Plastics in Simulation

Hubert Lobo & Brian Croop

What makes plastics unique

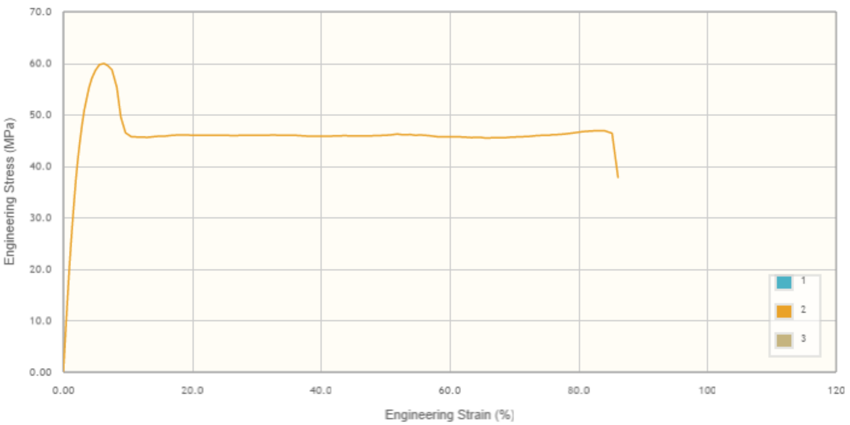
- Non-linear elasticity
- Complex plasticity (pre-yield, post-yield)
- Viscoelastic (time-based behavior)
- Properties change over product operational temperature
- Properties change with environmental exposure

Behavioral classes

- Ductile
  - Post-yield behavior
- Brittle
  - No post-yield behavior
- Elastomeric
  - Hyperelastic with plasticity

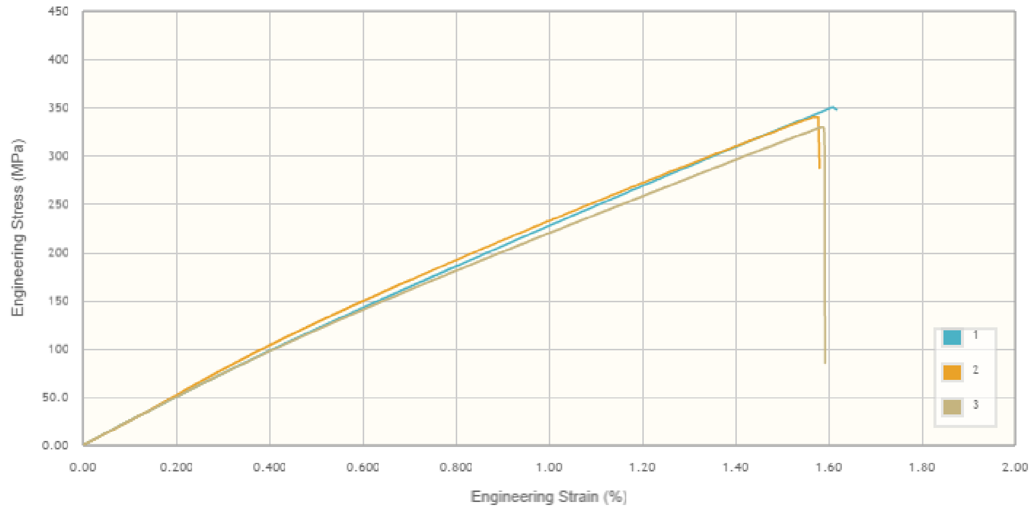
Ductile polymer

- Behavior
  - Non-linear elastic
  - Yield point
  - Post-yield localization
  - Large strain to fail
- Typical Plastics
  - HDPE, LDPE…
  - PP
  - PC, ABS
  - PTFE



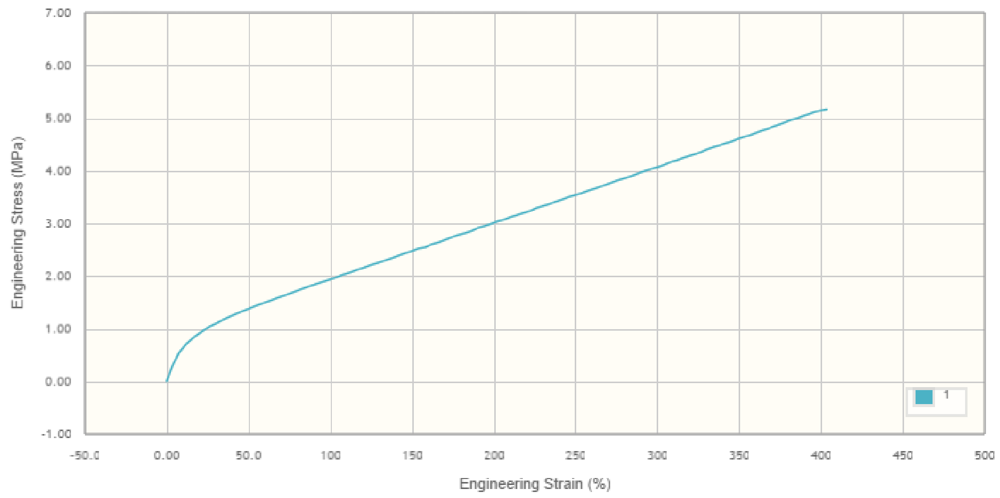
Brittle polymer

- Behavior
  - Linear elastic
  - Failure point
  - Small strain to fail
  - Stiff
- Typical Plastics
  - PS
  - Fiber-filled plastics

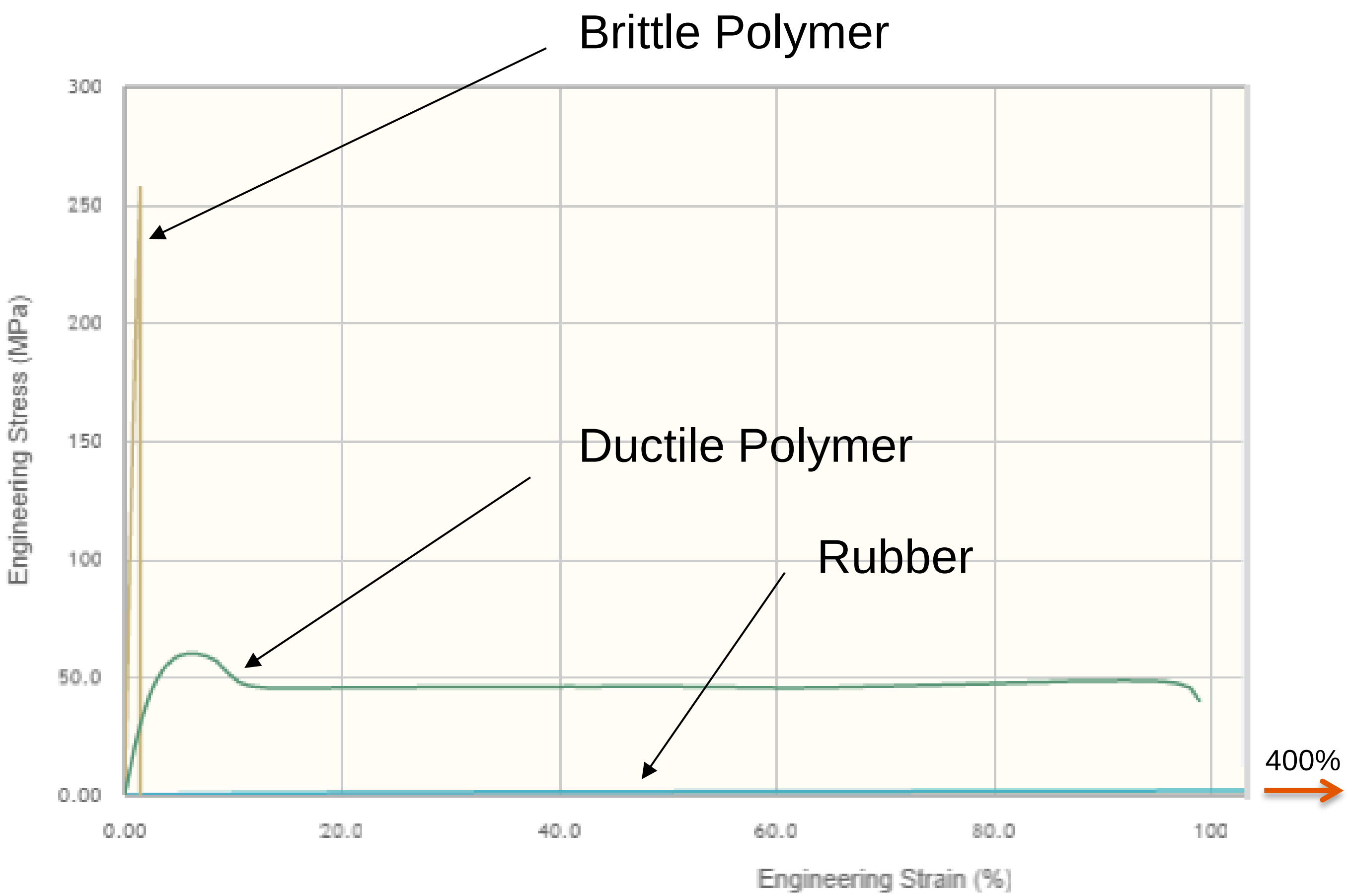


Rubbers and Elastomers

- Behavior
  - Hyperelastic
  - Post-yield plasticity
  - Large strain to fail
- Typical Plastics
  - TPE (santoprene)
  - TPU (polyurethanes)
  - SEBS, latex, silicone

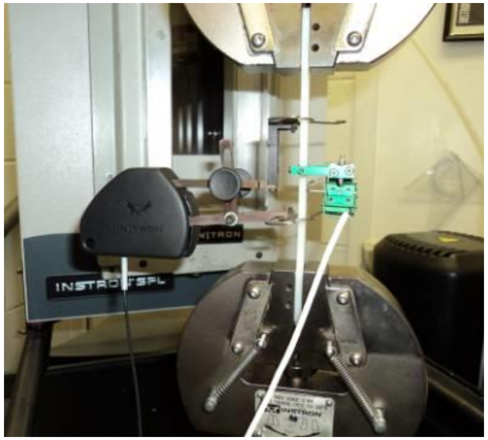


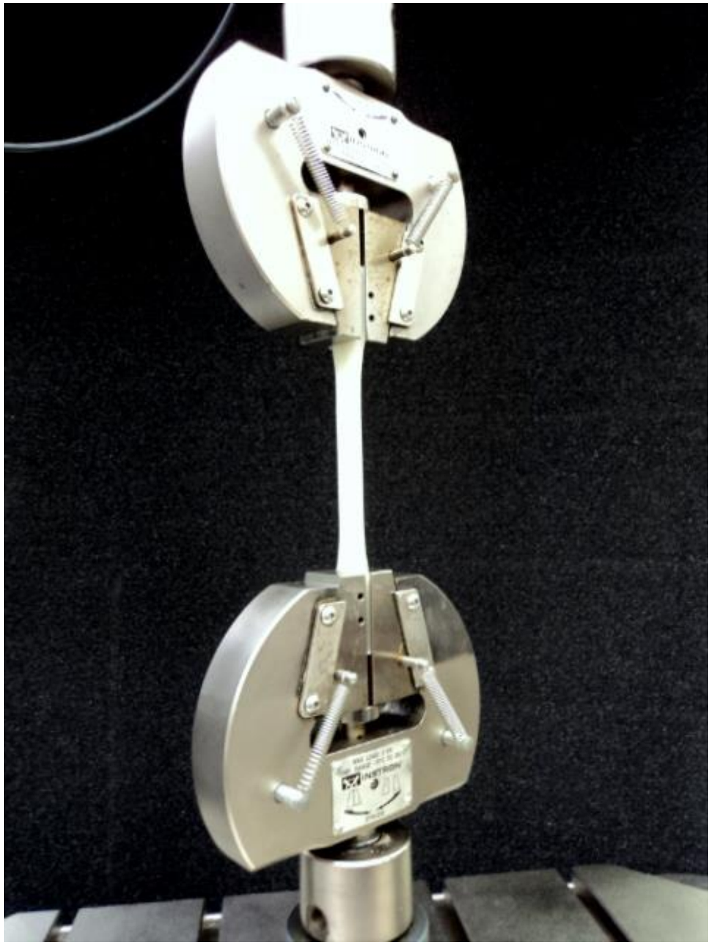
Comparison


Brittle Polymer
Ductile Polymer
Rubber
400%
300
250
200
150
100
50.0
0.00
Engineering Stress (MPa)
0.00
20.0
40.0
60.0
80.0
100
Engineering Strain (%)

