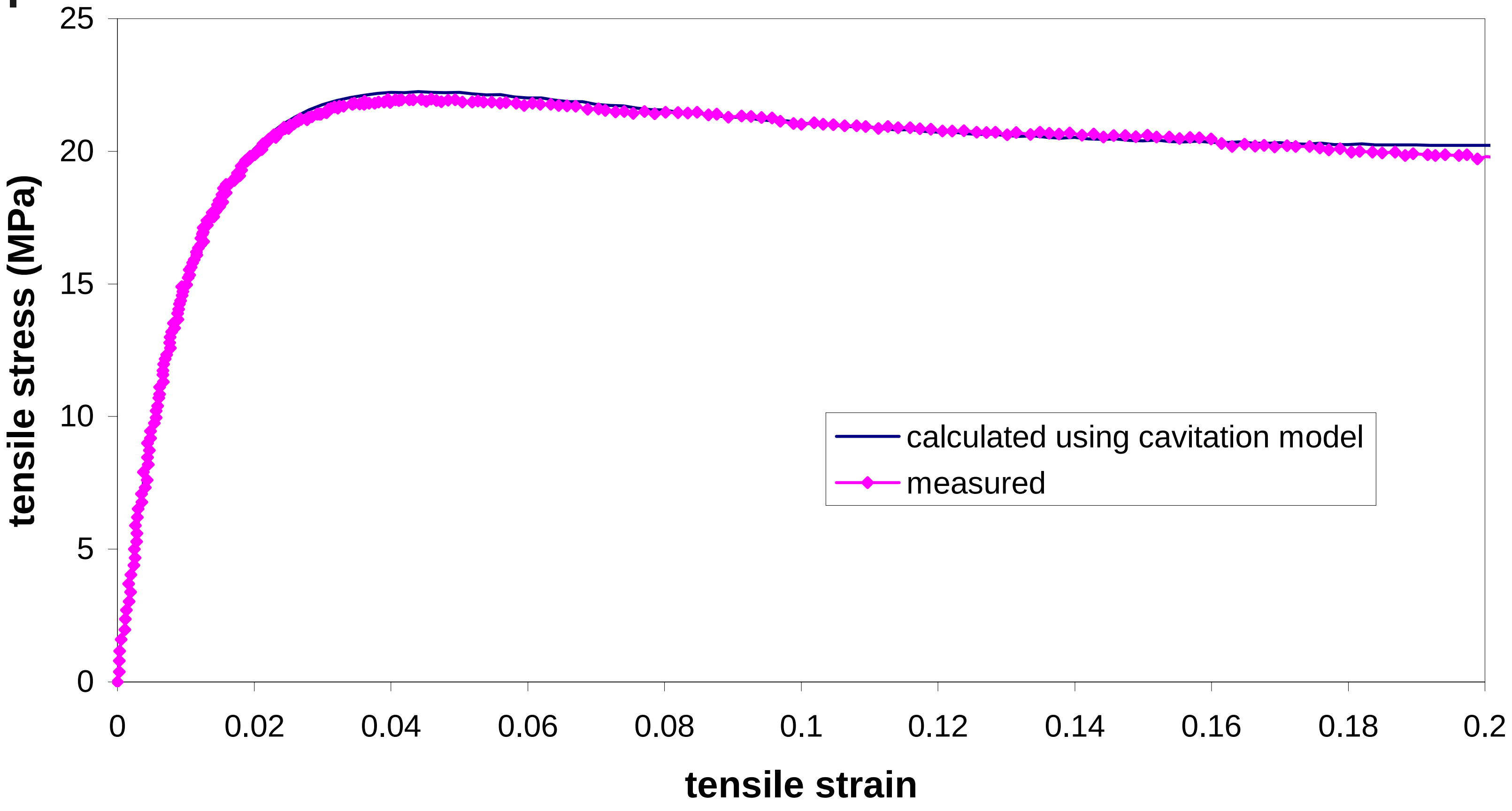
Parameters in the cavitation model

- E , ν_e
- $\sigma_o(\varepsilon_p)$ hardening curve from shear data
- μ from shear and compression data
- μ' from Poisson's ratio
- V_{ra} from materials supplier
- k from variation of yield stress with rubber volume
- ε_{1v}
- ε_{2v} from optimum fit to tensile data
- β

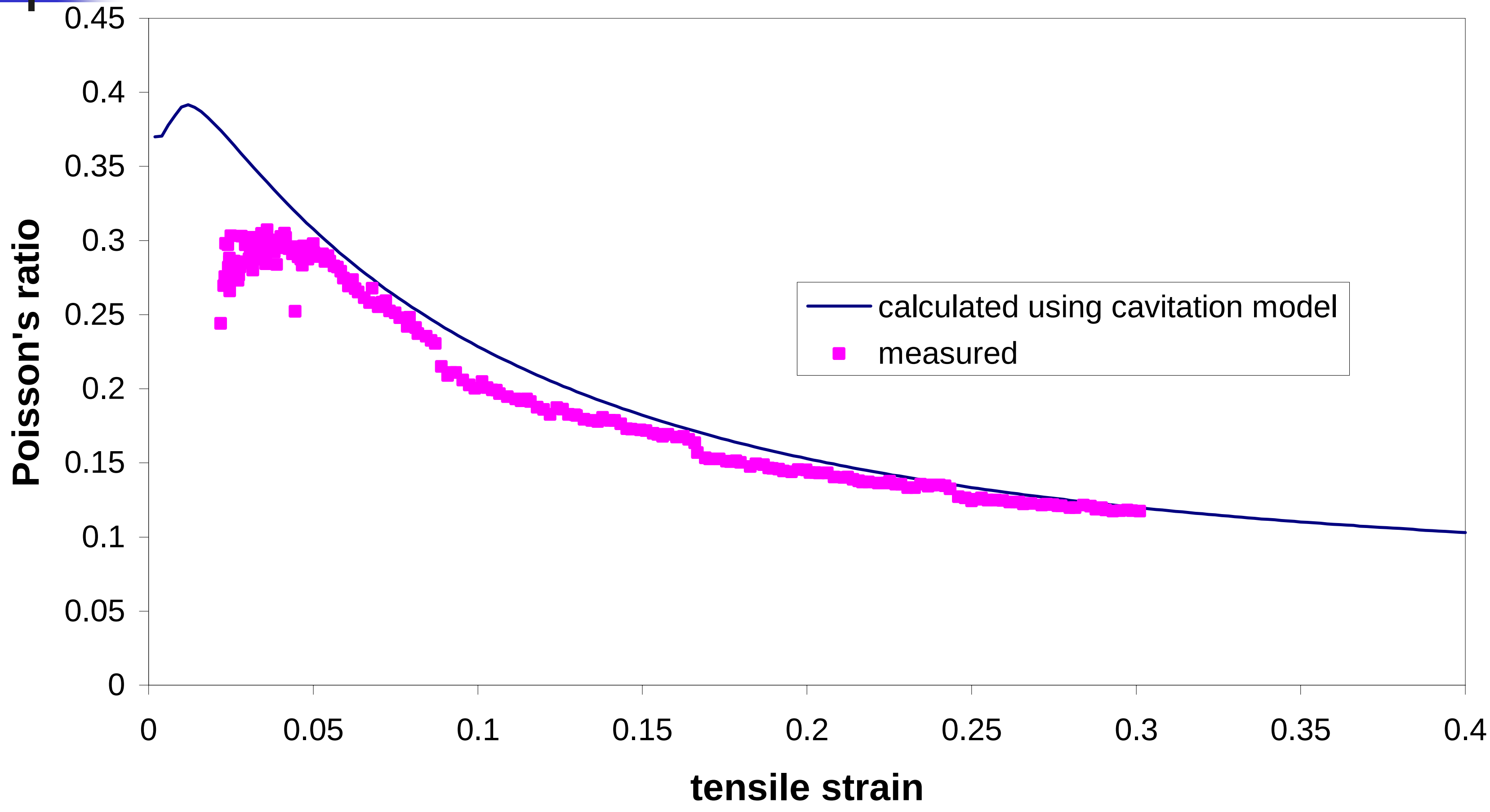
Compressive behaviour – cavitation model



