Insights into the Simulation of Failure of Ductile Plastics

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automotive CAE Grand Challenge 2017
April 5–6, 2017

Company Introduction

DatapointLabs
technical center for materials

matereality
software for materials

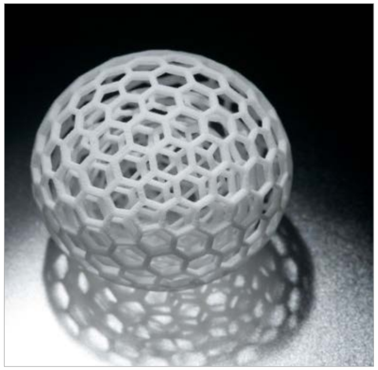
TestPaks
testing for simulation

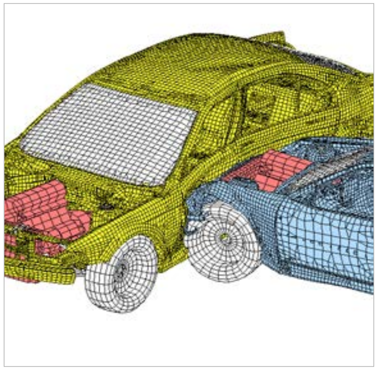
picsci
electronic lab notebooks

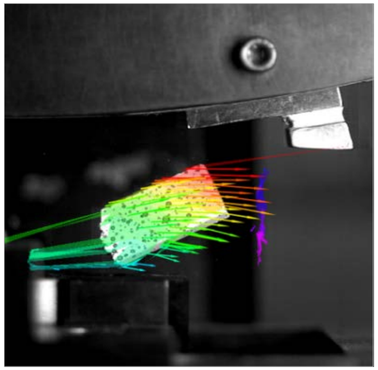
knowmats
materials in simulation

Mission

We strengthen the materials core of manufacturing enterprises to facilitate their use of new materials, novel manufacturing processes, and simulation-based product development.







Outline

Process

- **Use best in class test methods for properties**
- **Apply candidate material models**
- **Validate against high reliability complex experiments (DIC)**

Presentation

- **Identification of factors**
- **Test methods used**
- **Findings & observations**
- **Impact on simulation**

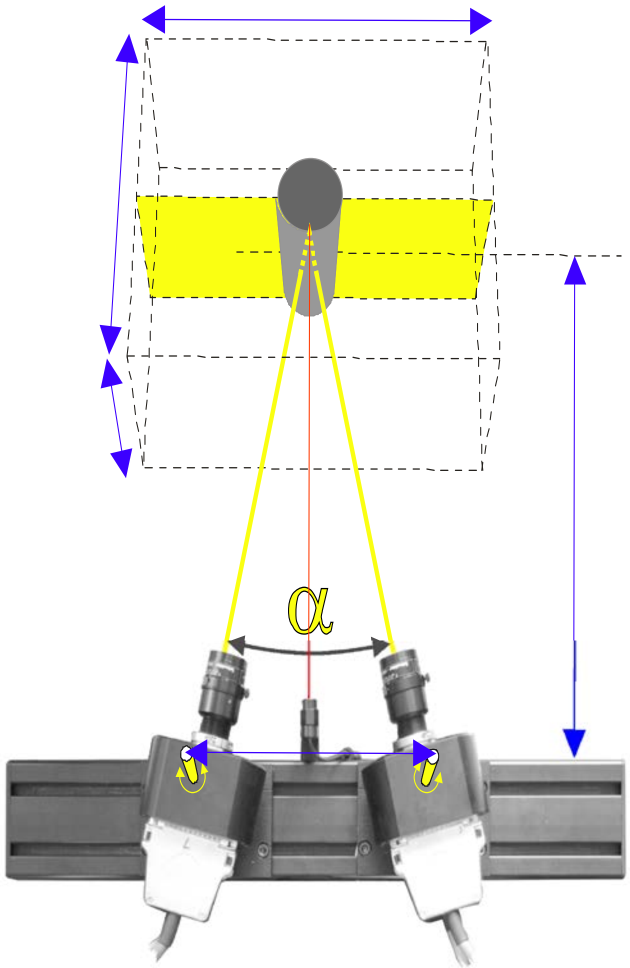
Factors

- **Non-linear elasticity**
- **Deviatoric plastic strain occurs prior to yield Lobo& Hurtado (2006)**
- **No increase in volume strain prior to yield Lobo, Croop, &Roy (2013)**
- **Onset of volumetric straining at yield Lobo, Croop, &Roy (2013)**
- **Strain localization coincides with onset of volumetric straining**
- **Yield surface is not von Mises**
- **Volumetric and deviatoric behavior in flow region**
- **Failure is accompanied by rapid volumetric expansion**

Other Factors not considered here

- **Visco-elastic (time-based behavior)**
- **Property change over product operational temperature**
- **Property change with environmental exposure**

DIC Operation



DIC Principle

- **Speckle pattern is broken into facets (elements)**
- **Speckle pattern is tracked frame to frame**
- **Calibration of a volume is performed through measuring calibration panel in various orientations in the test space.**
- **Strains can be captured on the micro-strain level**
- **Strain field can be mapped over the actual part image**