Testing of polymers

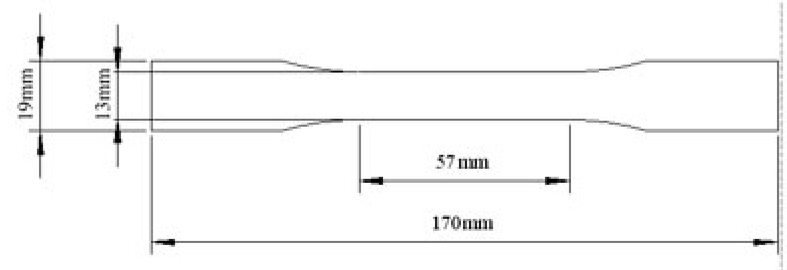
- Universal Testing M/c
- Extensometry for strain
- Stress-strain data

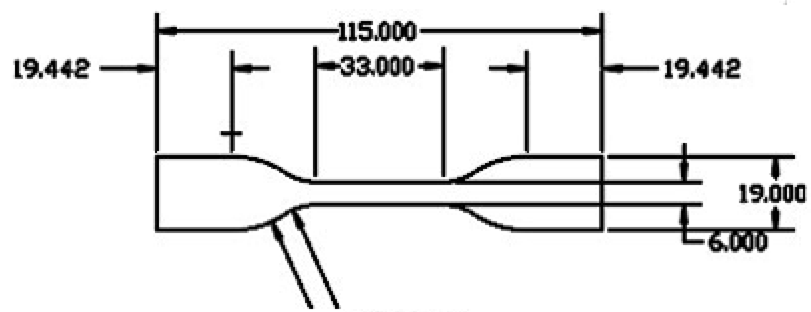


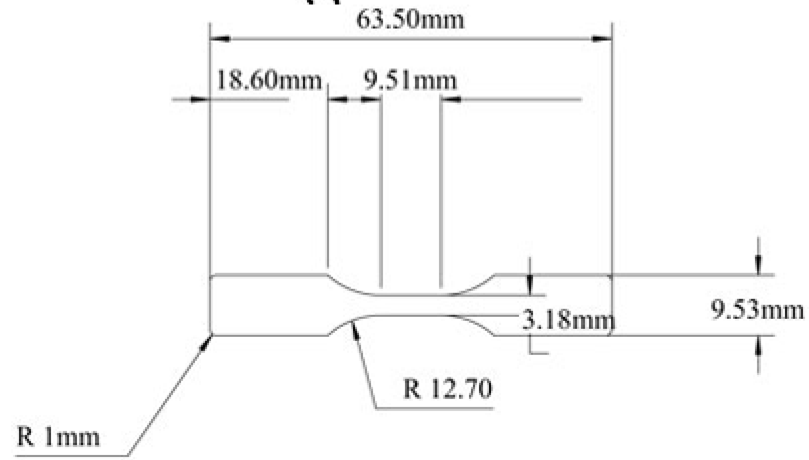


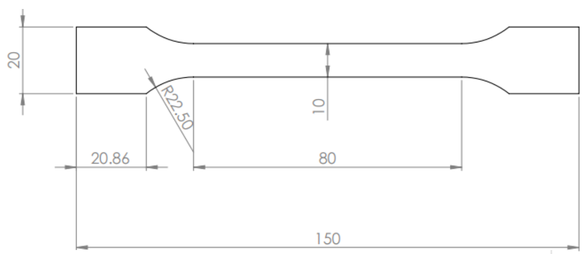
Test specimens

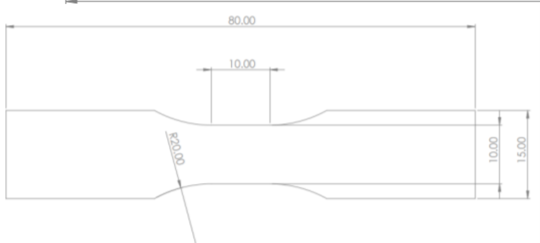
- ASTM D638
  - Type 1 – most plastics
  - Type IV – elastomers
  - Type V – rate dependency
- ISO 527
  - Type 1 – most plastics
- ISO 8256
  - Type 3 – rate dependency





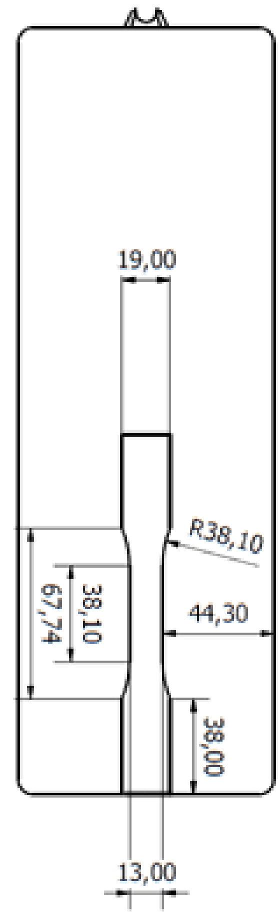






Making test specimens

- Mold tensile bar
  - Most plastics
- Punch from sheet
  - Elastomers
- CNC from molded plaque
  - Fiber-filled plastics

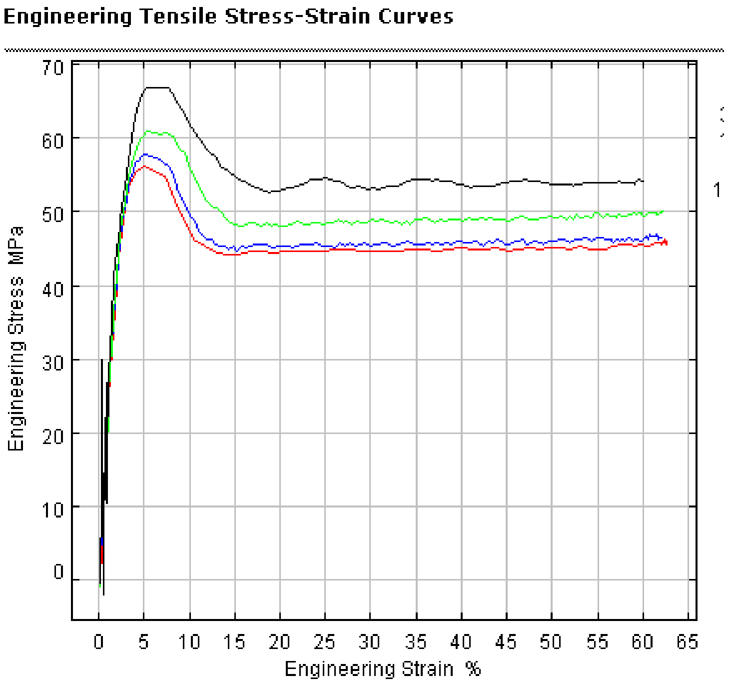


Testing variables

- Test speed (strain rate)
- Temperature
- Environmental conditioning
- Orientation (fiber-filled plastics)

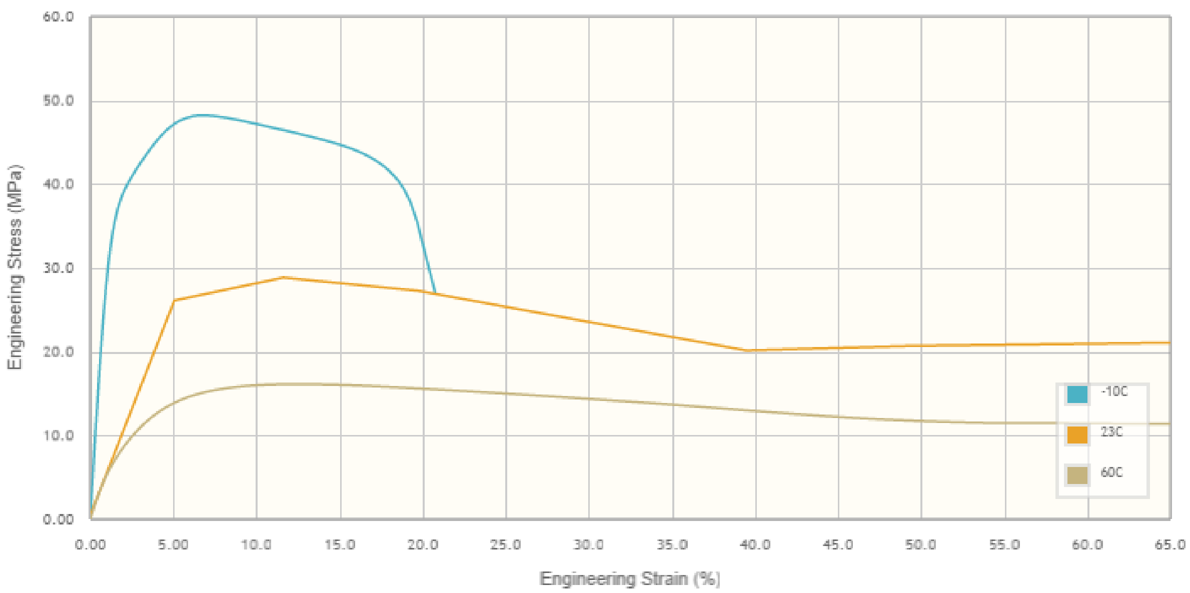
Test speeds

- Properties are rate dependent
  - To be considered later
- Solution
  - Use quasi-static data
  - Test to standard
  - 5 mm/min, constant speed



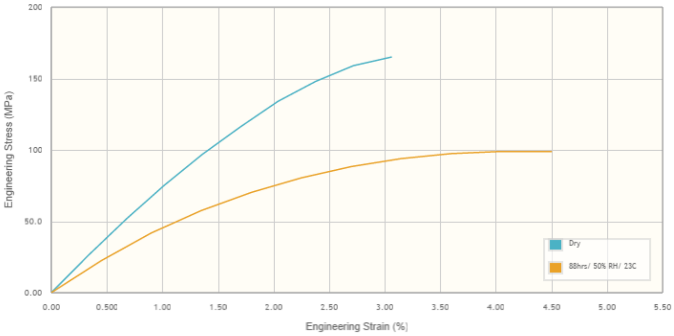
Test temperature

- Properties are temperature dependent
- Solution
  - Test over product temperature range
  - Focus on worst case scenario
  - Watch for low temperature ductile-brittle transitions



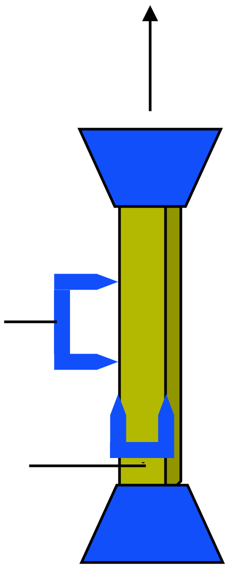
Environmental conditioning

- Properties change with environmental exposure
  - More severe with some polymers
- Solution
  - Determine product use environment
  - Expose specimens to analogous environment
    - Heat aging
    - Moisture conditioning, weathering
    - Fluid exposure
    - *In-vivo*
  - Test at time intervals after exposure -> equilibrium



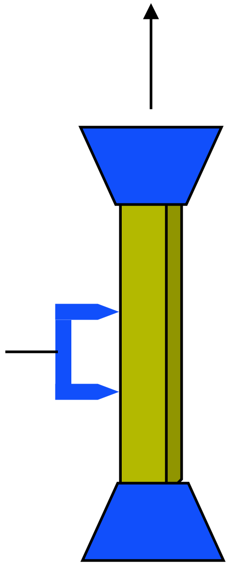
Linear Elastic models

- Elastic modulus + Poisson's ratio
  - UTM with 2 extensometers
  - Testing only in elastic region
- Material model:
  - ANSYS IsotropicElasticity
- Usage
  - NVH
  - Small deformation stiffness



