```
$ PIECEWISE_LINEAR_PLASTICITY_
$ ABS LC6 BHR - vonMises
$#     mid        ro         e
       100   1.13E-9    2500.0      0.
$#       c         p      lcss      lc
       0.0       0.0   1000000
$#    eps1      eps2      eps3      ep
       0.0       0.0       0.0       0
$#     es1       es2       es3       e
       0.0       0.0       0.0       0
$---+----1----+----2----+----3----+---
$                                LOAD C
$---+----1----+----2----+----3----+---
*DEFINE_TABLE
$#    tbid       sfa      offa
   1000000
$#               value      lcid
                 0.001   1000001
                   1.0   1000002
                  50.0   1000003
```

15th DEUTSCHES LS-DYNA FORUM

Testing and modelling of rubber-toughended polymers with LS-Dyna

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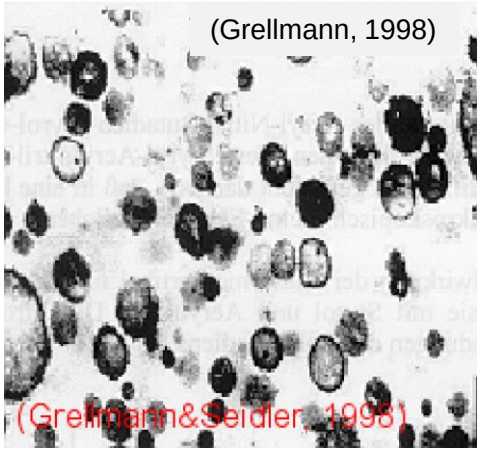
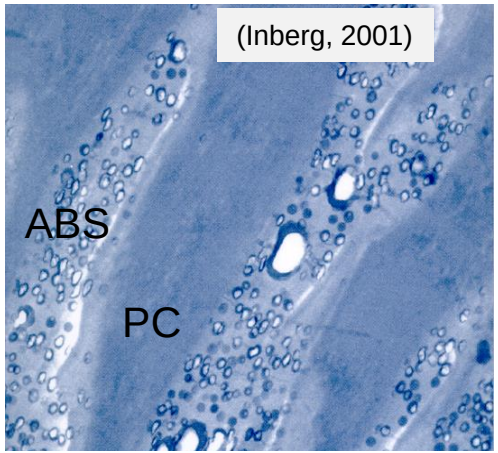
Rubber- toughened polymers

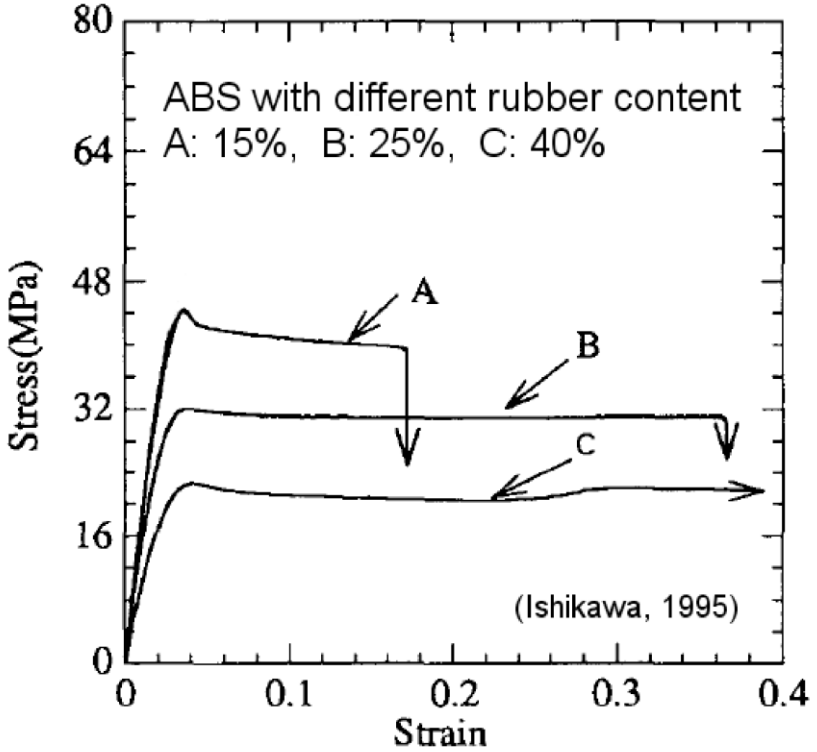
- products with rubber-toughened polymers