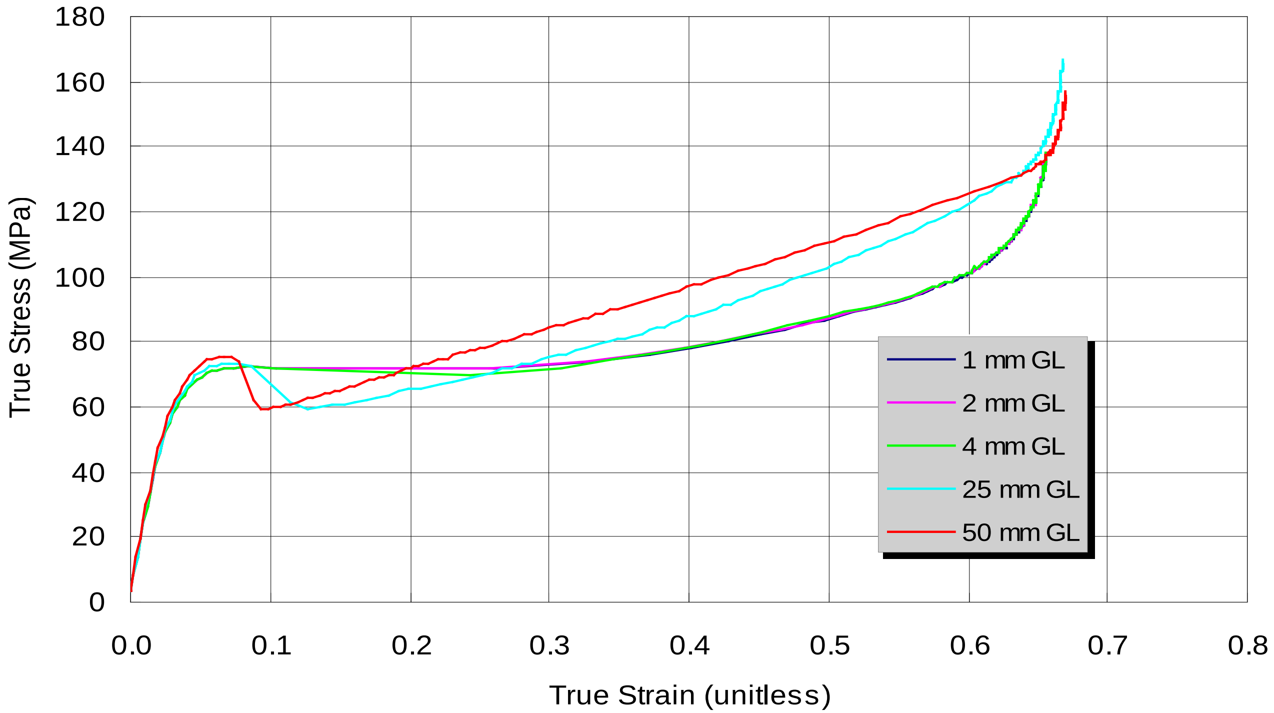
DIC Utilization in this work

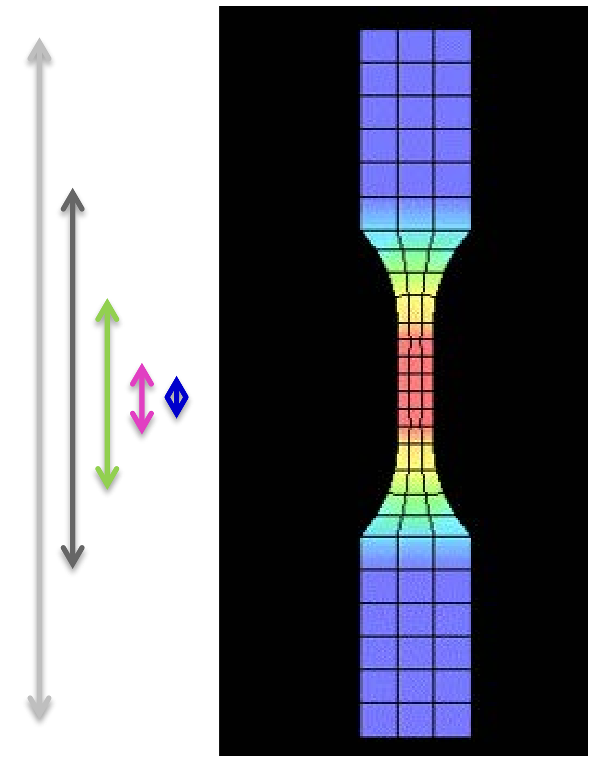
- **Local y, x, z strains are measured**
- **Surface strains for validation of simulation**

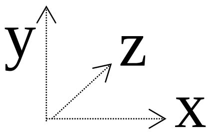
carhs.

Obtaining true stress-strain with localized DIC measurement

Effect of gage length selection



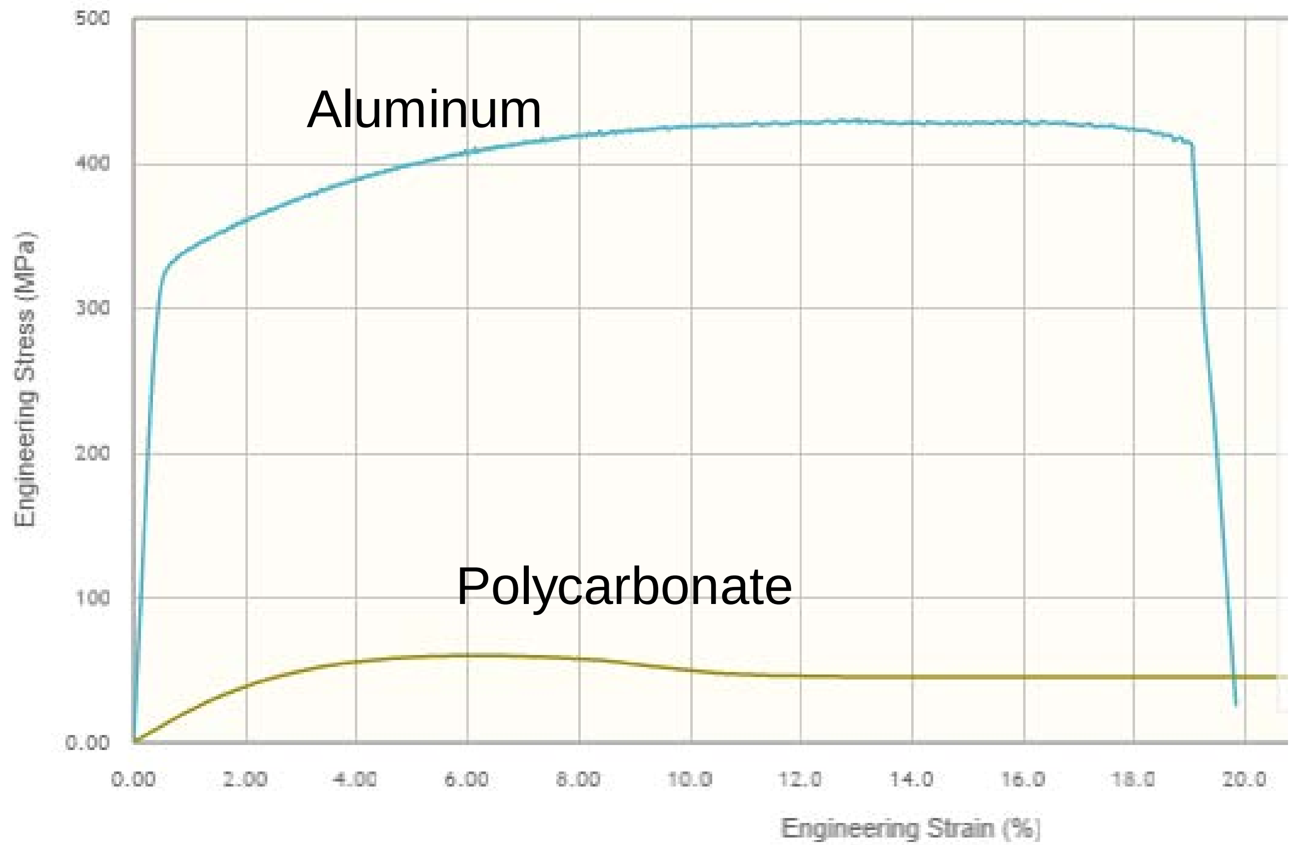




Non-linear elasticity in ductile plastics

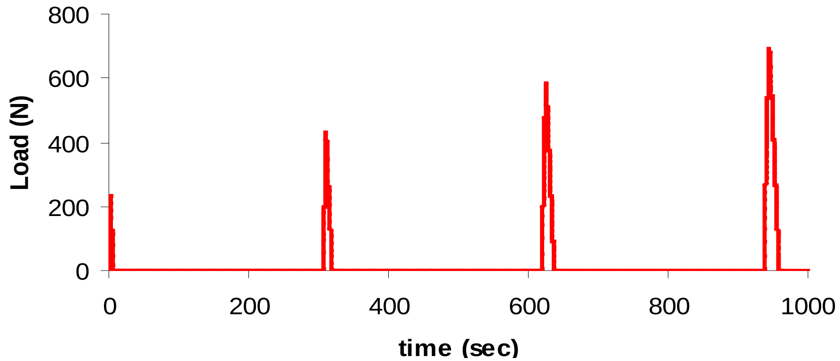
Absence of linear elastic region (unlike metals)

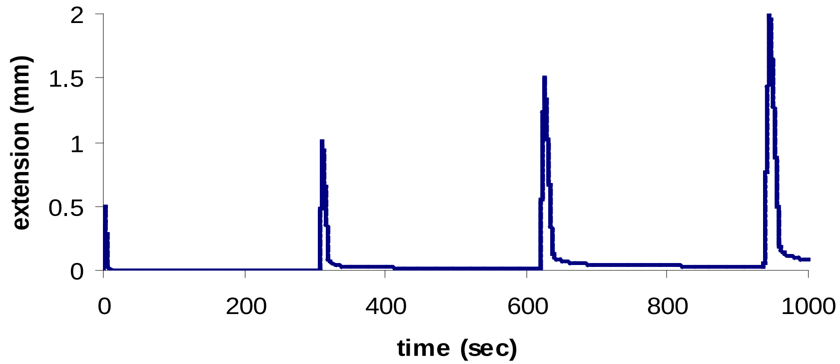
Presence of visco-elastic behavior (not considered in this work)