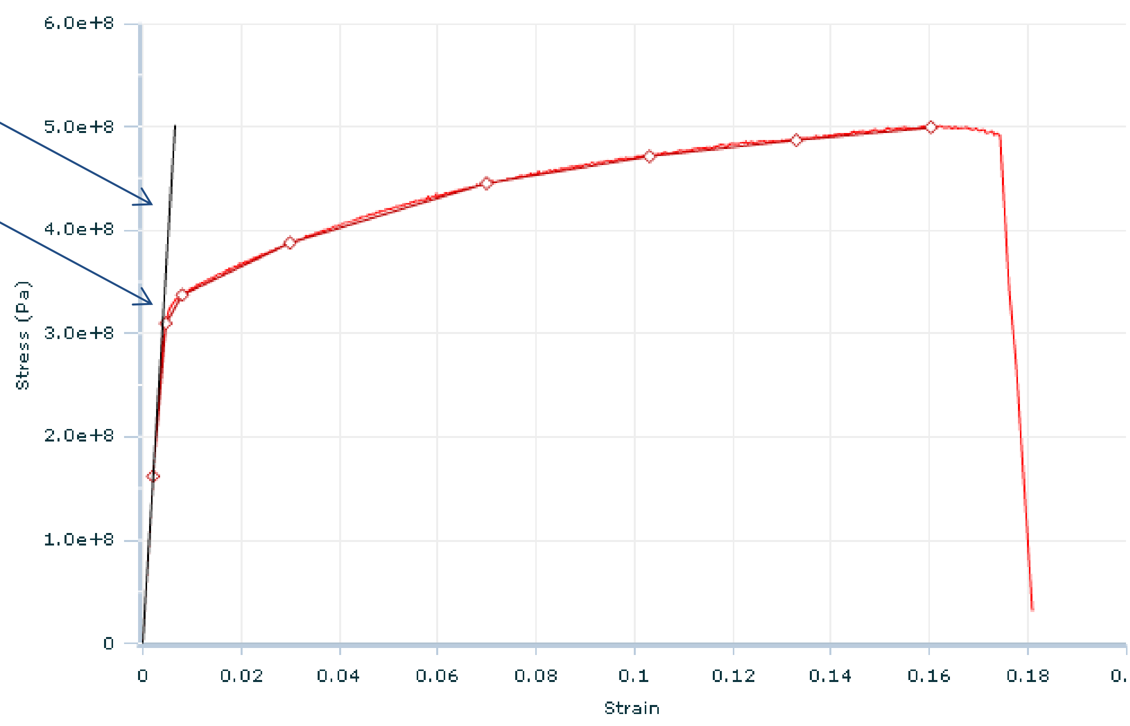
Non-linear models

- True stress-strain curves
  - UTM with extensometers
  - Testing to yield or break
- Model: MISO (BISO)
  - Reduce to elasto-plasticity based on yield point
  - Bilinear
  - Multi-linear
- Usage
  - Large deformation
  - von Mises yield or failure



MISO modeling

- Evaluate a modulus
- Define elastic limit
- Calculate multi-point plasticity



$$\varepsilon_t = E/\sigma + \varepsilon_p$$

where,

E = elastic modulus (MPa)

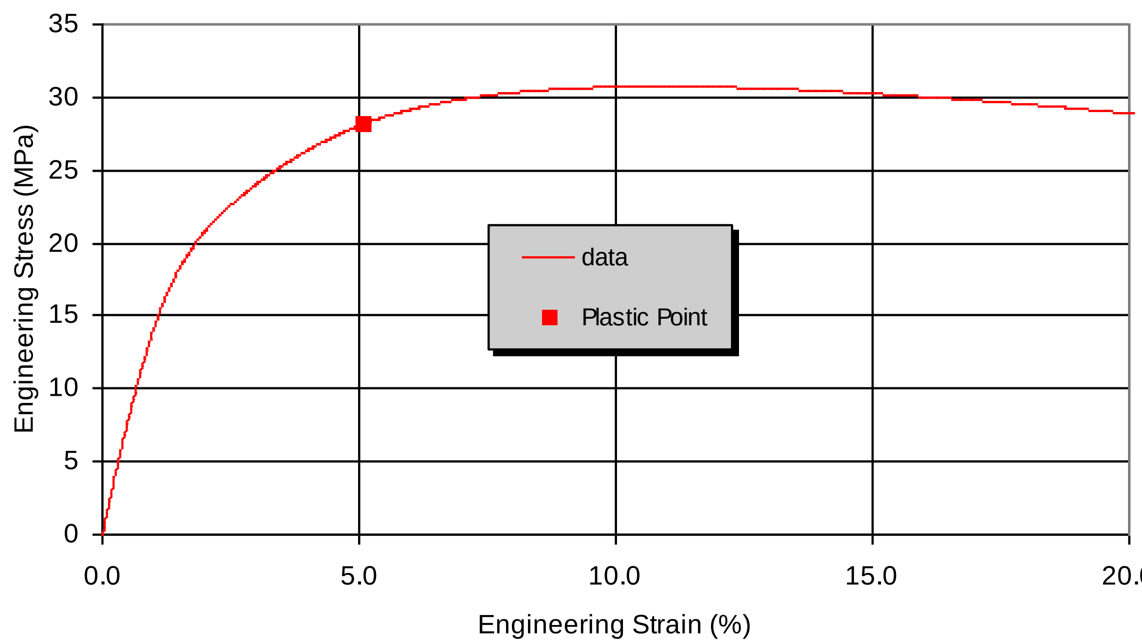
σ_t = true stress (MPa)

ε_p = plastic strain

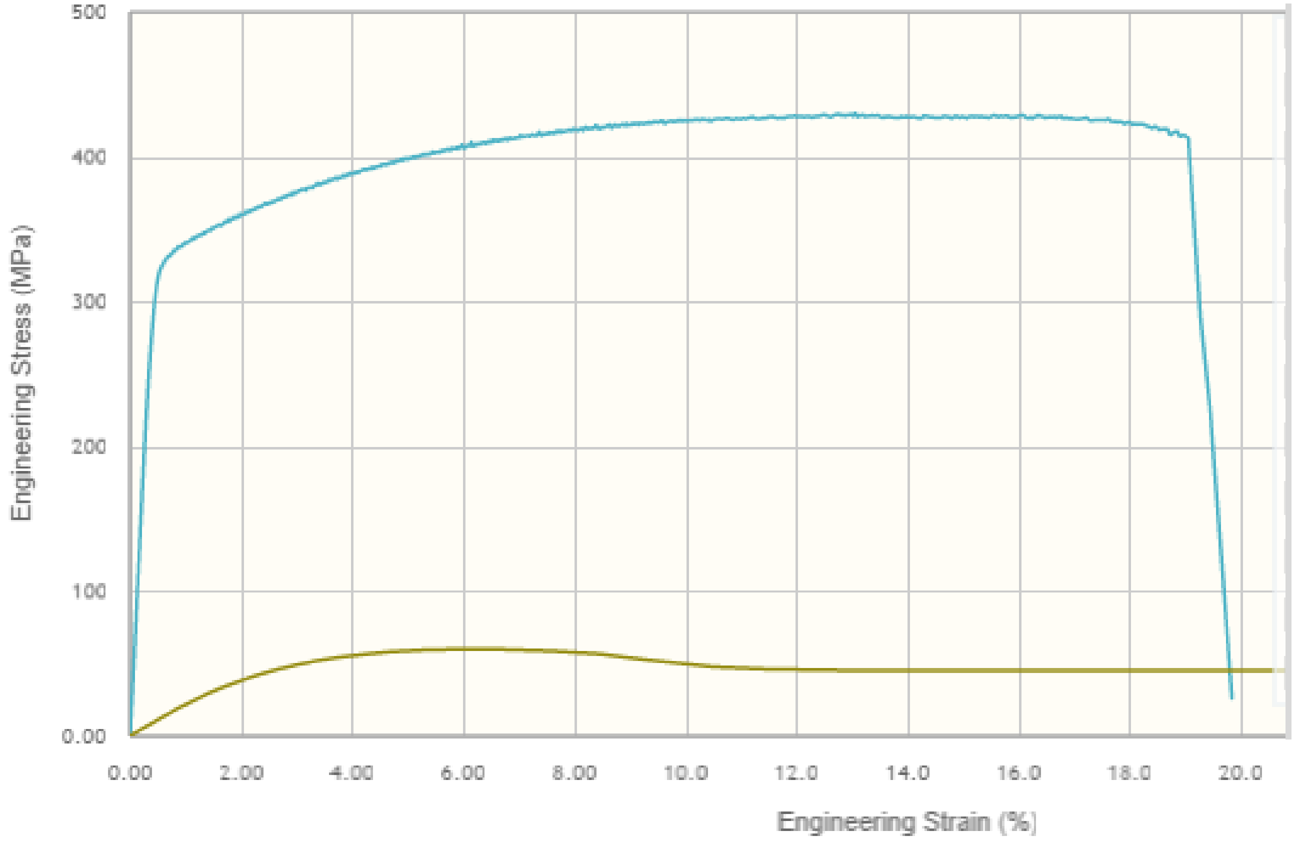
ANSYS CAE Modeler

Polymer elasto-plasticity

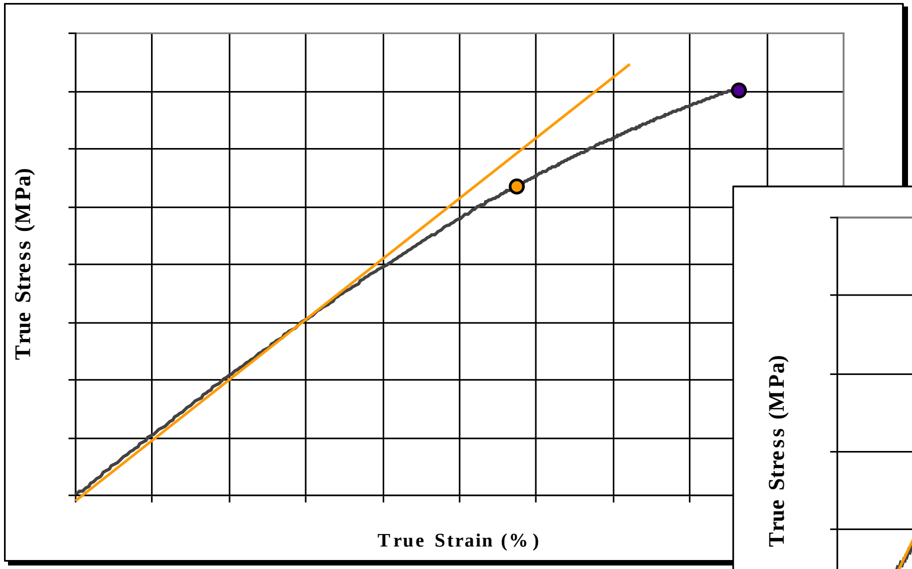
- Non-linear elasticity
- Elastic limit well below classical yield point
- Significant plastic strains prior to yield
- Post-yield with necking behavior