Tensile behaviour - cavitation model



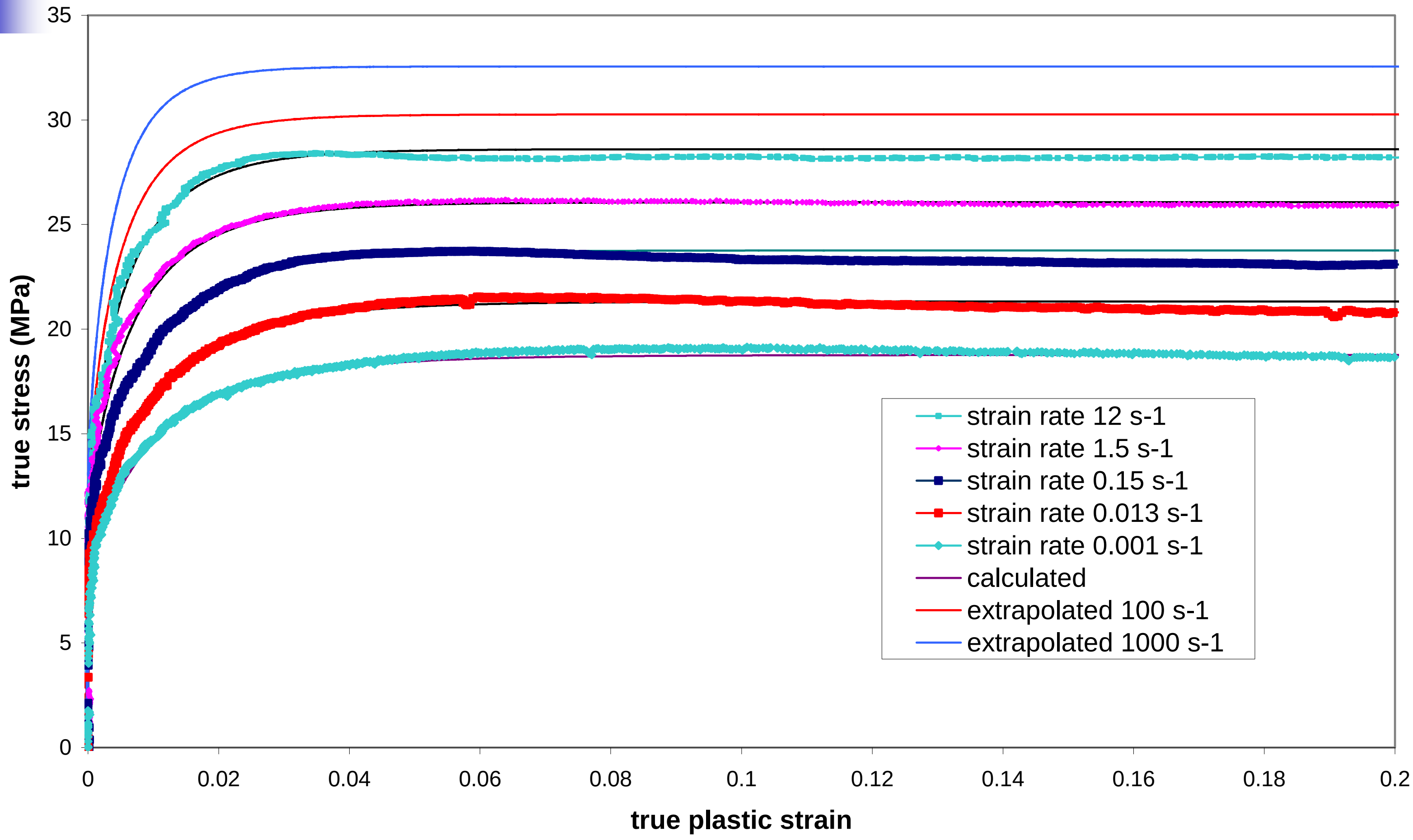
Poisson’s ratio – cavitation model



Determination of properties at high strain rates – see IAG minutes March 04

- Measure stress/strain curves at low and moderate strain rates
- Model hardening behaviour
- Extrapolate to high strain rates

Tensile hardening curves at different strain rates



Development of an ISO Standard

- ISO/CD 18872 – Determination of tensile properties at high strain rates
  - Comments from the CD ballot will be discussed at the ISO meeting in October

NPL Report DEPC-MPR 007

- Determination of Material Properties and Parameters Required for the Simulation of Impact Performance of Plastics Using Finite Element Analysis