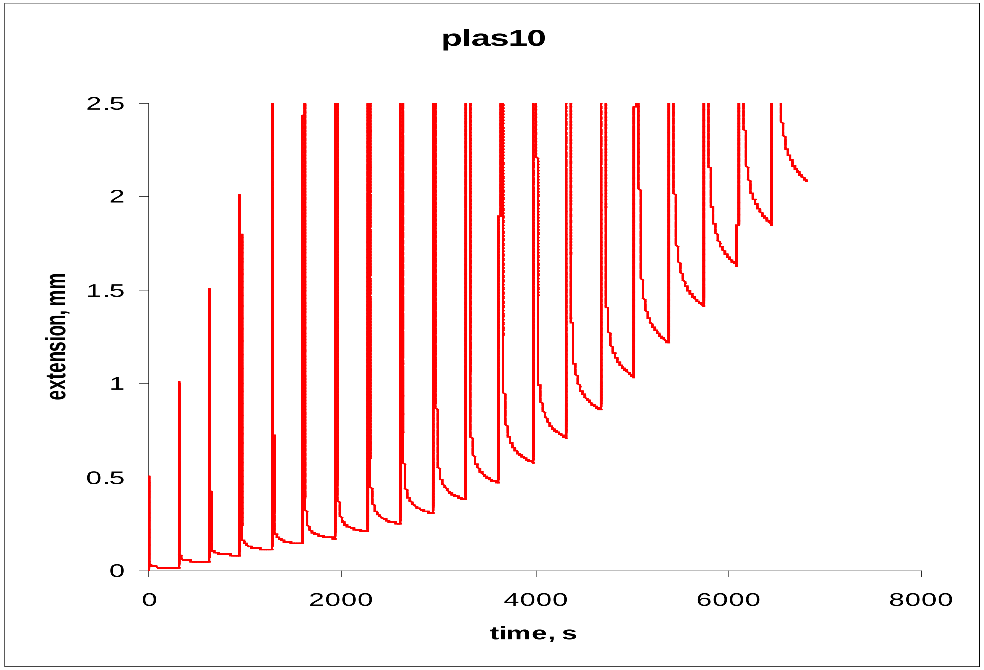


Determining onset of plasticity

Incremental increasing load-relaxation cycles: capture unrecovered strain







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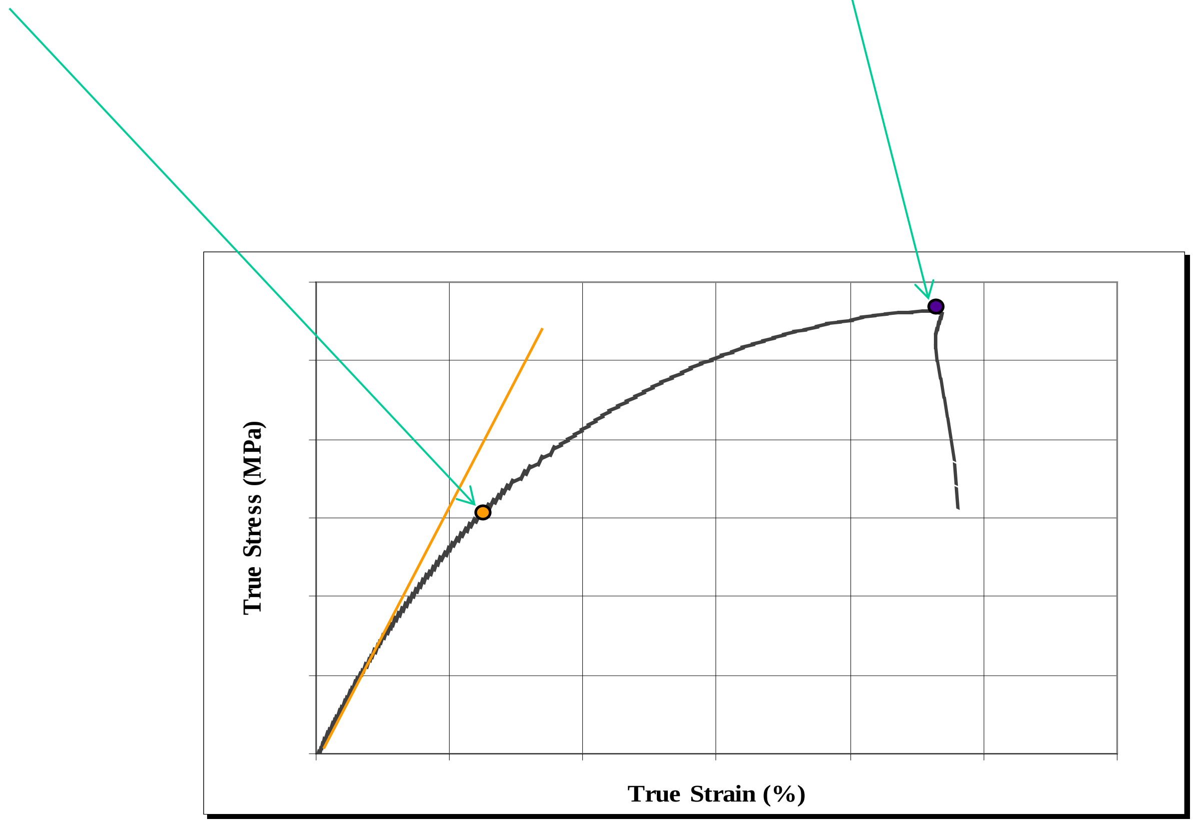
The onset of deviatoric straining

Non-linear elastic limit occurs before the yield point



Elasto-plastic model limitations

Unable to capture non-linear elastic behavior

Cannot correctly capture deviatoric strain prior to yield

Cannot capture post-yield volumetric strain

Elasto-plastic model validation

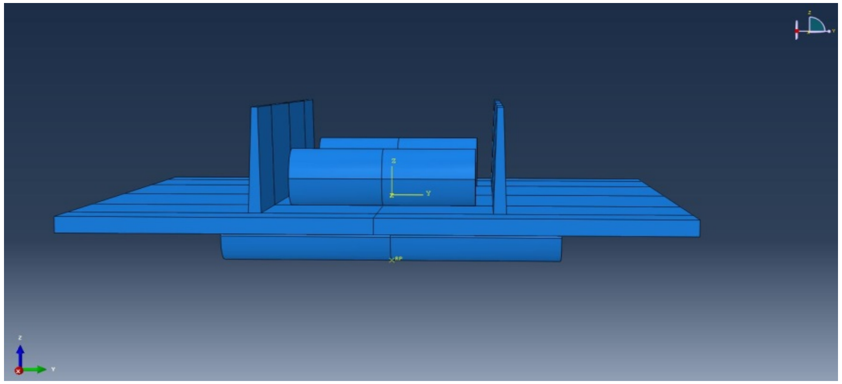
Instron 8872 universal testing machine (UTM)