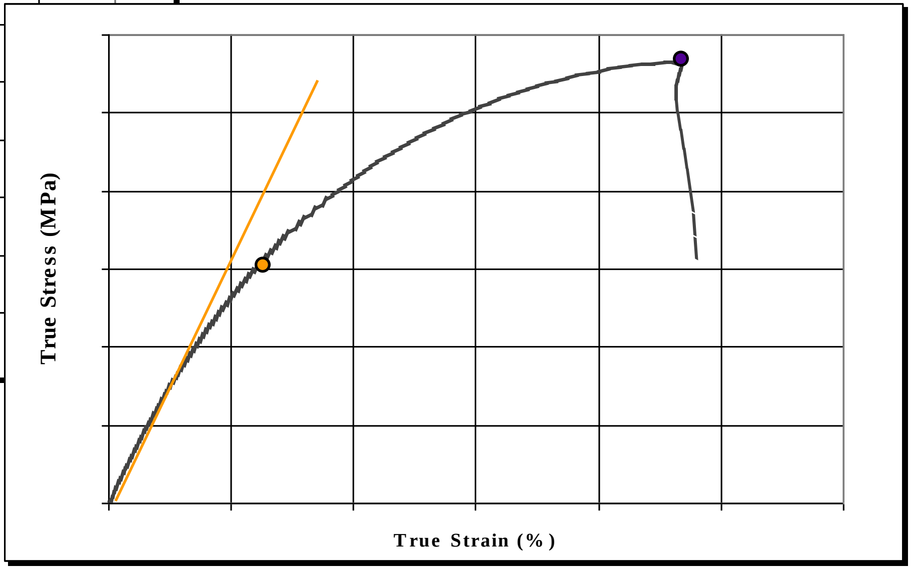
Comparing PC to Al



The question of yield



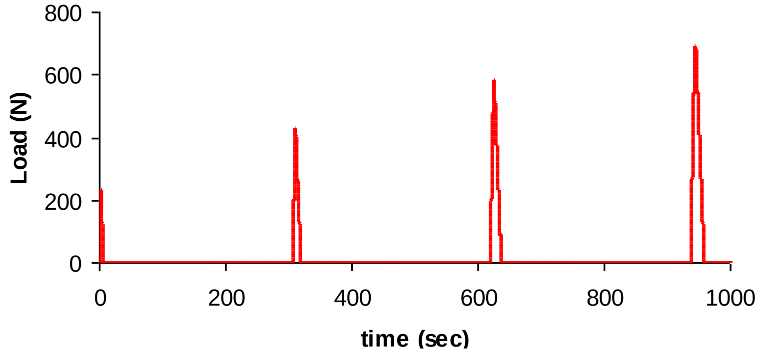
Linear elastic

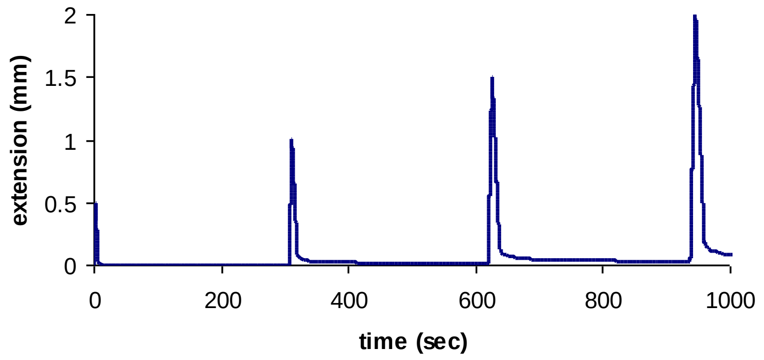


Non-linear elastic

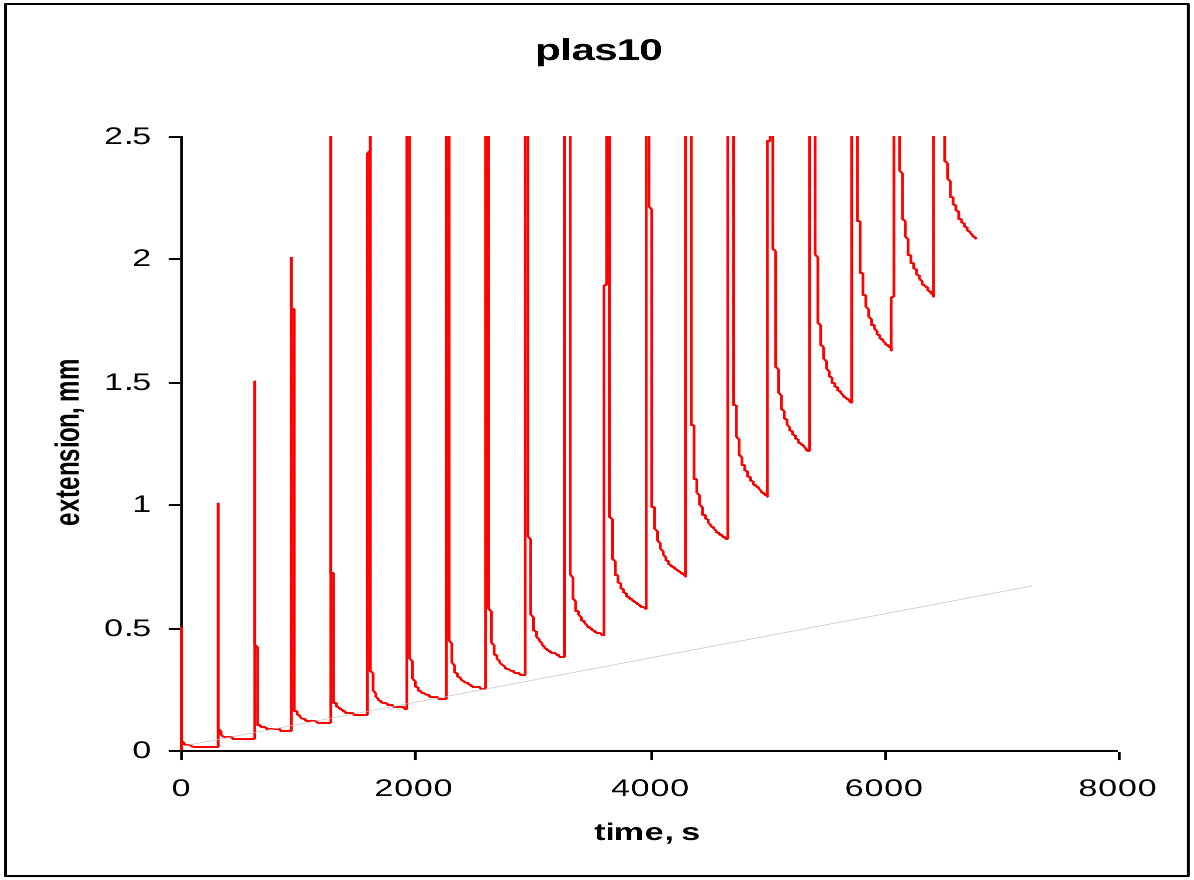
Determining onset of plasticity

- Successive increasing strains followed by relaxation
  - Start at very small strains
  - Unload and allow to relax