G. Dean and R. Mera

July 2004

FE Modelling

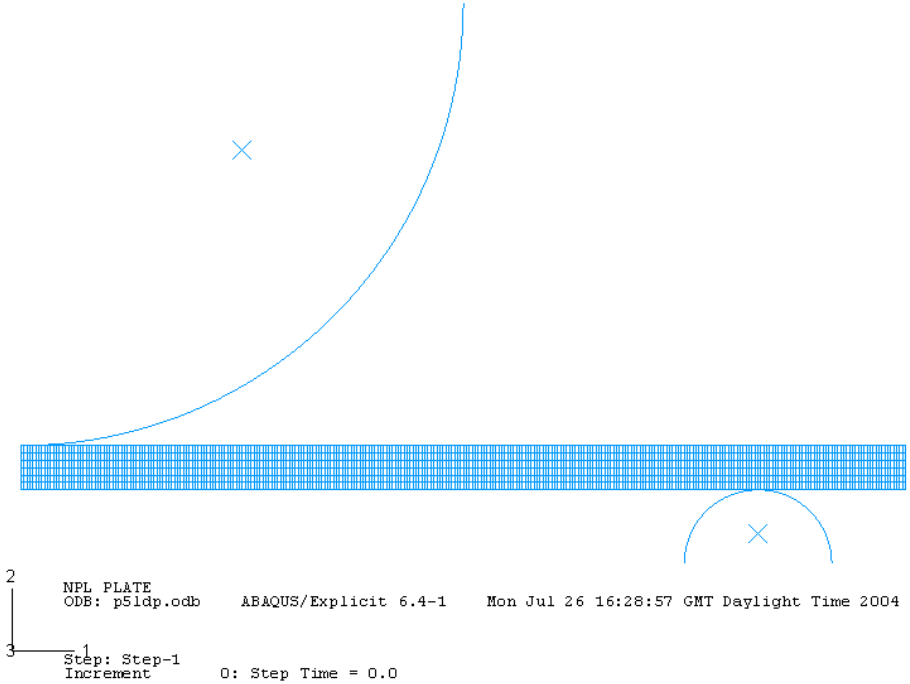
- Have obtained parameters for
  - Von Mises
  - Linear Drucker-Prager
  - Cavitation model

- Plus rate-dependant data

Rate-dependence is newly implemented in the cavitation model

Verification of rate-dependant cavitation model

- Use plate analysis
- ABS material
- Indentation speeds
  - Slow (0.1 mm/s)
  - Fast (1 m/s)



Verification of rate-dependant cavitation model

- Four different materials models
  - Single rate cavitation
  - Rate-dependent cavitation
  - Rate-dependent cavitation with cavitation turned off (equivalent to linear Drucker-Prager)
  - Rate-dependent linear Drucker-Prager

- Compare “no cavitation” cavitation model with ABAQUS linear Drucker-Prager model to verify the implementation of rate-dependent data in the cavitation model

- Use explicit analysis – good for dynamic events and high deformation situations

Verification of rate-dependant cavitation model

- Explicit analysis
  - Lengthy analysis for slow rate – small time increments
  - Initial results poor – rounding errors
- To speed up analysis
  - Increase maximum stable time increment
    - Increasing mesh size
    - Increasing material density
    - Decreasing material stiffness
  - Best to increase density
    (*mass scaling factor)
  - Can cause inertial effects
    Lose contact between
    9 and 13 mm

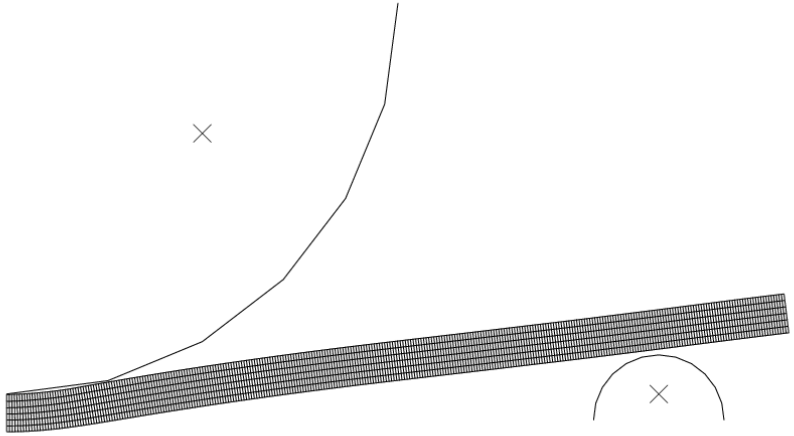
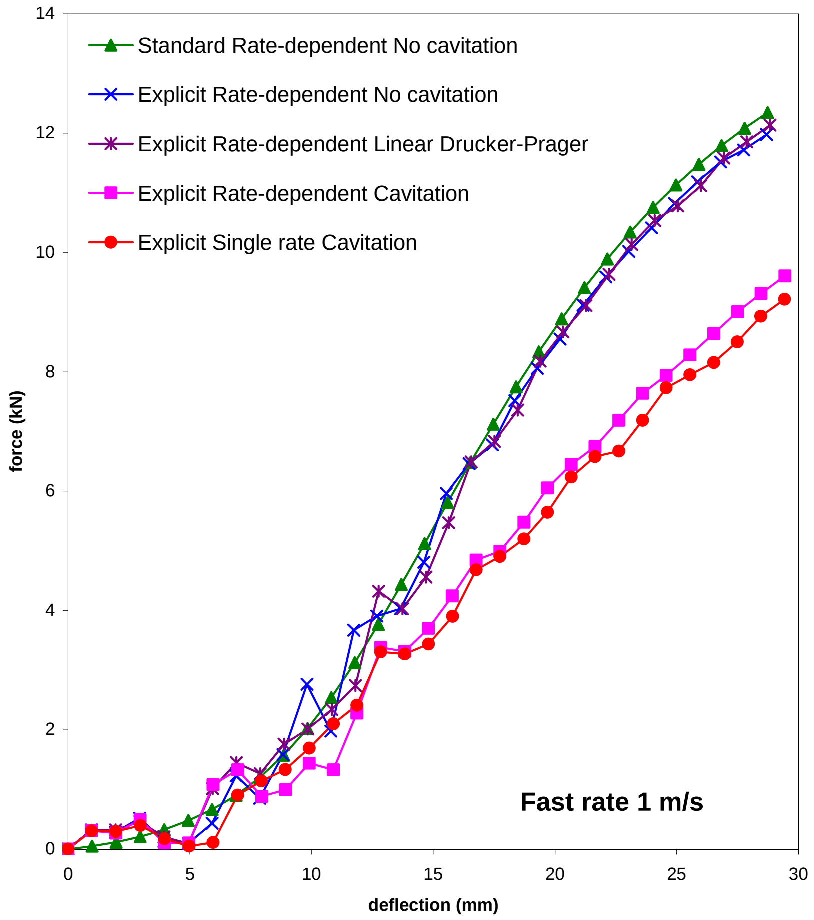