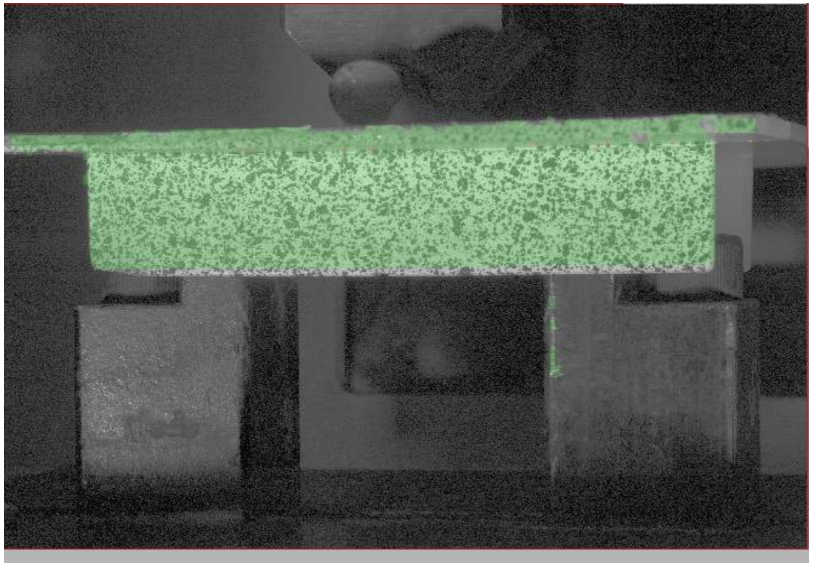
1 mm/min displacement of nose

Apply speckle patter to part to allow use of DIC strain capture

Two camera DIC to capture

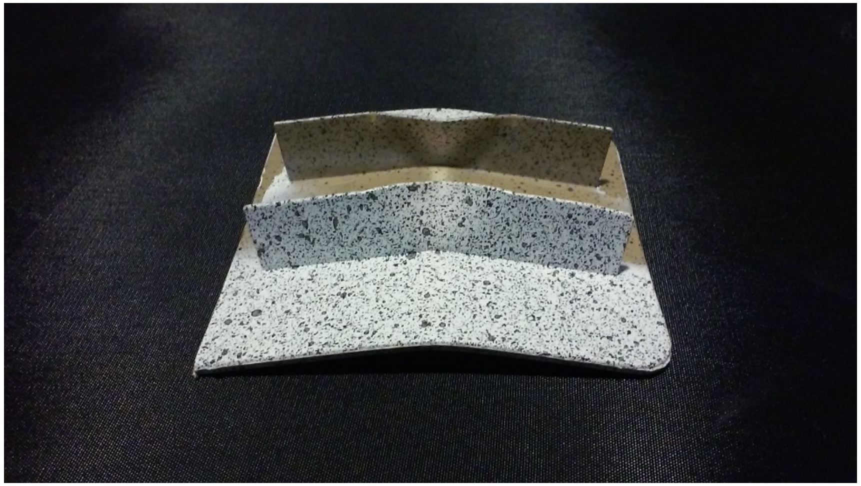
- 3D strain





Deformed Part

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

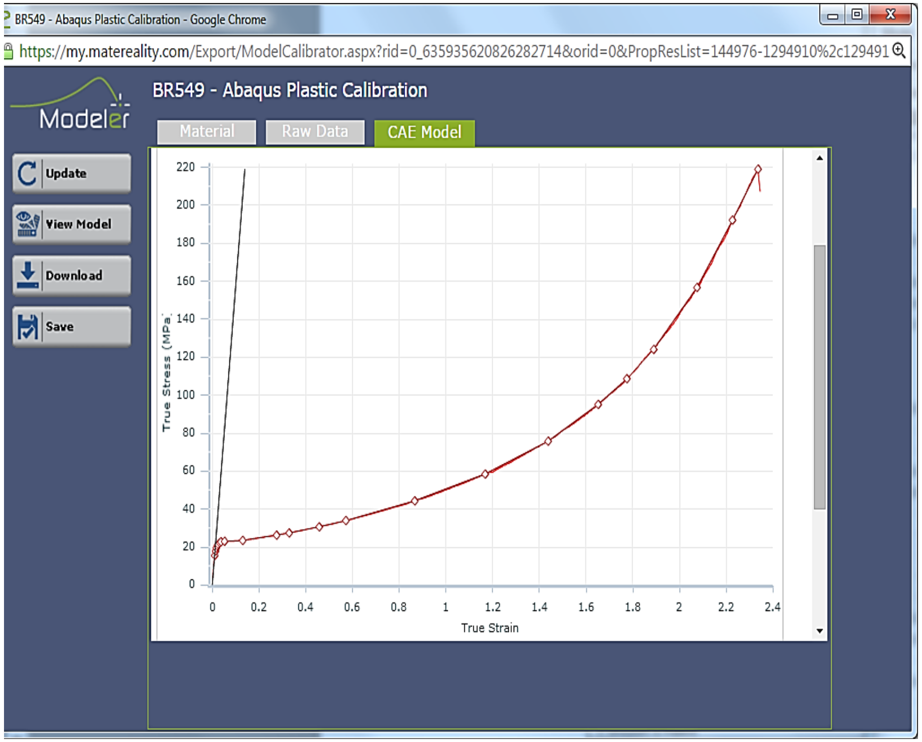


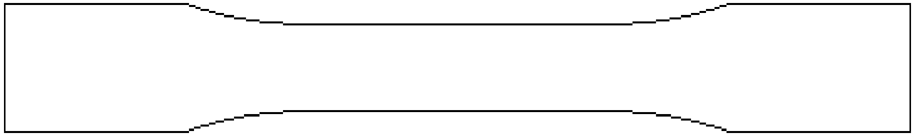
Simulation with Abaqus: material model

Polypropylene

- **Tensile and Density Test**
- **Elastic**
  - *E = 1572 [MPa]*
  - *υ = 0.29*
- **Plastic curve (Right)**
- **Density**
  - *ρ = 7.9 E-06 [tonne/mm3]*

Measured at QS speeds





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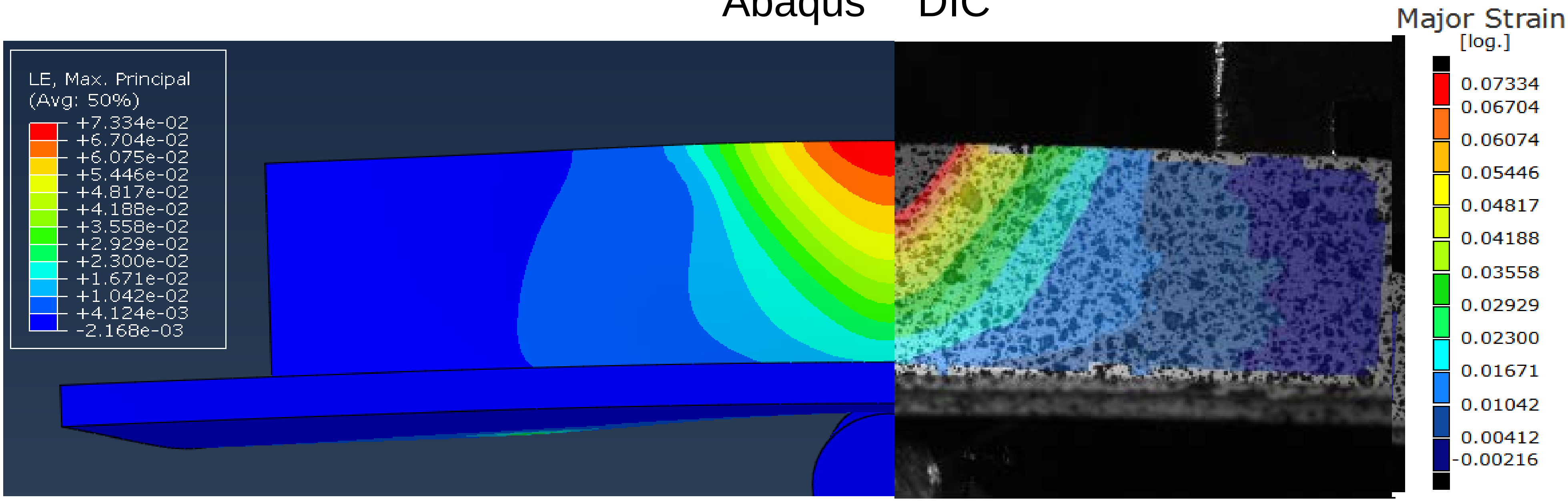
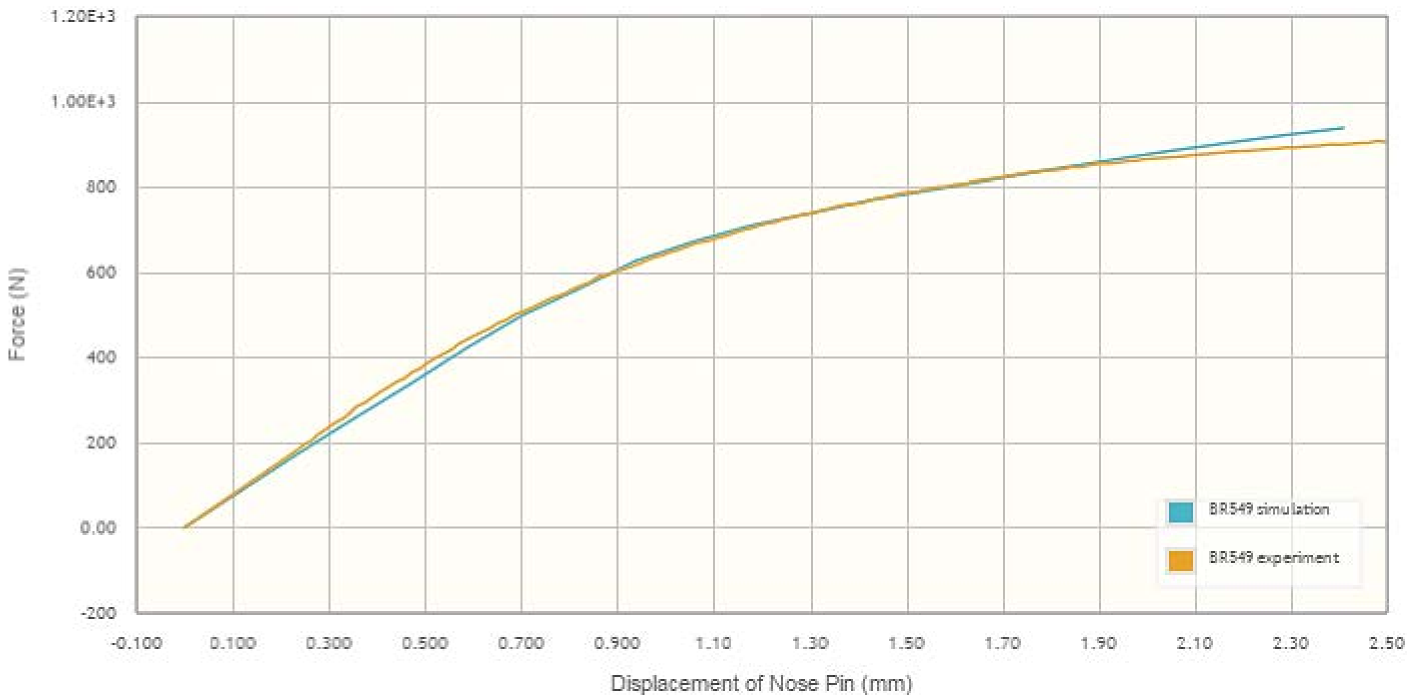
Strain field validation