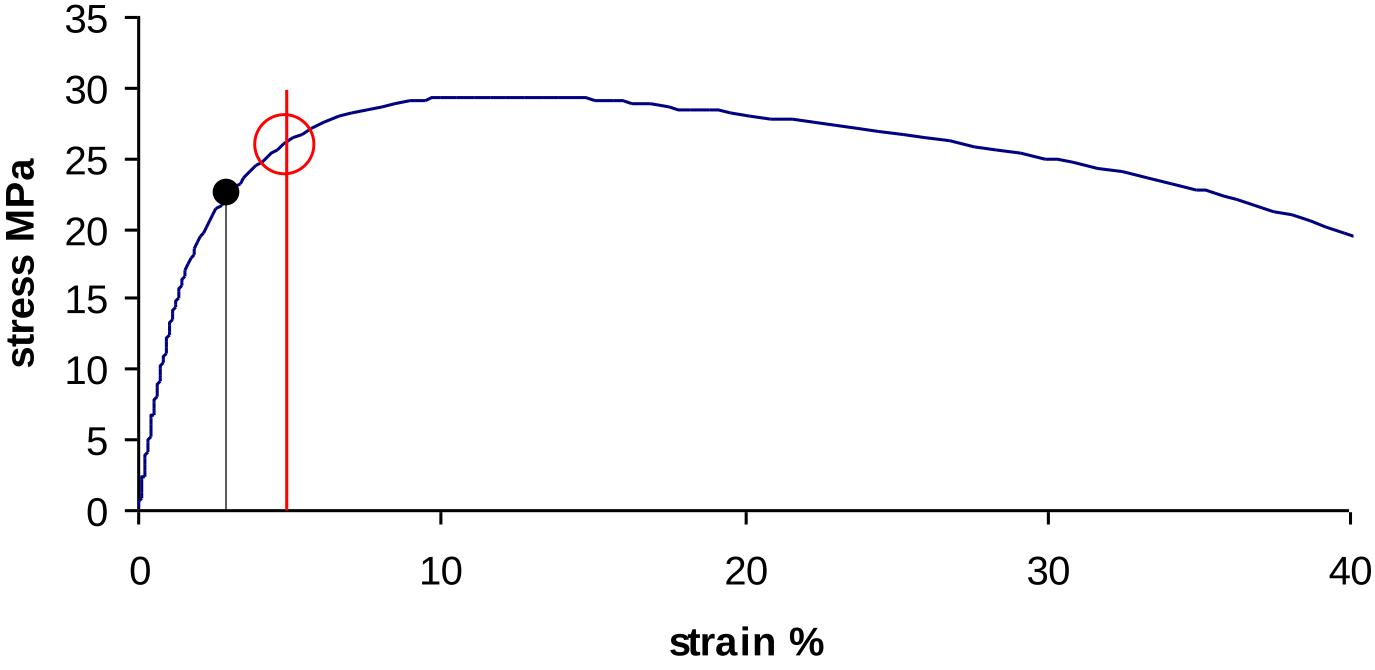


Residual extension

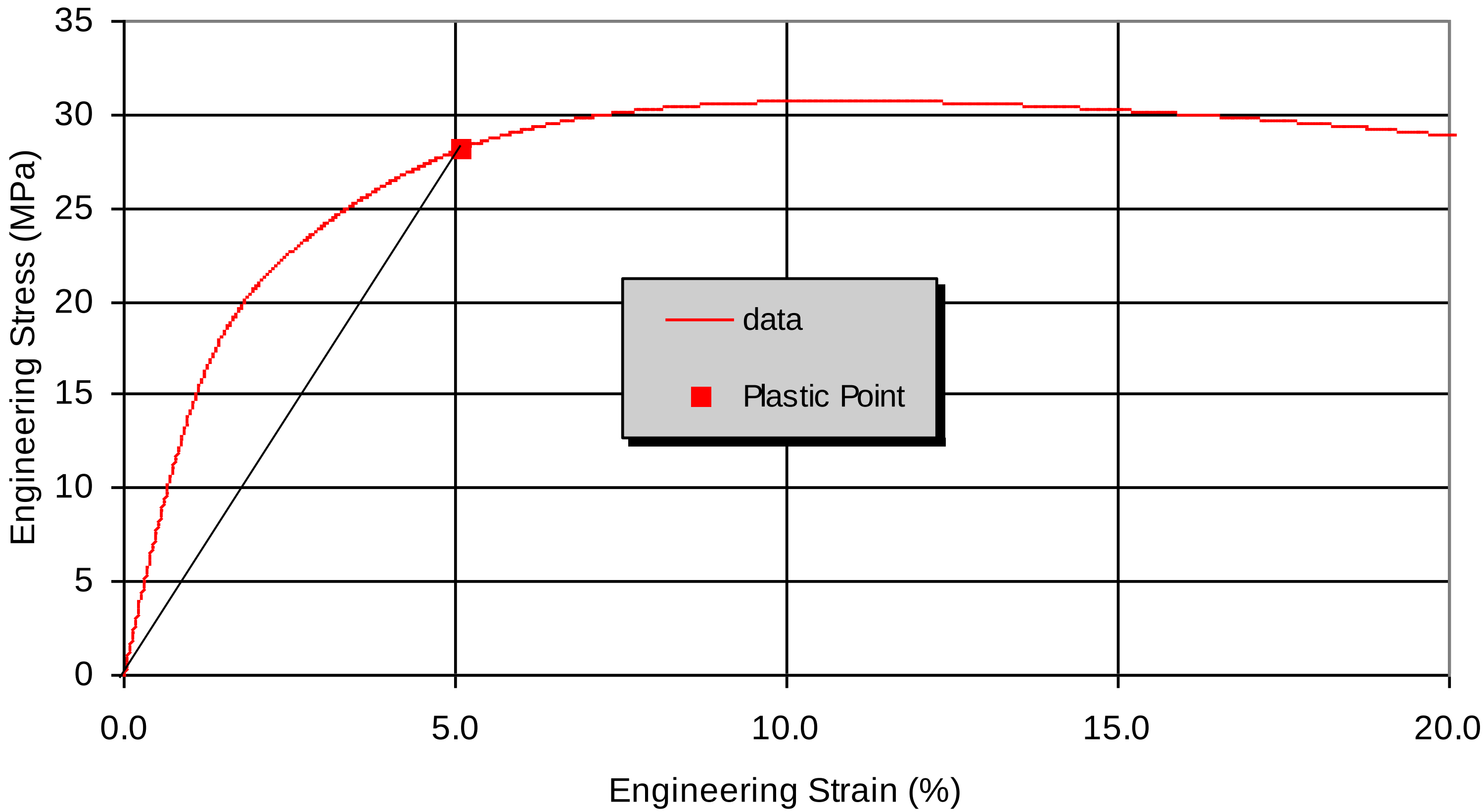


Non-linear elastic limit

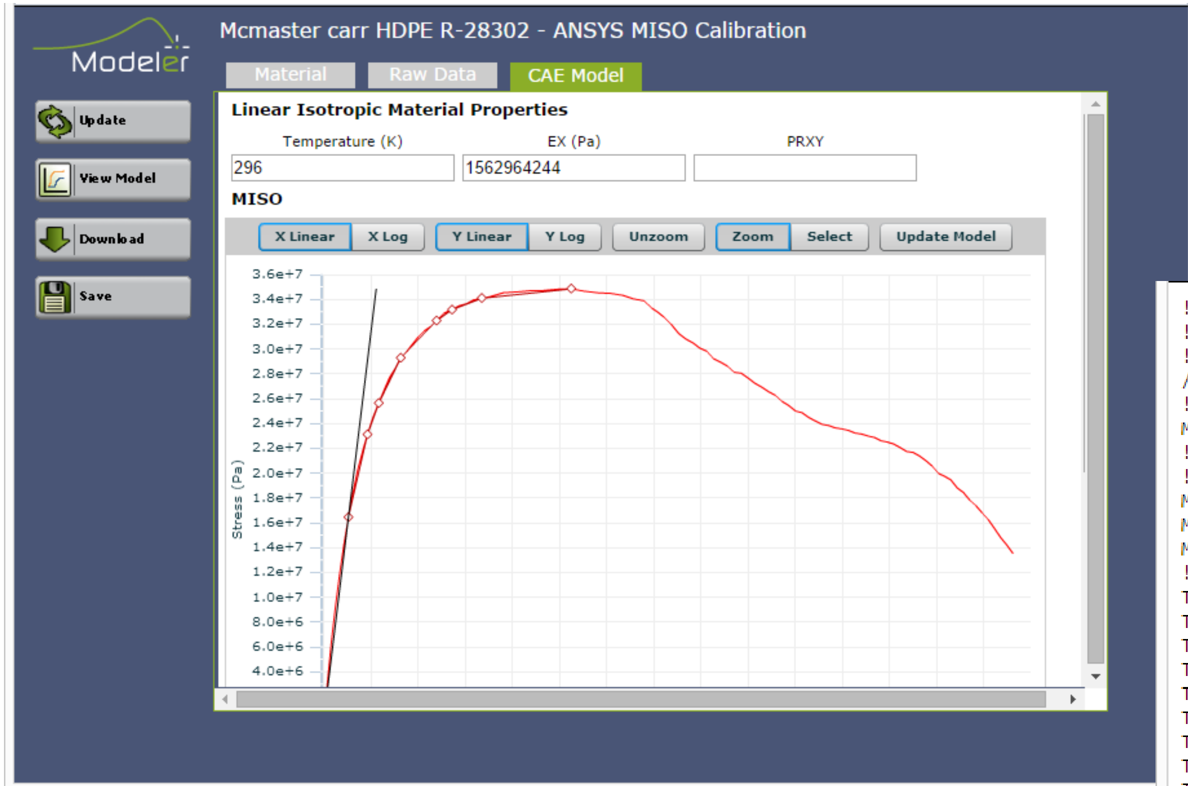
- “True” plastic point occurs below the defined yield



Elasto-plastic models for plastics

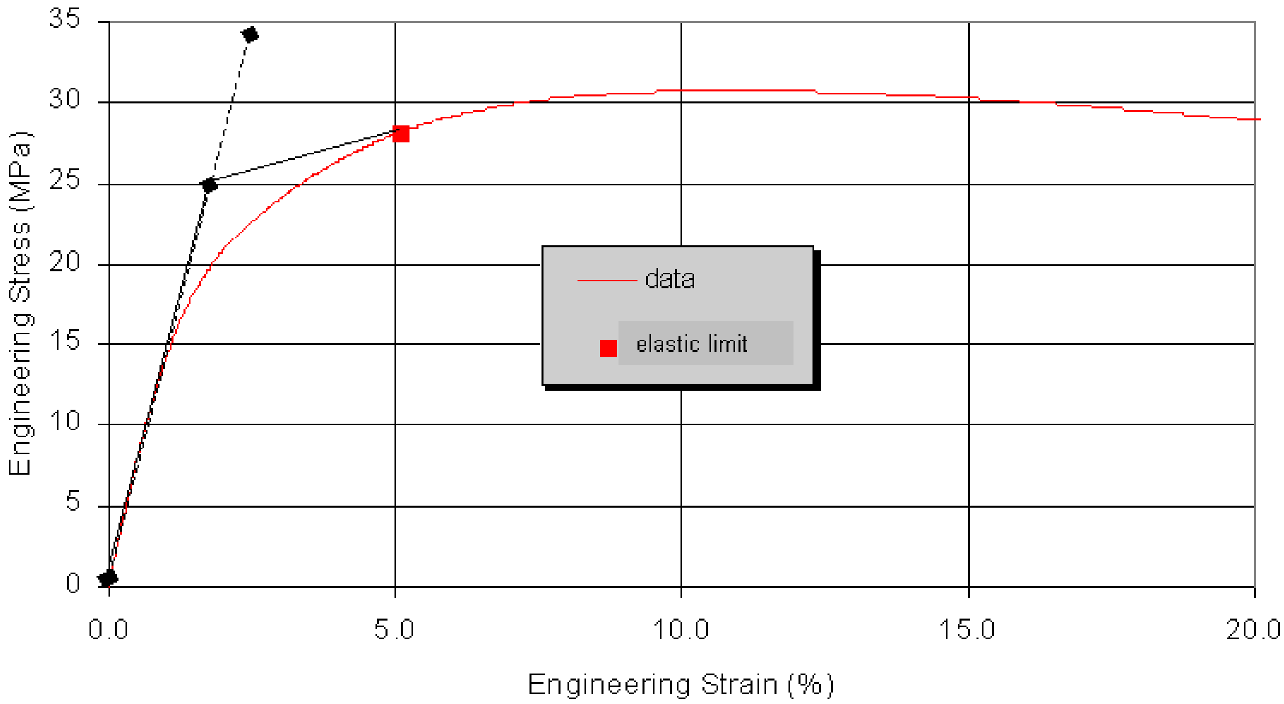


Pragmatic elasto-plasticity

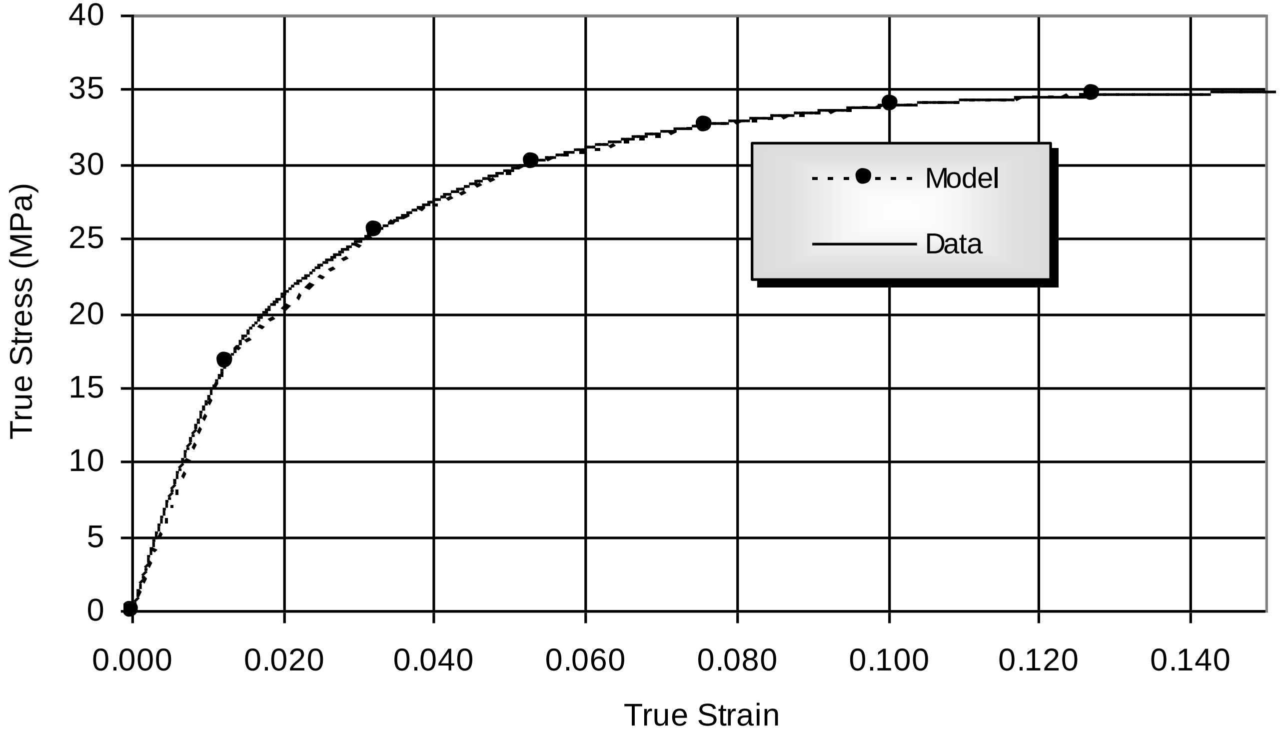



```
! Output generated by Matereality
! ANSYS MISO Model Model
! Setup and Clear existing temperatures
/PREP7
!*
MPTEMP,,,,,,,,
! MATERIAL, name=Zytel70G35HSLNC010
! Elastic Data
MPTEMP,1,296
MPDATA,EX,1,,9651841282.3487263
MPDATA,PRXY,1,,
! Stress v. Strain
TB,MISO,1,1,,,,
TBTEMP,296
TBPT,,0.0123237496888319,118946876
TBPT,,0.0147900854726353,138980406
TBPT,,0.0161685811615837,149142025
TBPT,,0.019018005835762,168320880
TBPT,,0.0205866336083883,177568160
TBPT,,0.0221528046411333,185770080
TBPT,,0.0237165266173161,193976320
TBPT,,0.0257652078860264,202264832
TBPT,,0.0278097006392672,209793928
TBPT,,0.0299470763679521,216662208
TBPT,,0.0325639908732626,222281796
TBPT,,0.0359461267734691,224859272
```