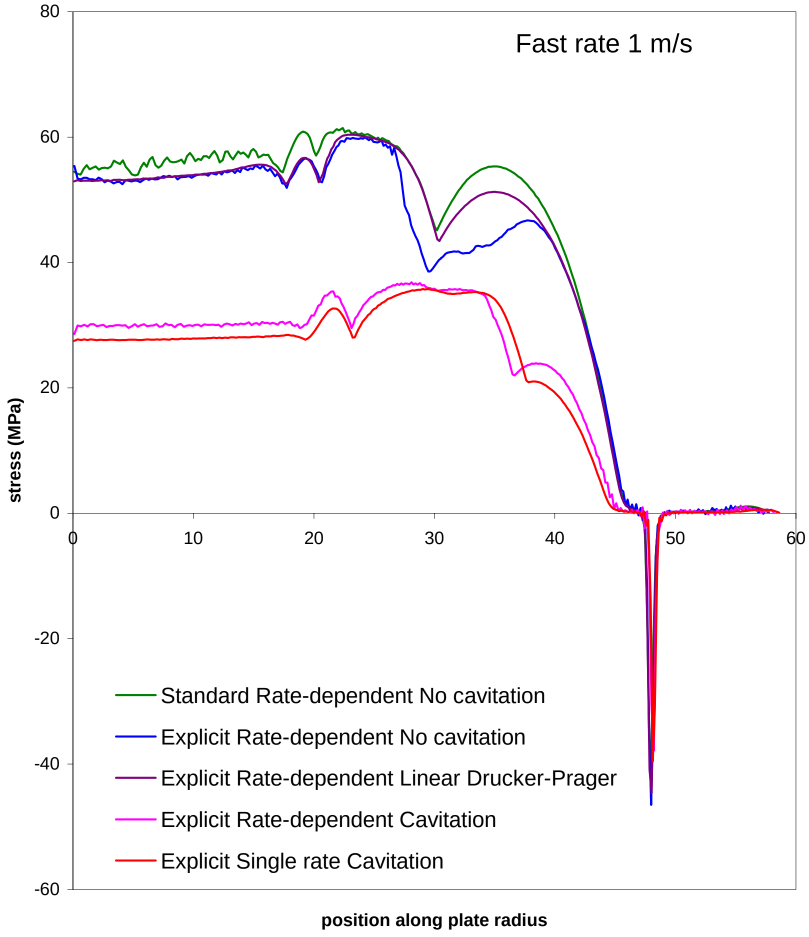
Plate predictions – 1 m/s



- Good match between explicit and standard “no cavitation” predictions and ABAQUS linear Drucker-Prager model
- Single rate and rate-dependent model predictions are similar – due to choice of single rate curve
- Cavitation model predictions are lower than linear Drucker-Prager model

Plate predictions – 1 m/s

- Same trends in stress and strain predictions



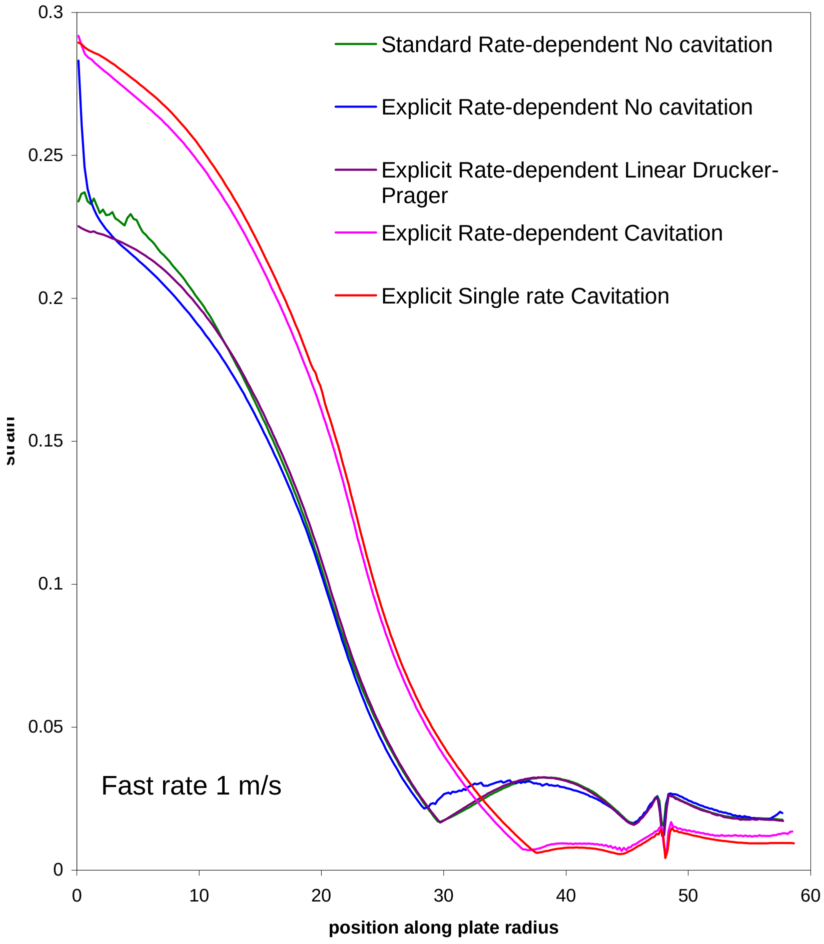
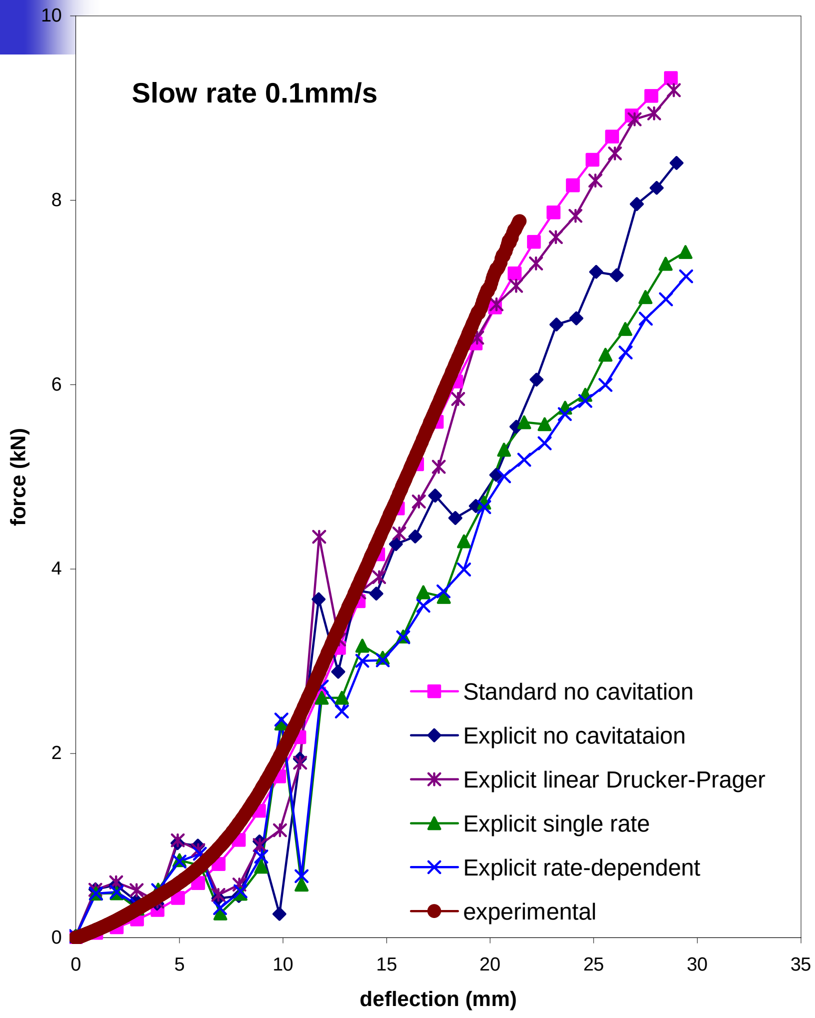