Abaqus DIC



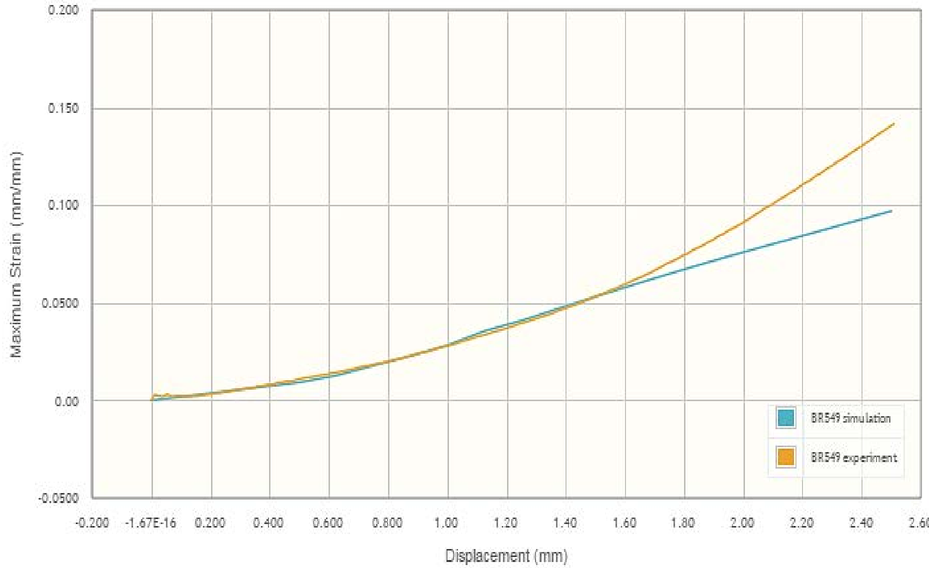
Comparison of Simulation to Experiment

- Force vs. loading nose displacement
  - **Similar response throughout**



DIC Comparison of Simulation to Experiment

- Local strain vs. Displacement
  - **Diverges after 2 mm**
  - **Corresponds to yield on stress-strain curve**



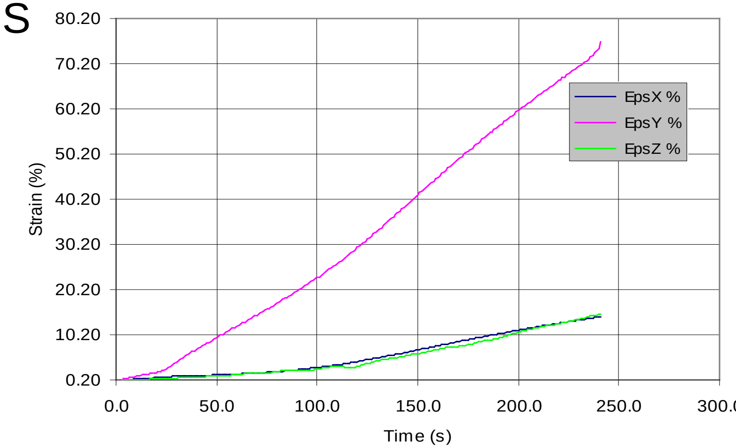
POST YIELD BEHAVIOR

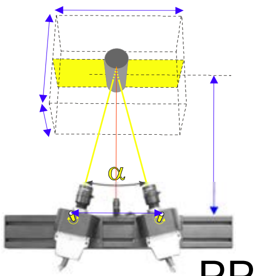
3D Stress-strain measurements for plastics

Actual measurements in 3D

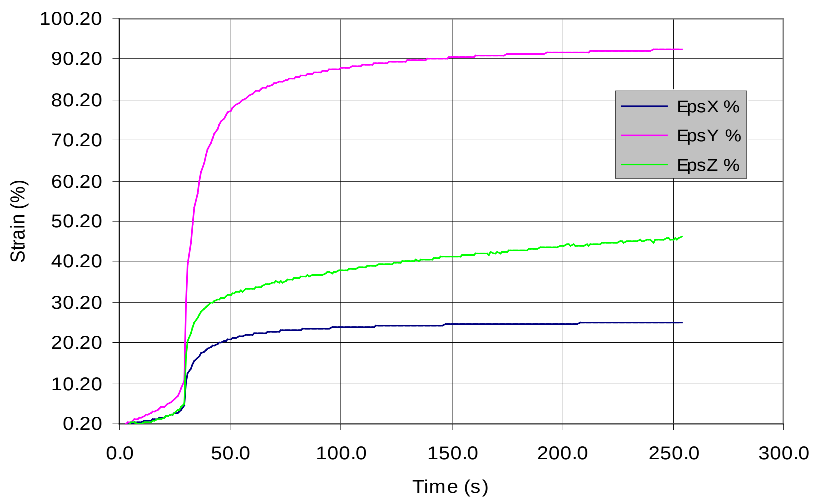
Local y, x, z strains are measured

ABS

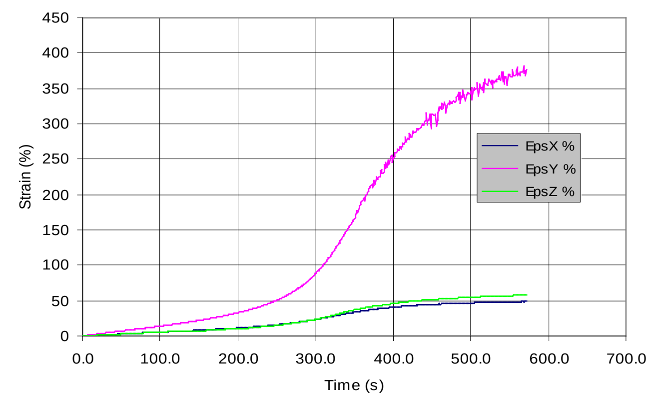




PC



PP



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True stress v. volumetric strain and true strain

True stress calculated from x-z strain

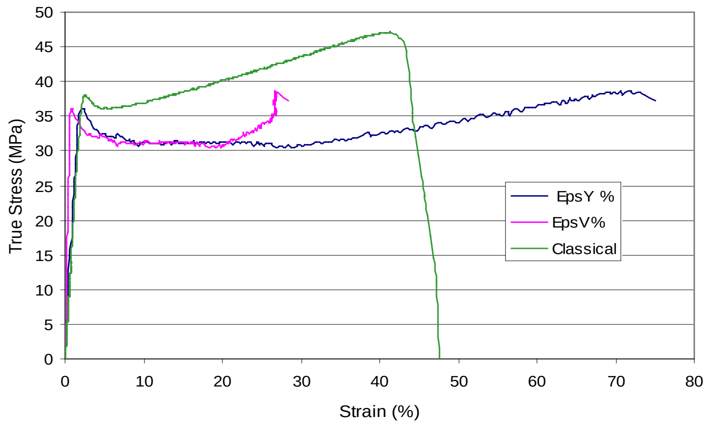
Y-strain is localized, true

Volumetric strain obtained from YXZ strain

Fail strain is measured

Classical stress-strain does not correlate

ABS



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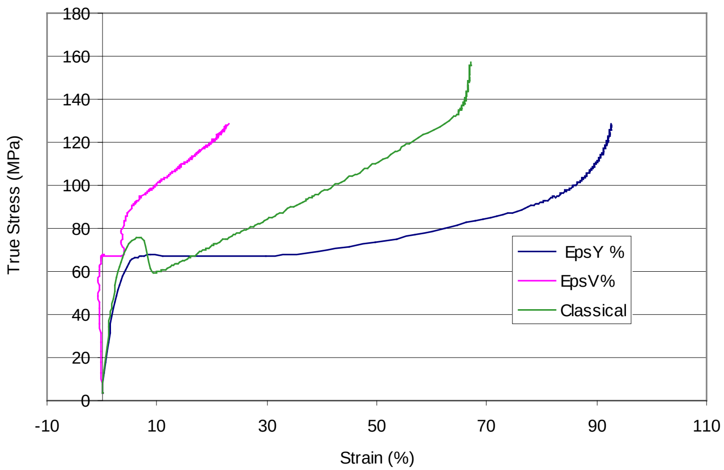