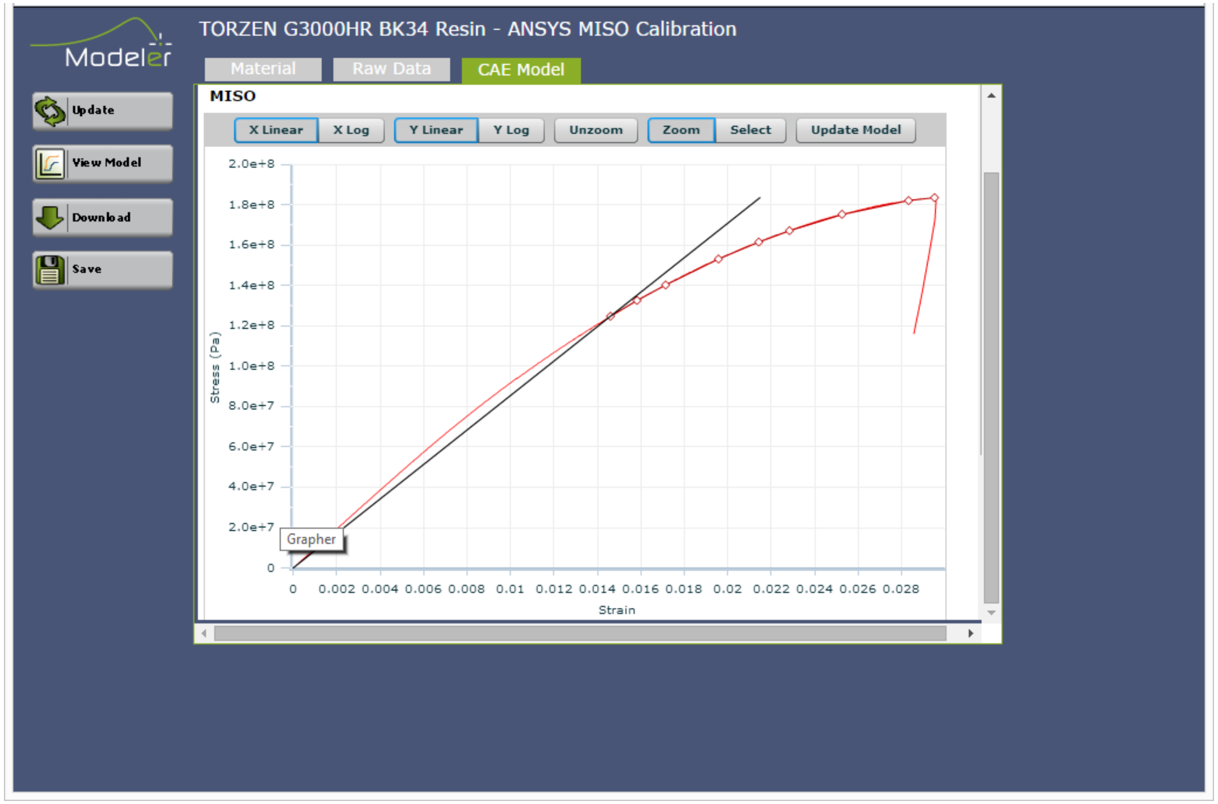
Tangent modulus basis



Secant modulus basis

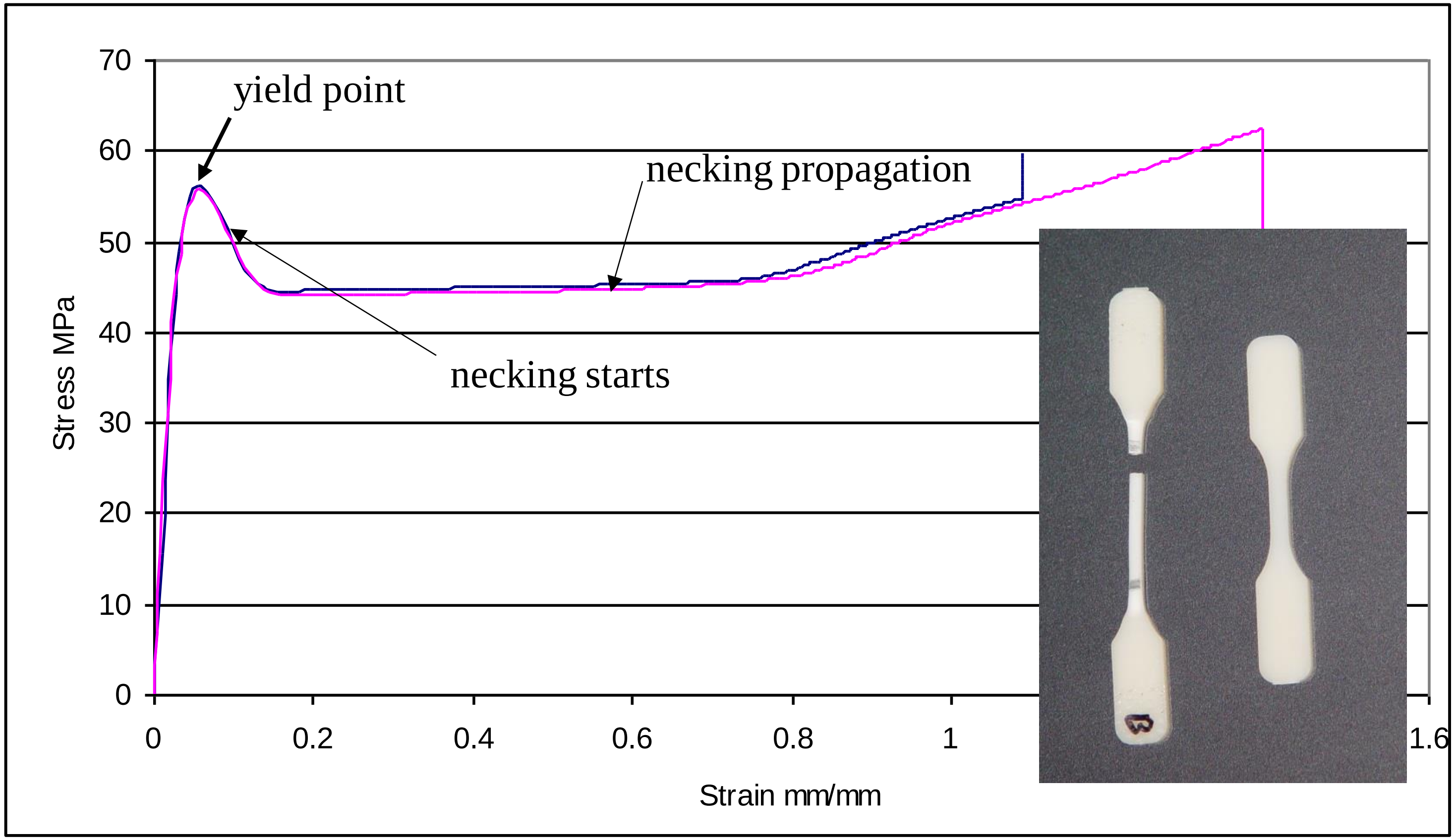


Fidelity to plastic point



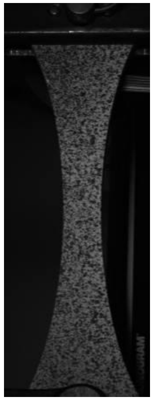
Fidelity to curve shape

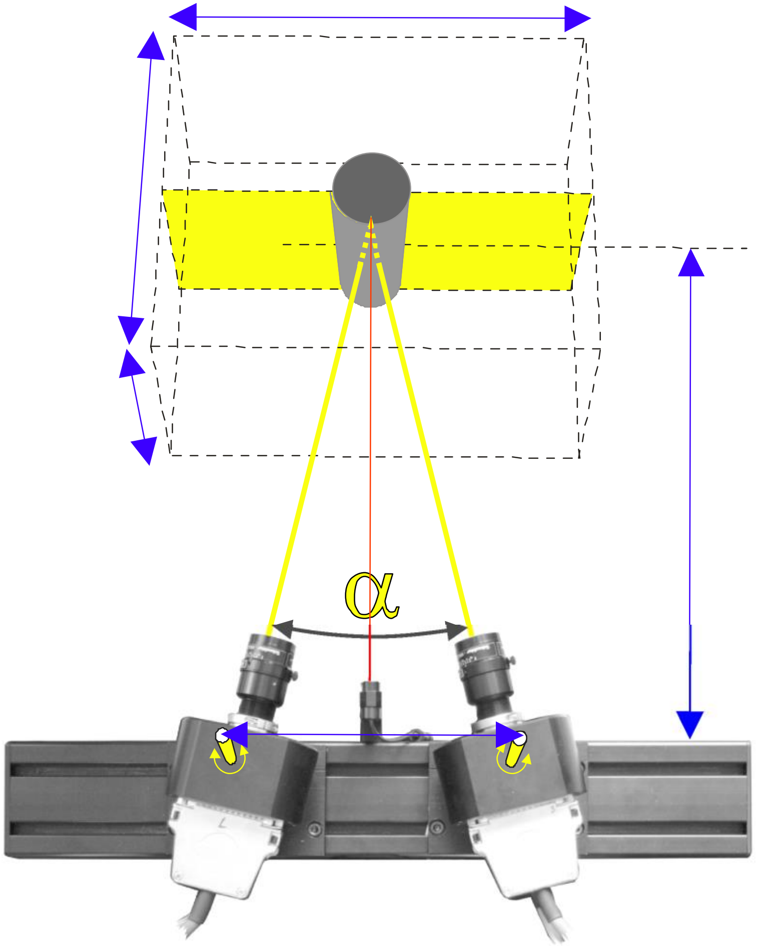
Understanding post-yield ductile behavior



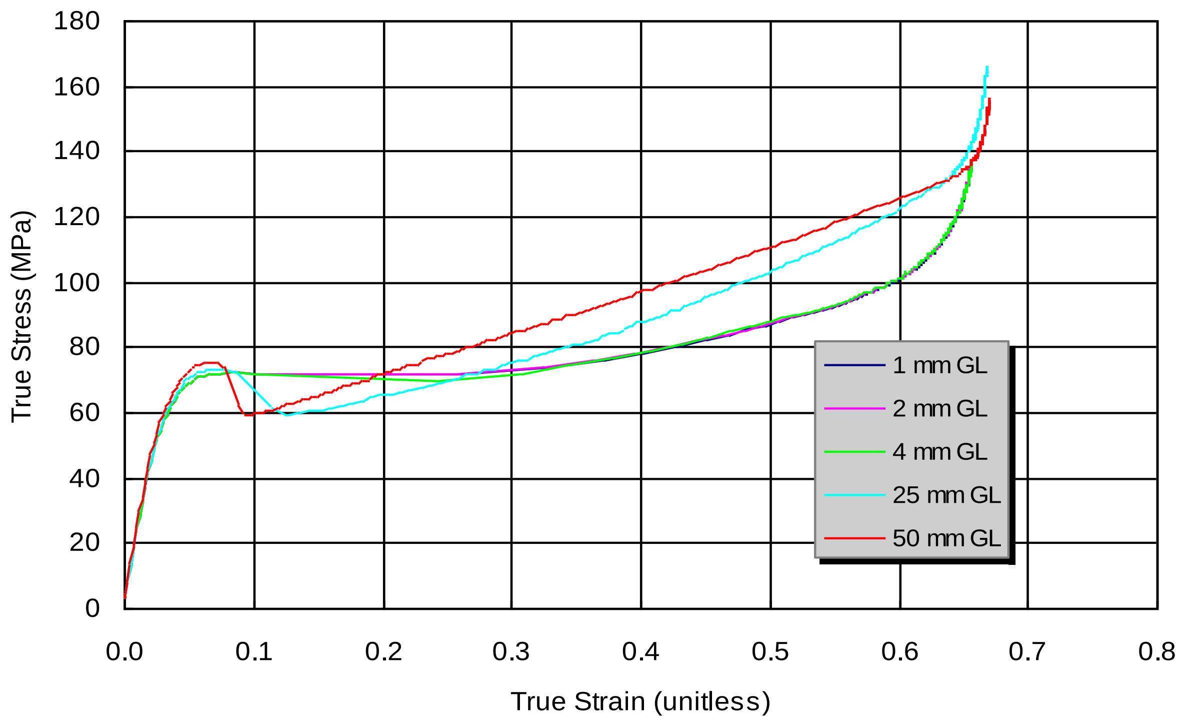
Digital Image Correlation(DIC)