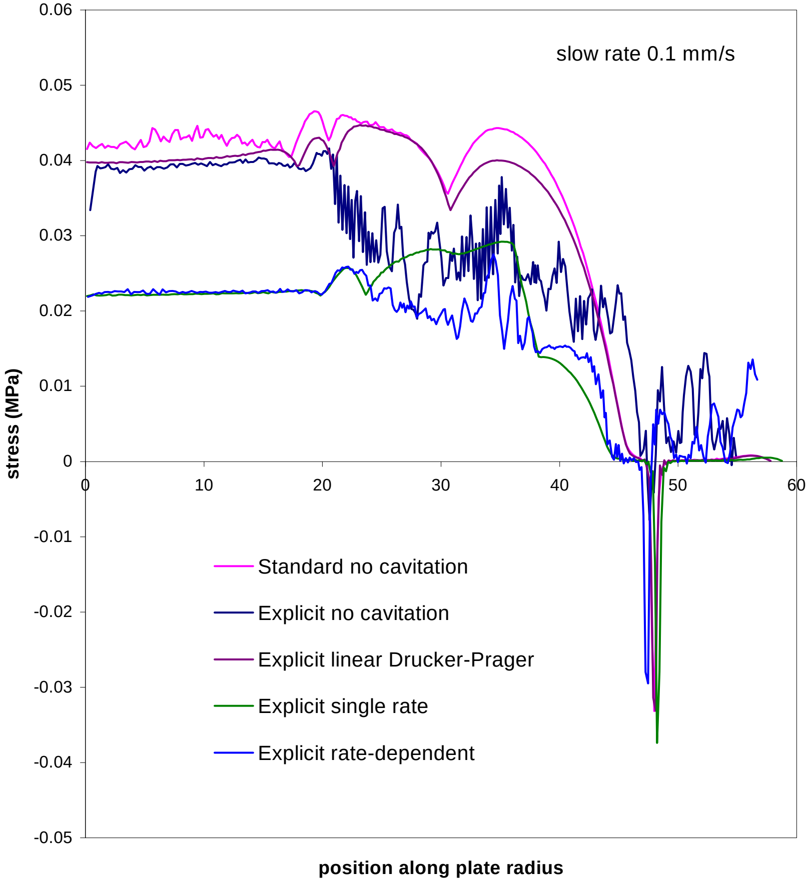
Plate predictions – 0.1 mm/s

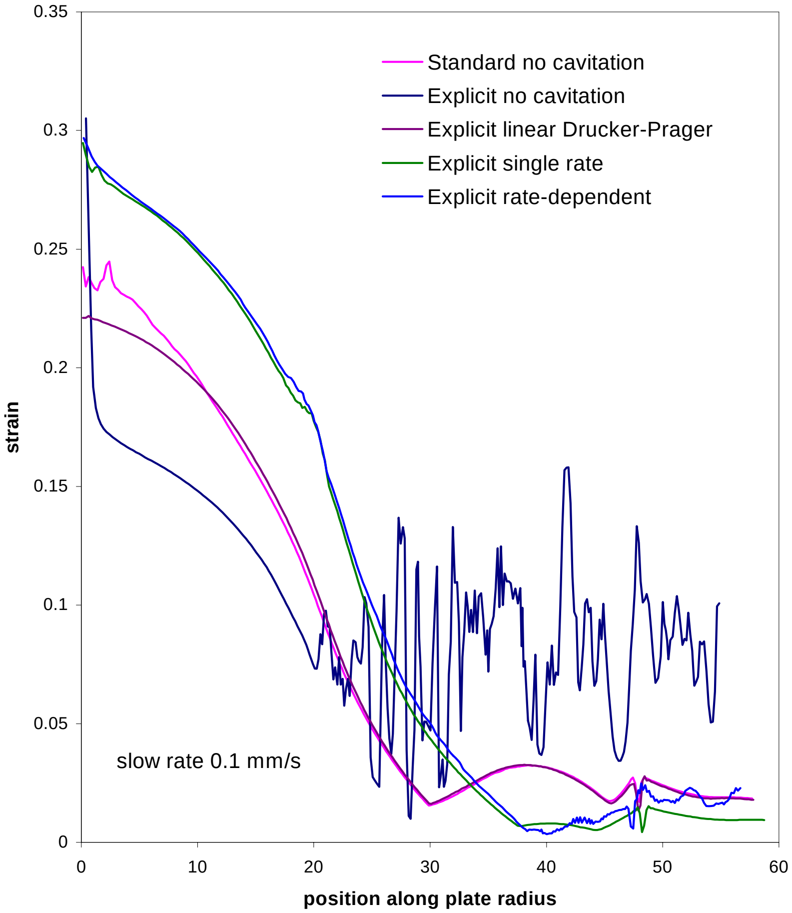


- Good match between standard “no cavitation” predictions and ABAQUS linear Drucker-Prager model.
- Explicit “no cavitation” predictions are poorer at higher deflections
- Single rate and rate-dependent model predictions are similar – due to choice of single rate curve
- Cavitation model predictions are lower than linear Drucker-Prager model
- Experimental data match linear Drucker-Prager – suggests material does not cavitate
- See results of inertial effects