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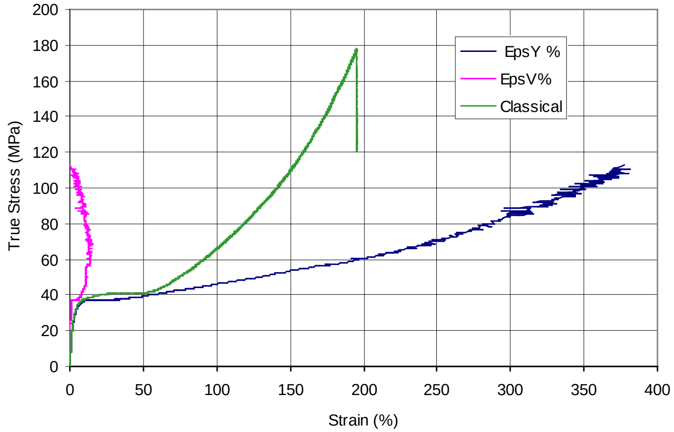


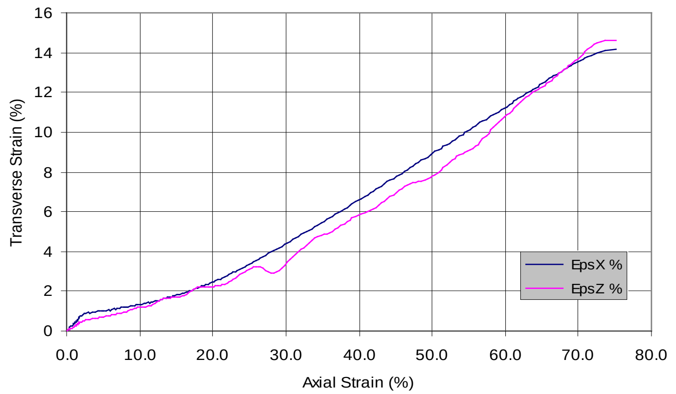
extruded sheets

Transverse v. axial strain

X and z strains may not coincide

May depend on material and processing

ABS



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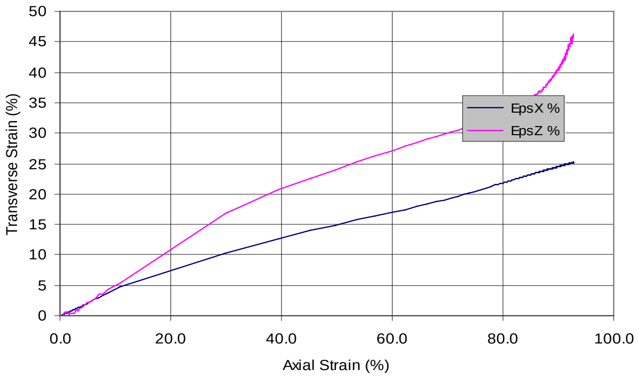

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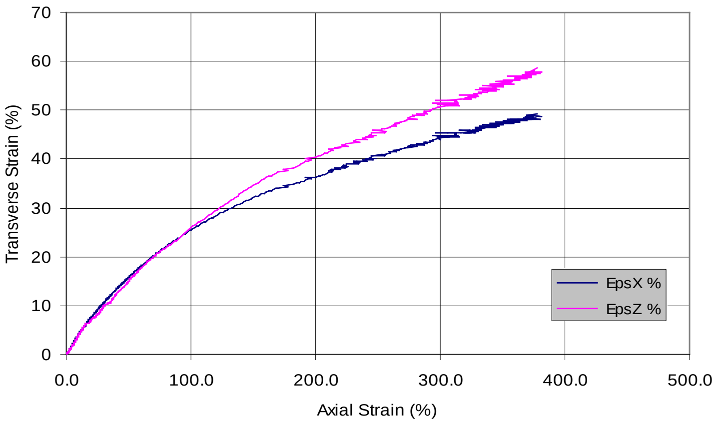
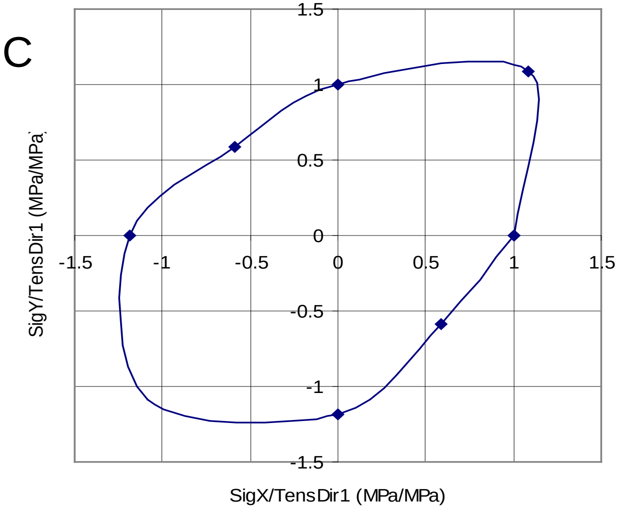


Yield behavior in plastics

Yield surface – Available test modes

- **Tensile**
- **Compressive (CLC)**
- **Shear (classical or Iosipescu)**
- **Biaxial**

PC



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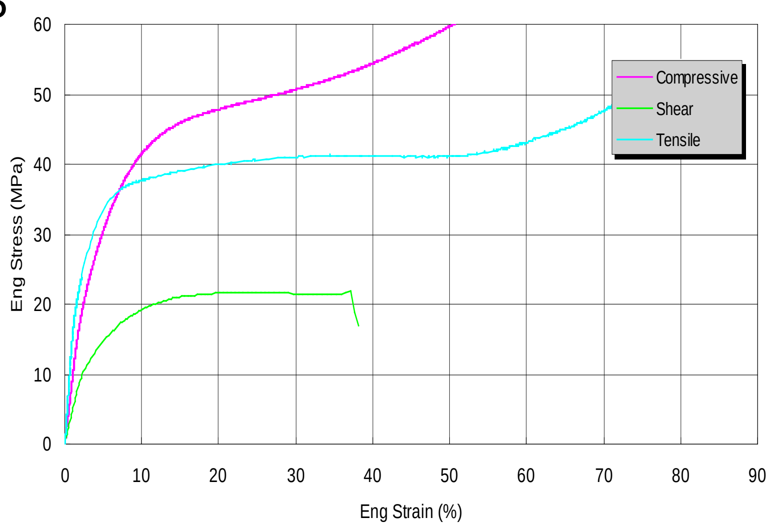