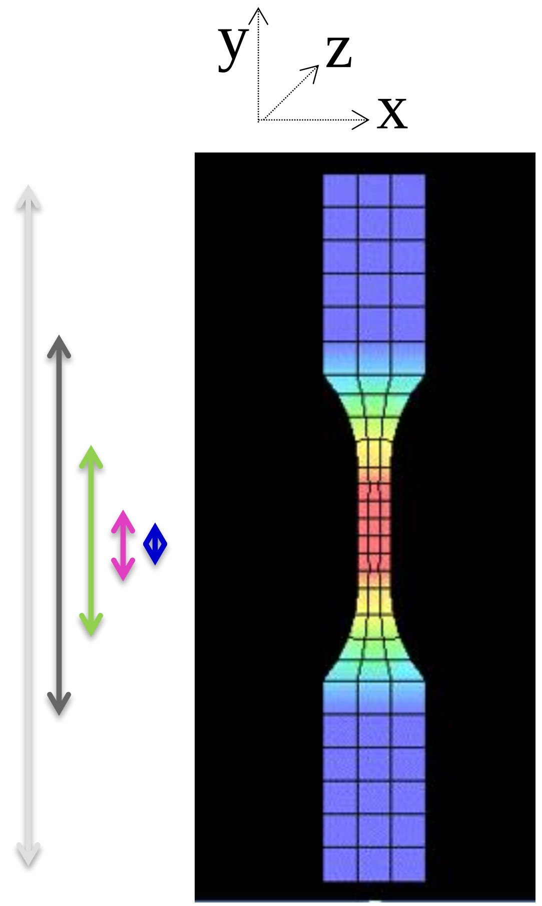
- Stereo camera system (ARAMIS)
- Simultaneous xyz dimension change
- Complete surface is measured
- Post-measurement selection of region of interest





Measuring post-yield stress-strain





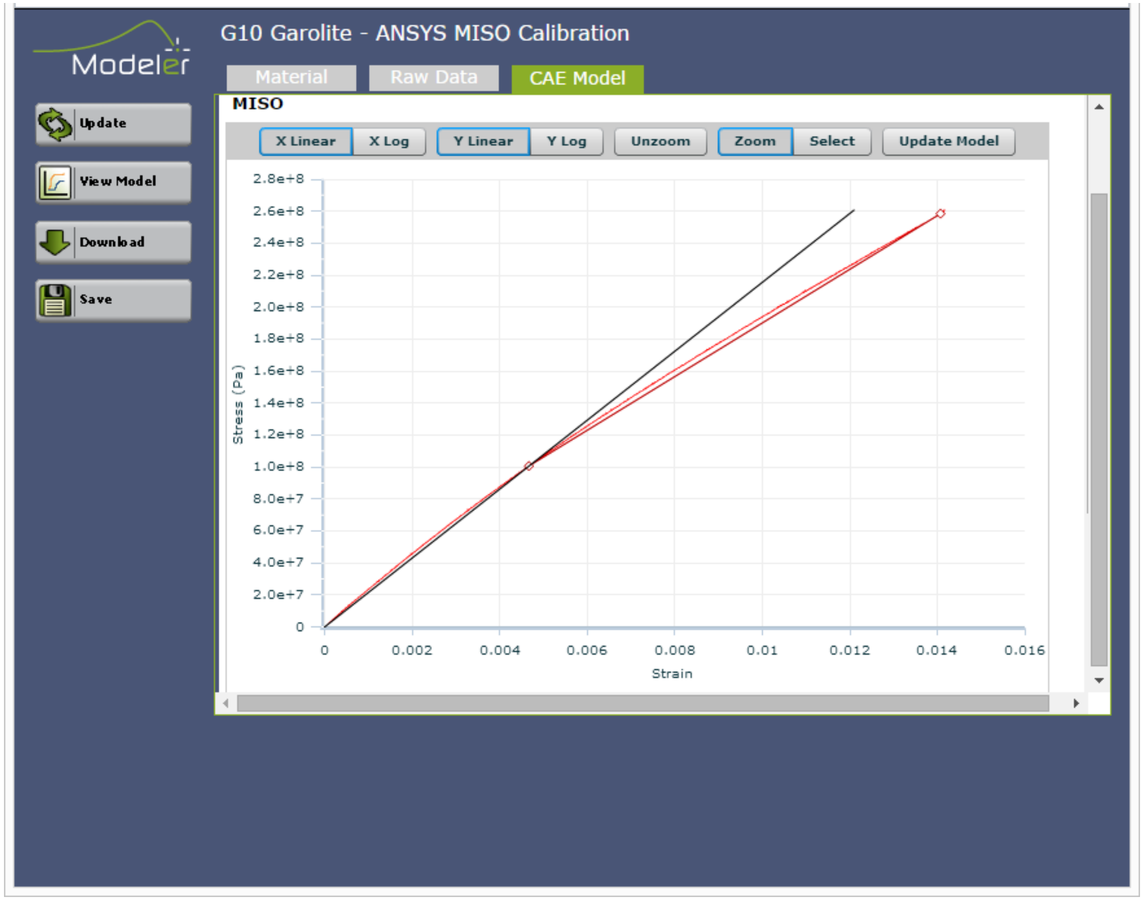
Modeling up to yield

Modeling post-yield

Modeling brittle polymers

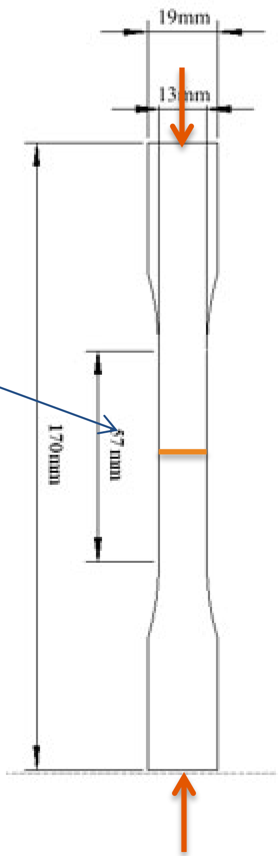
- Isotropic
  - PMMA, PS
- Anisotropic/Orthotropic
  - Fabric laminates
  - Fiber-filled plastics

Linear elastic or bilinear (BISO)



Handling weld line failure

- Test double-gated tensile bars
  - Actual process conditions
  - Obtain tensile strength at failure
- Now, obtain weld line location from injection mold analysis
- Model weld line with cohesive element
- Apply fail strength to element



Validation of elastic-plastic material models

- Create a process to validate solver+ simulation inputs before real-life application
- Benefits
  - Increase confidence
  - Reduce risk
  - Save time

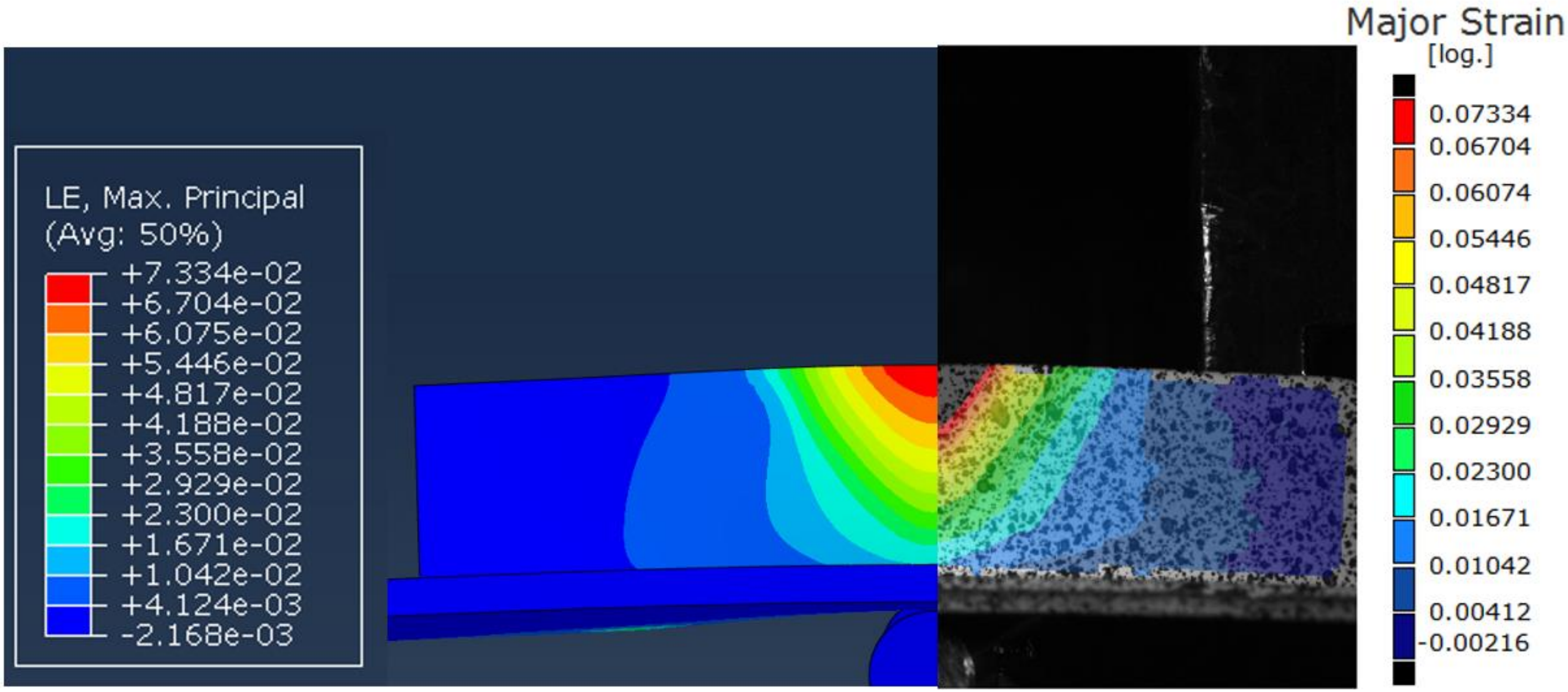
CAETestBench validation mechanism

- Use a standardized geometry
  - May not be real-life part
- Test must be ‘perfect’
  - Boundary conditions can be correctly simulated
  - Load case can be correctly simulated
- Comparison
  - Obtain test output that is also available in simulation
  - For example, DIC strain pattern, force v. time…

Overview of this validation

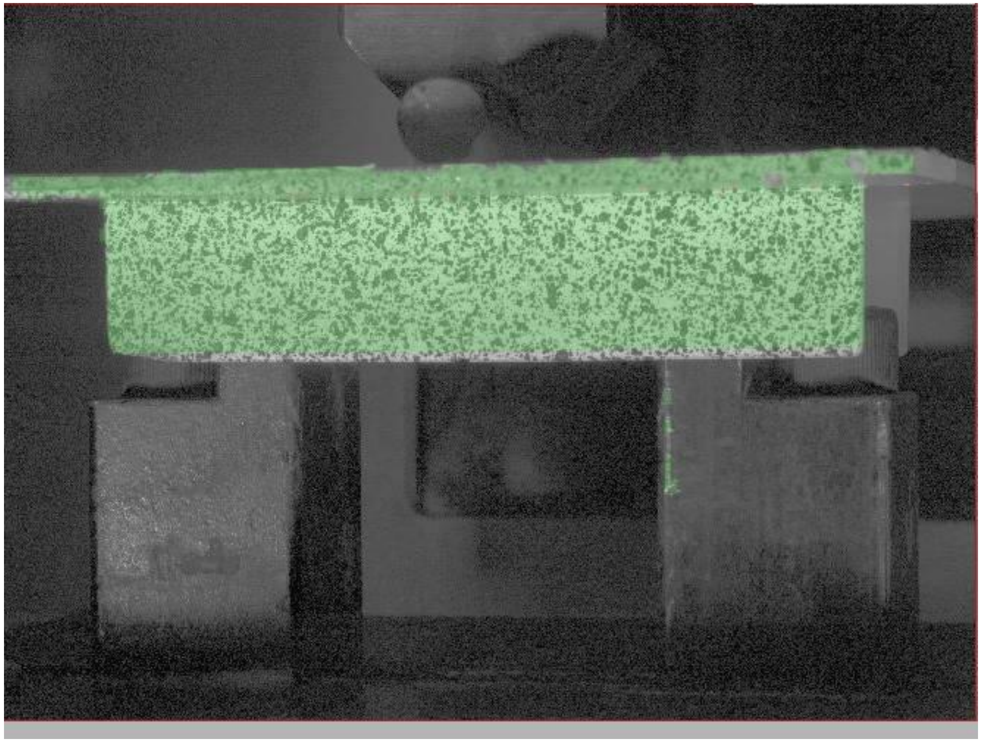
- Measure properties
- Obtain material model parameters
- Perform open loop validation
  - Not a test used to create the material model
- Simulate and compare to experiment with DIC
- Quantify simulation accuracy