Plate predictions – 0.1 mm/s

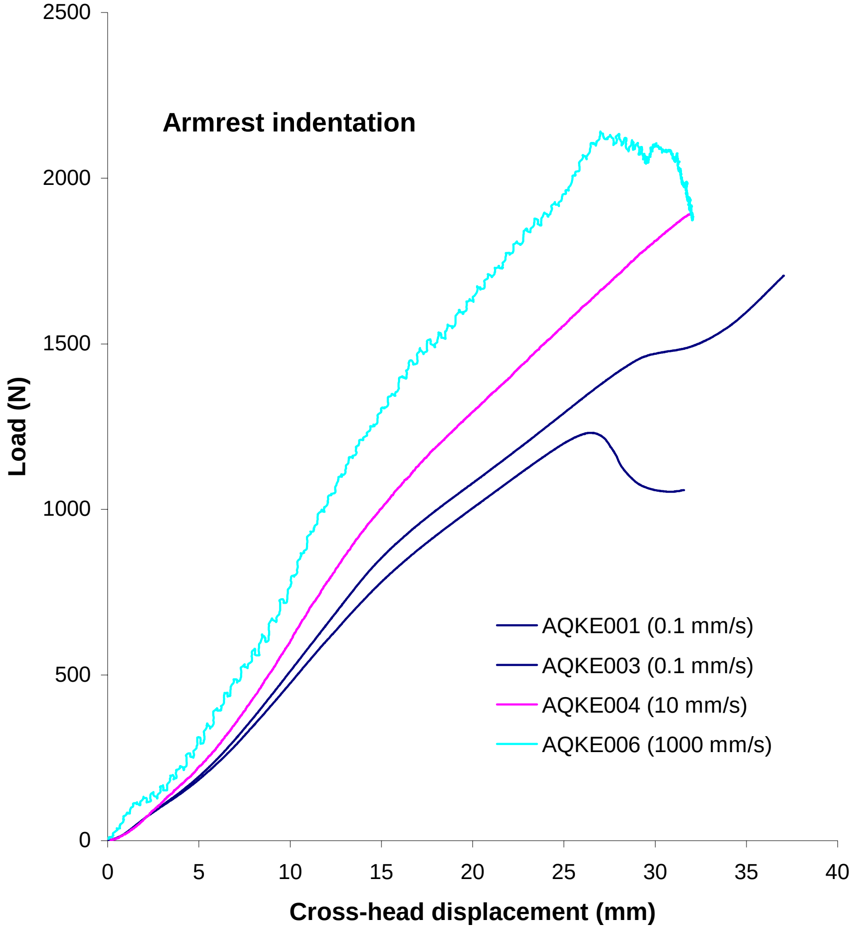
- Same trends in stress and strain predictions
- Explicit rate-dependent results are poorer away from centre of the plate