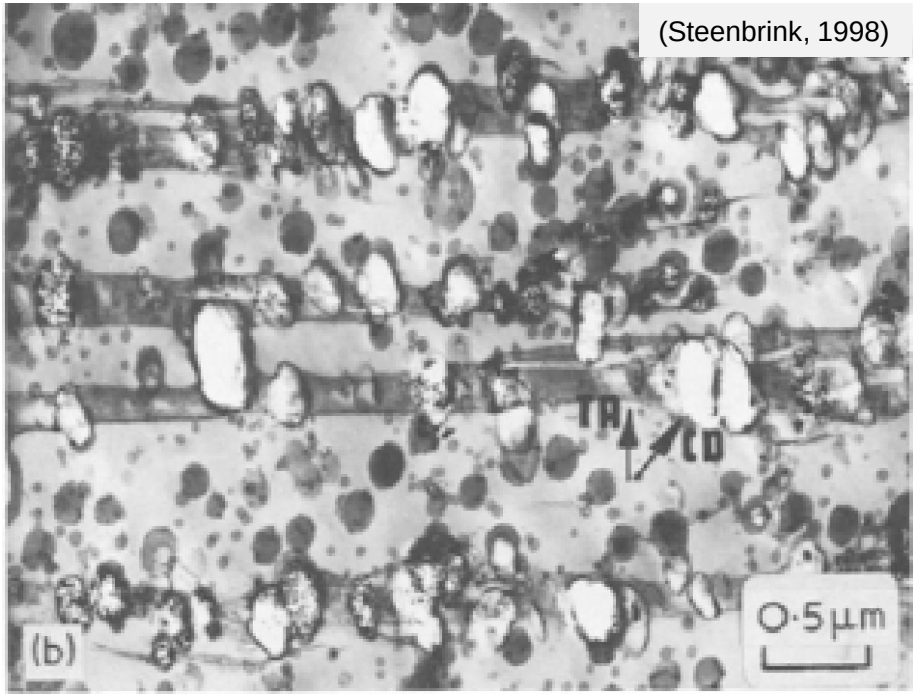
- Glassy polymer matrix
- Fine dispersed rubber particles
  - Acrylonitrile butadiene styrene (ABS)
  - high-impact polystyrene (HIPS)
  - Polymerblends (PC/ABS)

Macroscopic Effect of rubber particles



- With increasing rubber content:
  - Reduced stiffness and yield strength
  - Enhanced ductility
  - Enhanced fracture toughness

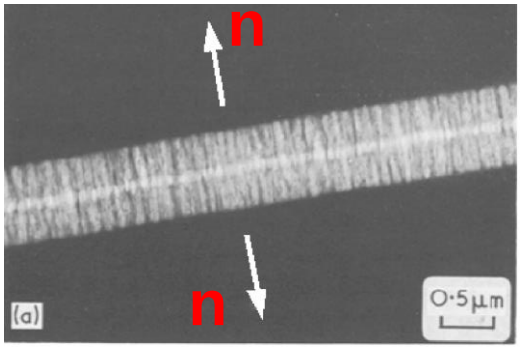
Micromechansisms



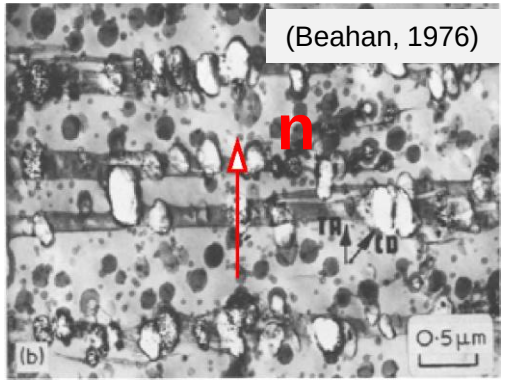
- Void growth (rubber particle cavitation)
- Shear yielding
- Crazing

Crazing and distributed crazing

- Crazing
  - Localized zones of fibrilled matrix material
  - Normal to principal tensile stress direction **n**
  - Fibrills are able to transfer stress
  - Craze growth until failure at critical craze width