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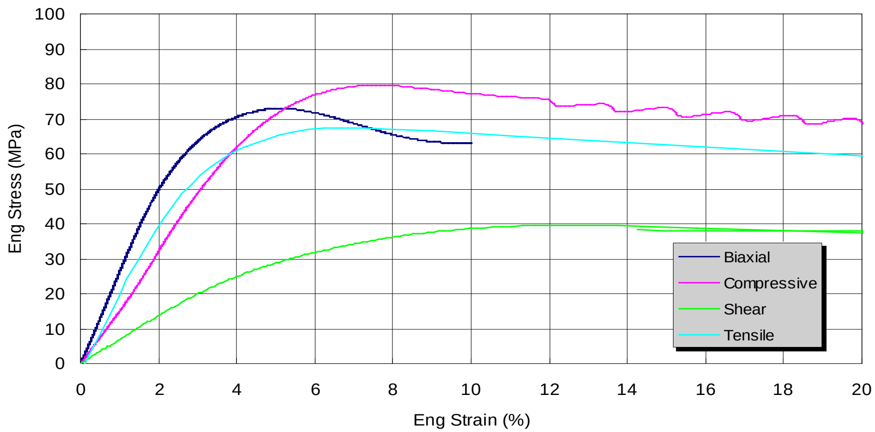
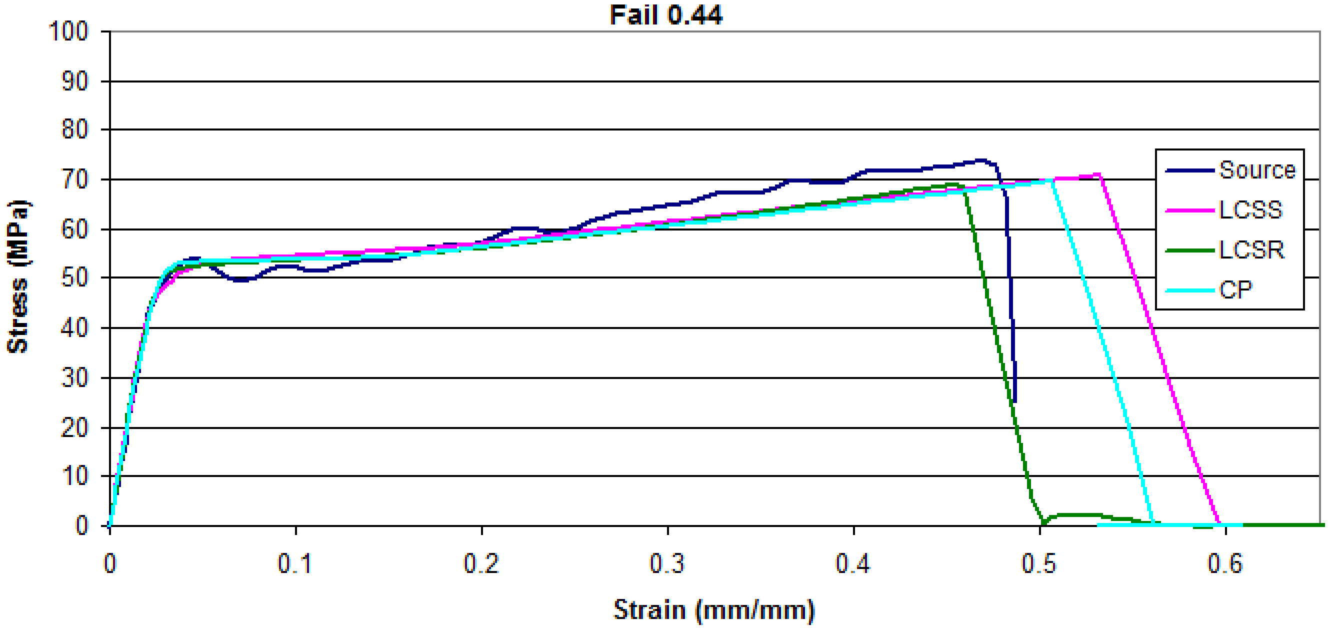


Tensile experiment validation with measured FAIL strain

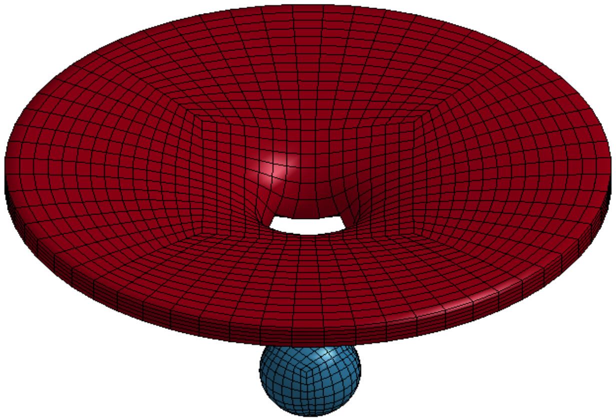
ABS, LS-DYNA MAT_024, 100/s, FAIL at 0.44

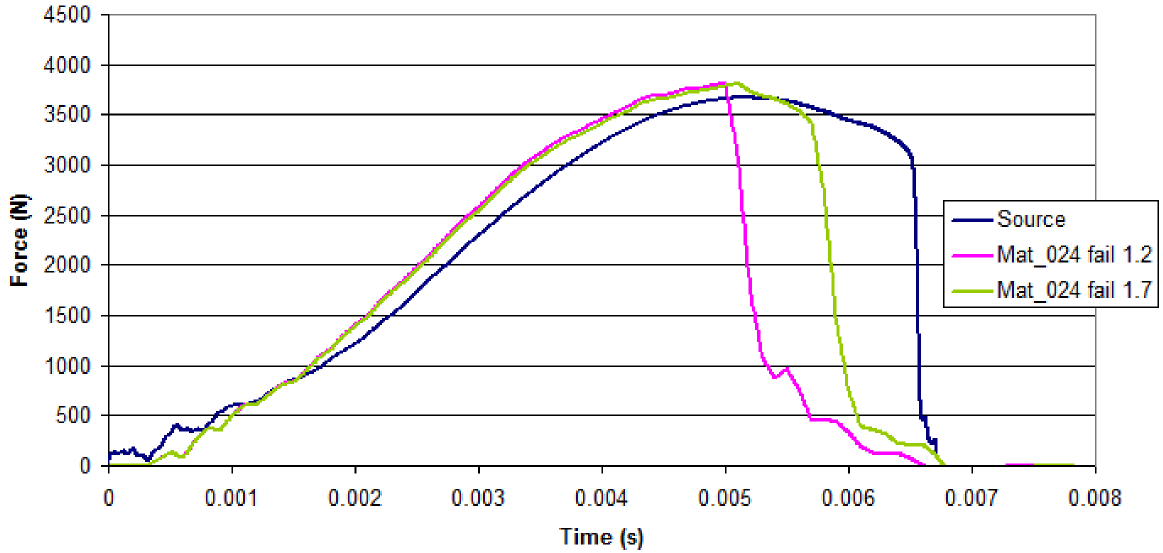


Dart impact validation for ABS

LS-DYNA MAT_024

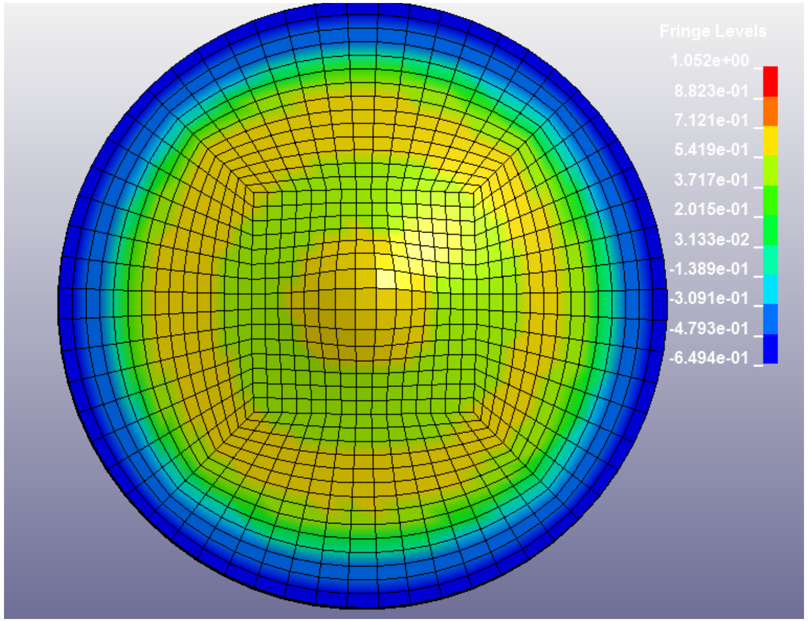
- **Failure strain is arbitrary**
- **Much greater than tensile fail strain**
- **Model extrapolation is needed**
- **Model cannot predict softening behavior**





Rationale for using larger fail strain

Falling dart is a biaxial experiment



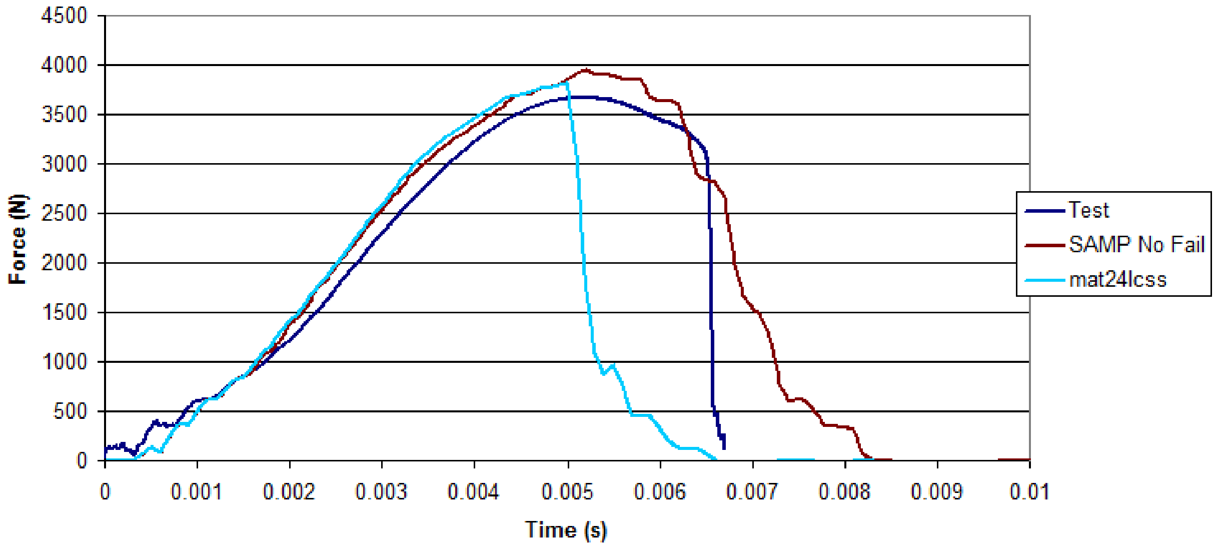
Measured biaxial fail strain for ABS is 1.8

(Ericchsen Cupping experiment combined with DIC, with advice from Dr. H. Gese.)