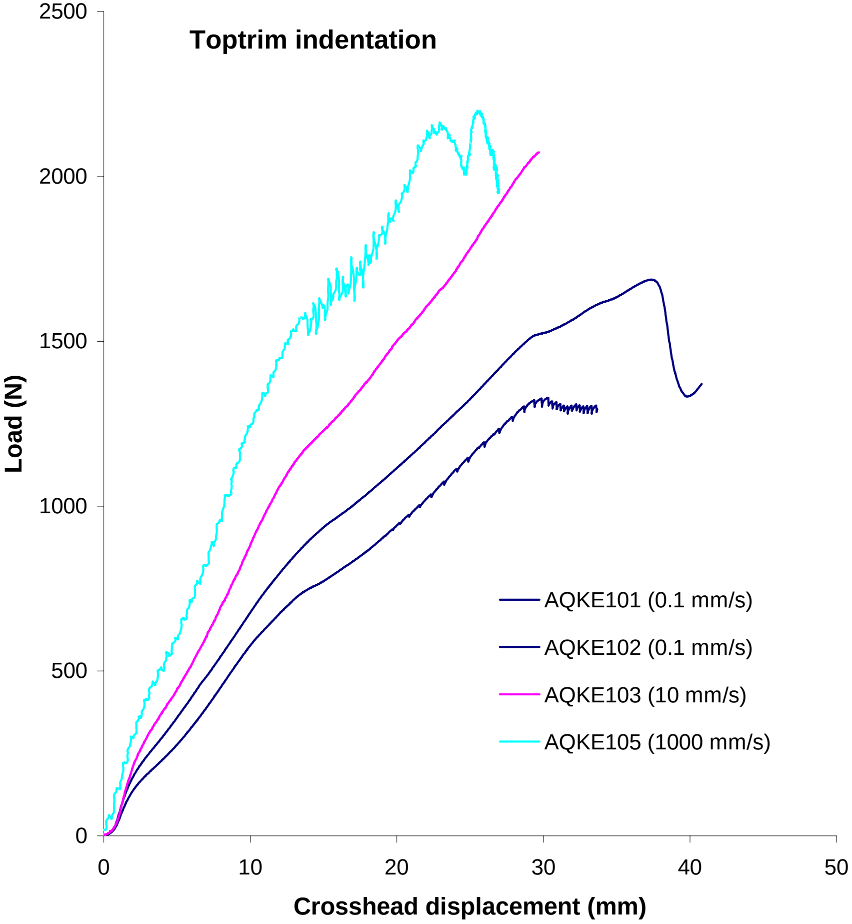




FEA of component parts

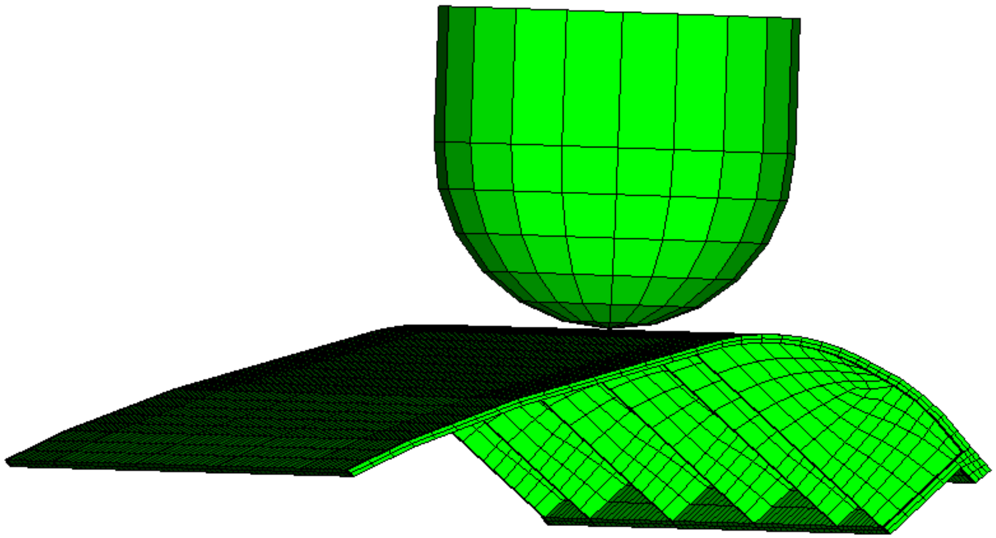
- Experimental results



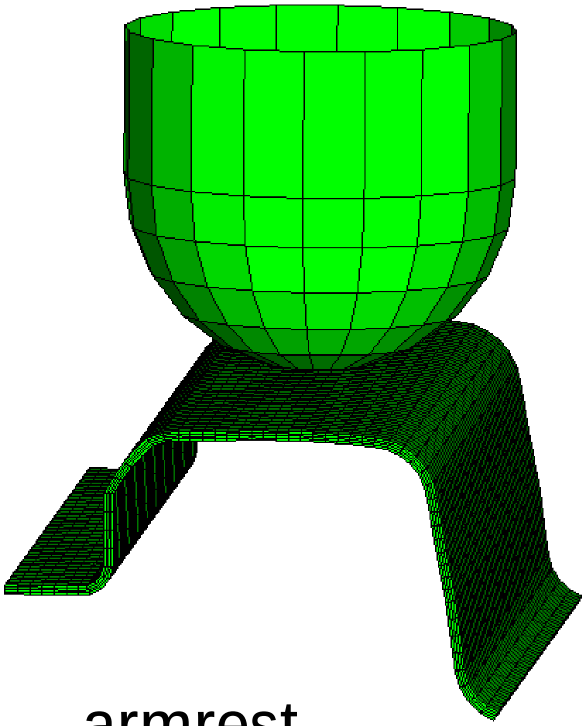


FEA of component parts

- FEA Meshes



toptrim



armrest

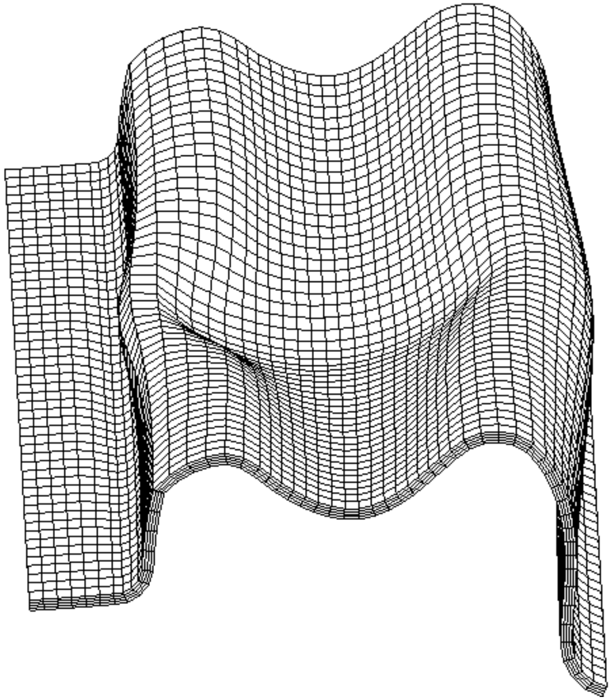
FEA of component parts

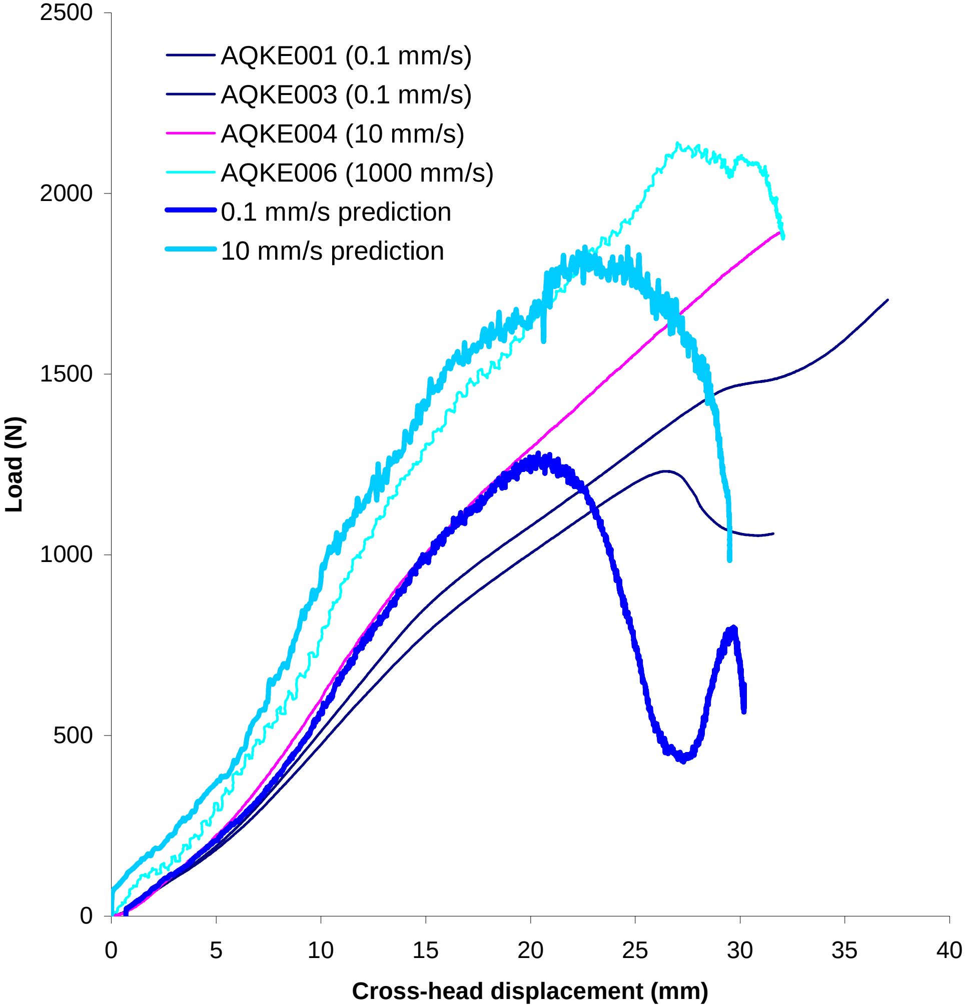
- Two models:
  - Explicit rate-dependent linear Drucker-Prager
  - Explicit rate-dependent cavitation model