Case 1: ribbed plaque 3-point bend



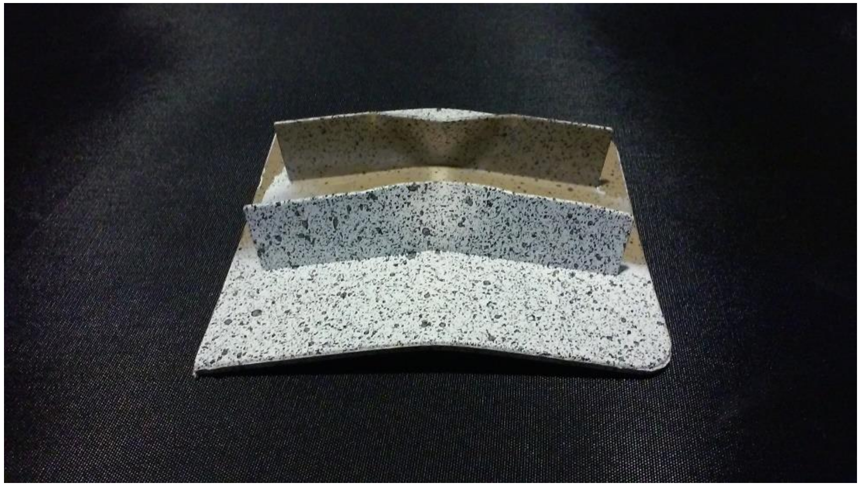
Test setup

- Instron 8872 UTM
- 1 mm/min displacement of nose
- Apply speckle pattern to part to allow use of DIC strain capture
- Two-camera DIC to capture 3D strain



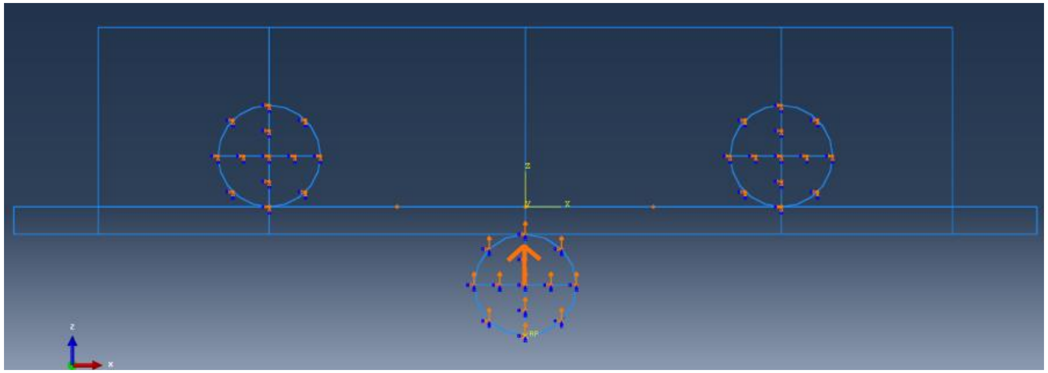
Deformed part

- Loaded past yield
- Observed symmetric buckling inwards
- Slight indentation of support pins causing stress whitening on the reverse side of the part



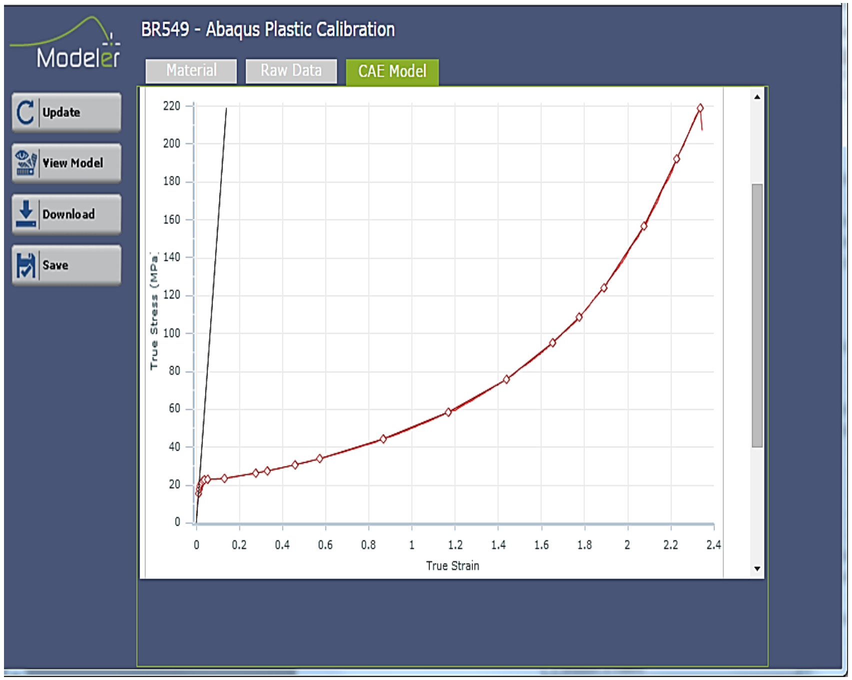
Simulation setup

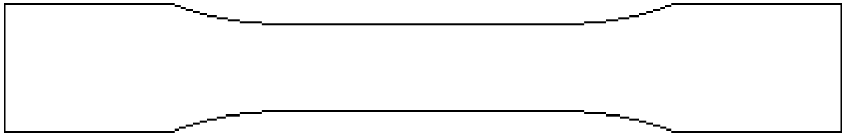
- Nose pin:
  - Constrained in all DOF with 2.5mm displaced in Z (quasi-static)
- Fixed support pins
- Part geometry constrained to prevent rigid body movement in the x y direction
- Contact applied in initial step
- Mesh: 2.25 mm^2



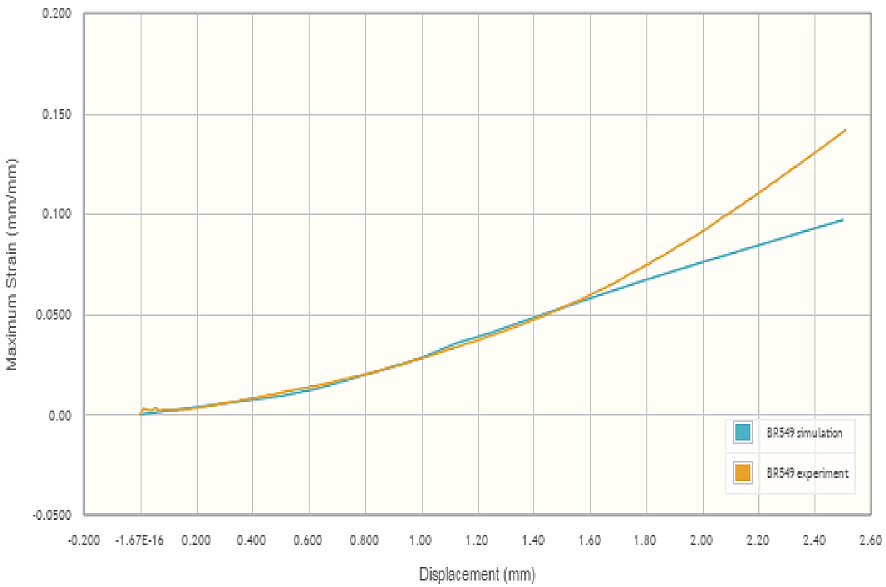
Material model

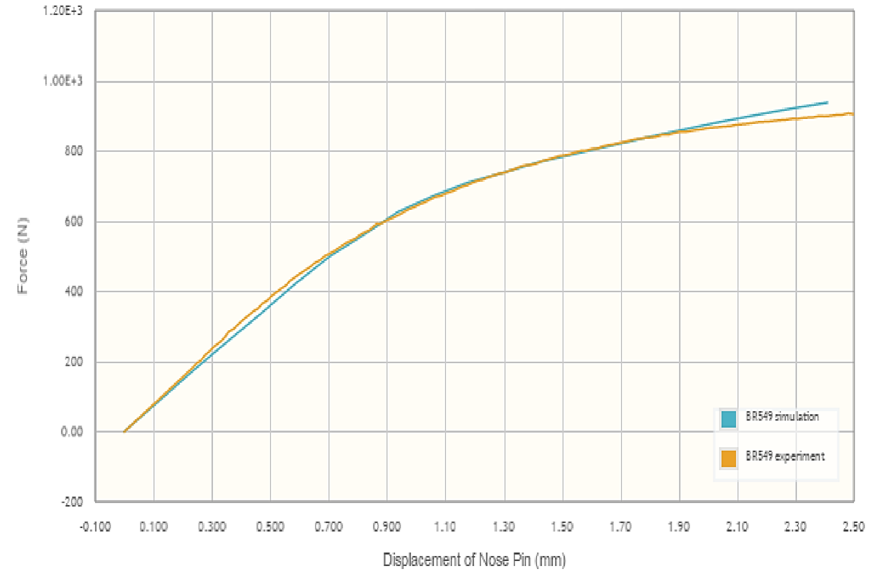
- Tensile and density tests
  - Elastic
    - E = 1572 [MPa]
    - υ = 0.29
  - Plastic curve (right)
  - Density
    - ρ = 7.9 E-06 [tonne/mm3]
- Measured at QS speeds





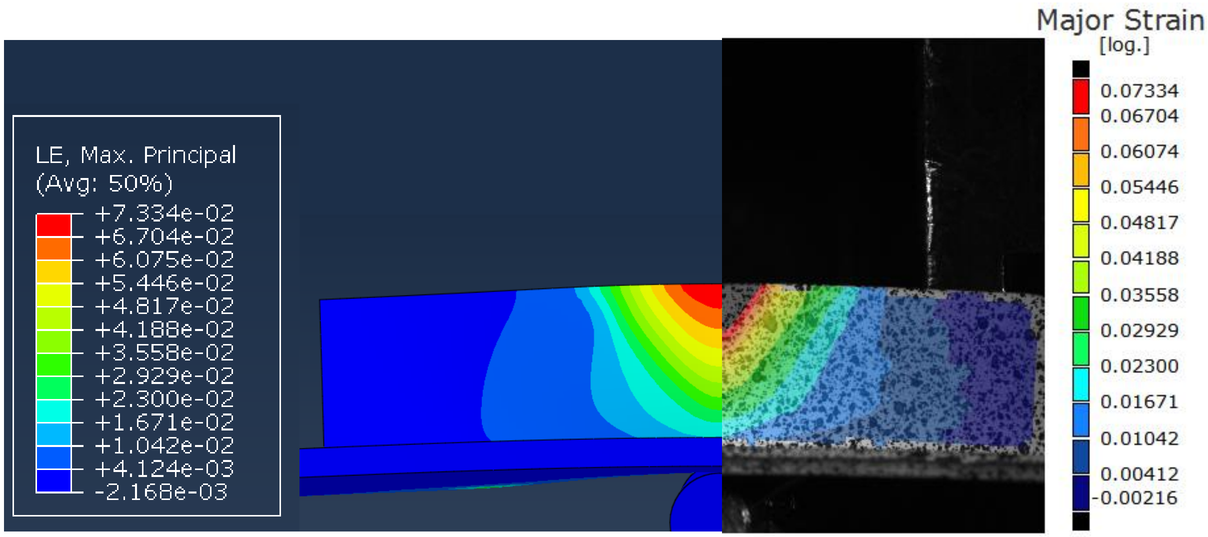
Comparison: simulation to experiment





- Strain vs. Displacement
  - Diverges after 2 mm
- Force vs. Displacement
  - Similar response throughout

Side-by-side comparison of strains



- Matched the strains in the legend for the DIC image for easy comparison
- The lower strains match closely but the shape of the higher strains on the experiment ends up more triangular than the simulation

Results

- Abaqus/Explicit models the elasto-plastic behavior of a ductile plastic up to moderate strains when complex modes of deformation are present (complex material model)
- At larger deformations the model deteriorates due to limitations of the elastic-plastic model (Lobo 2006)
- Limits of simulation validity can be applied. Deformations beyond 2 mm may produce inaccurate strain prediction.
- Although strains showed inaccuracy, force values were accurate to higher deformations.

Conclusions

- Plastics are complex
- Properties change considerably over product operating range
- Using correct material data can improve simulation accuracy
- Existing material models can be reasonably adapted to capture material behavior