Incorporating volumetric behavior

SAMP material model

Post-yield volumetric behavior converted to plastic Poisson's ratio

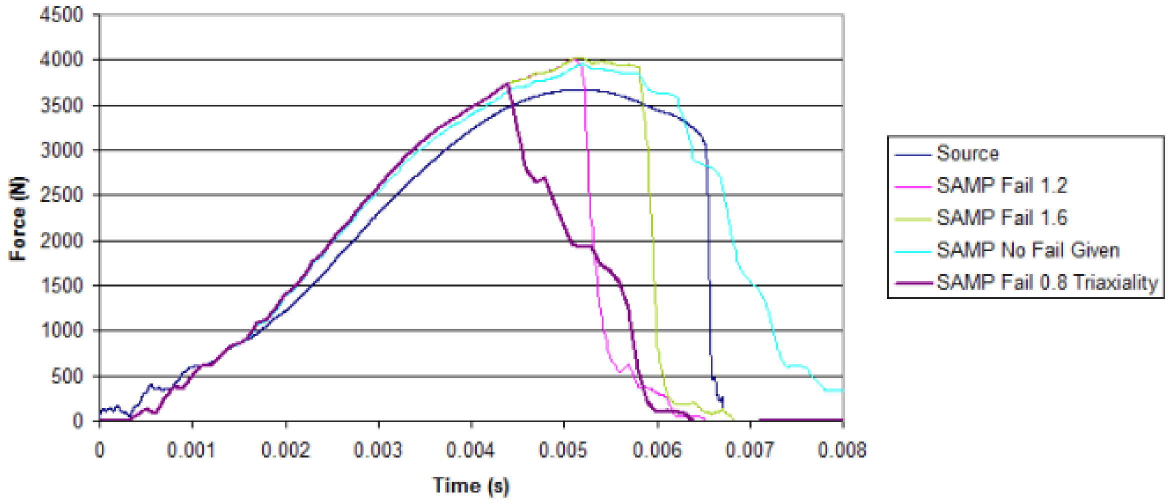


Applying failure criteria to SAMP

Using FAIL = biaxial fail strain approaches test data

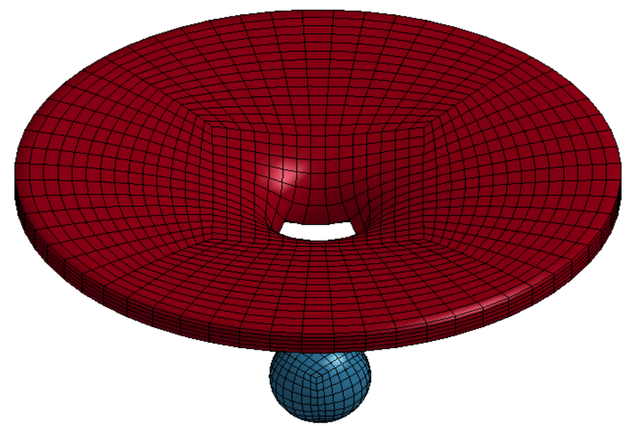
Softening behavior is predicted

Using triaxiality v. fail strain does not work well



LS-DYNA Validation of Dart Impact - PP

MAT_024 material model fitted with Matereality



Falling dart validation for PP

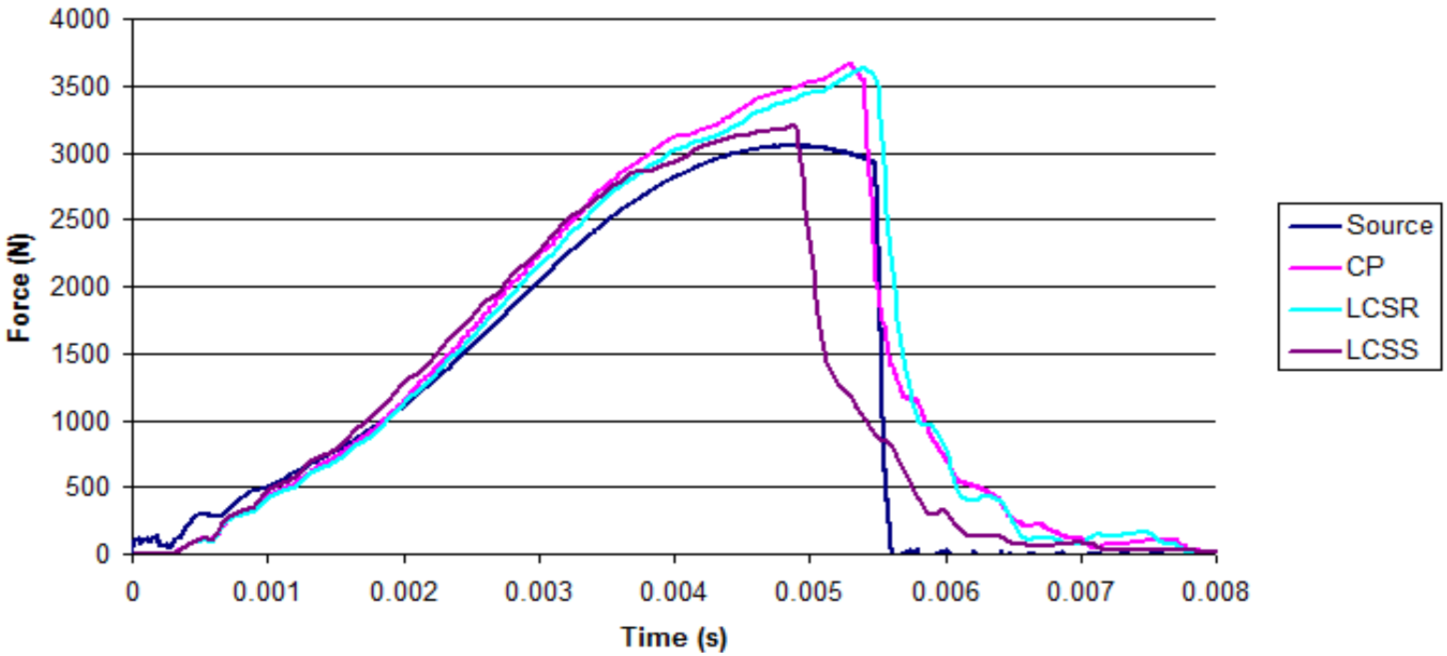
MAT_024 Material Model

- **Various rate dependency options**

VP=1

Fail Strain extrapolated to 1.2

SAMP less important where no softening behavior is seen



Insights

Build a post yield material model containing deviatoric and volumetric terms

Decouple two effects

- **Allow deviatoric straining prior to yield**
- **Volumetric straining starts at yield**

Effect of non von-Mises yield surface should be considered

Look at failure strain as a function of stress triaxiality (eg. SAMP)

- **Vital for failure prediction**
- **Alternately, arbitrary model extrapolation is required**
- **Not easy to objectively measure fail strain at different stress triaxiality**
  - *Tensile is feasible*
  - *Biaxial is feasible*
  - *Shear is not feasible; reverts to tensile mode for ductile plastics*

Error accumulates due to model infidelities

20 years of DatapointLabs

Focused on “materials in simulation” since 1995

Deep domain expertise

- **physics of materials, CAE parameter conversion, software for materials**