- Three test speeds
  - 0.1 mm/s, 10 mm/s and 1 m/s

FEA of component parts

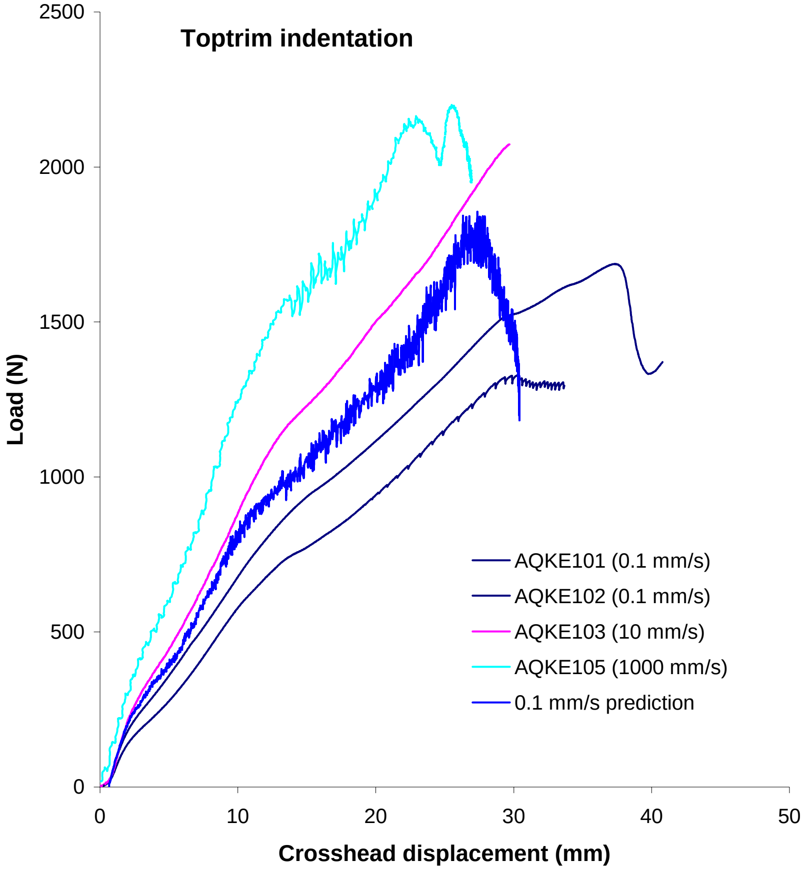
Armrest

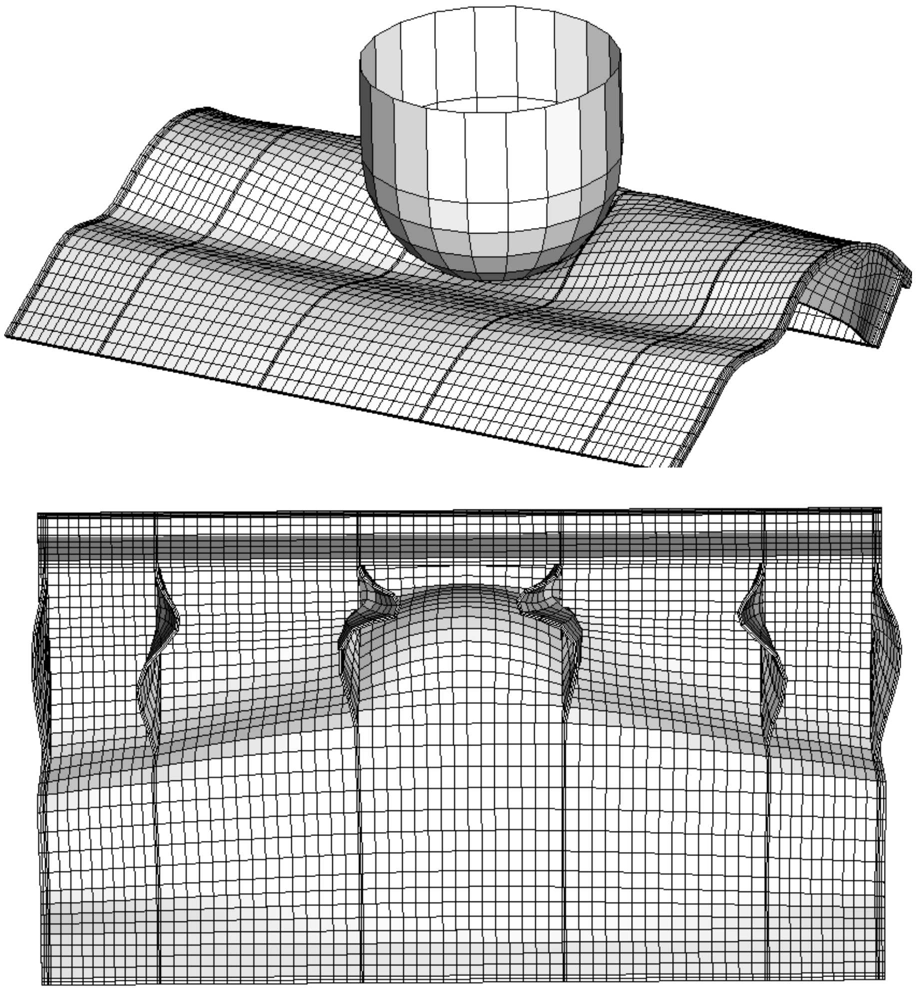




FEA of component parts

Toptrim





FEA of component parts

Further work

- Complete linear Drucker-Prager predictions
- Analysis of component parts with:
    - Rate-dependent cavitation model
    - Von Mises
- Land Rover to analyse parts using their preferred model
- FE sensitivity analysis – look at effects of changes in parameters etc