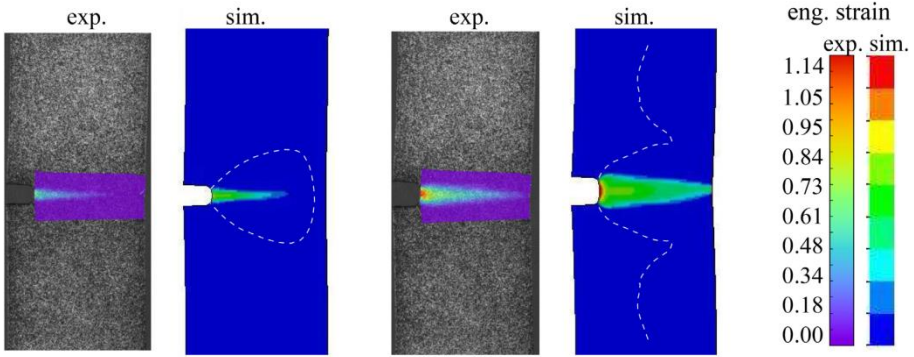


- Distributed crazing
  - Many band-like damage zones between rubber particles
  - Normal to principal overall loading direction **n**



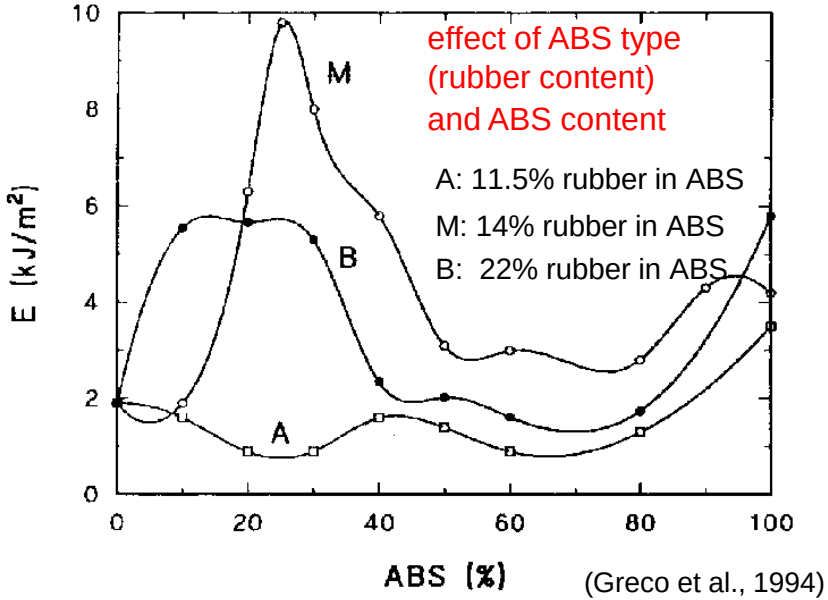
Crazing

- Crazing is non-delatan → increase of macroscopic volume
- Typical shape of the plastic zone at a cracktip
- For neat ABS or HIPS good agreement with micromechanical models (e.g. Ruge2017, Helbig2016)



(Helbig et al., 2016)

- composition of a polymerblend (ABS or PC content) and rubber content in ABS influences microscopic damage mechanism



(Greco et al., 1994)

Practical testing and modeling of Crazing in LS-DYNA

- Everyday Material:
  - **Microstructure is unknown** (rubber content and size, ..)
  - Influence of process parameters
  - Anisotropie
  - Time pressure
- Material card:
  - As simple as possible
  - As fast as possible
  - Calculation time

Goal:

→ Easy tests

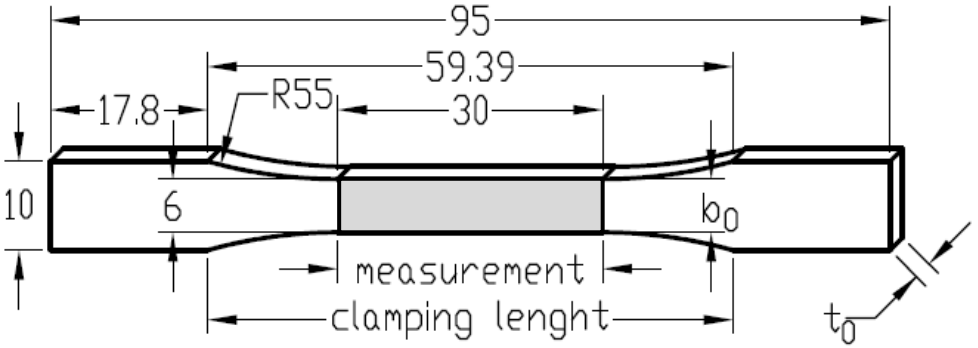
→ Easy, fast and robust material models

→ Easy determination of material parameters

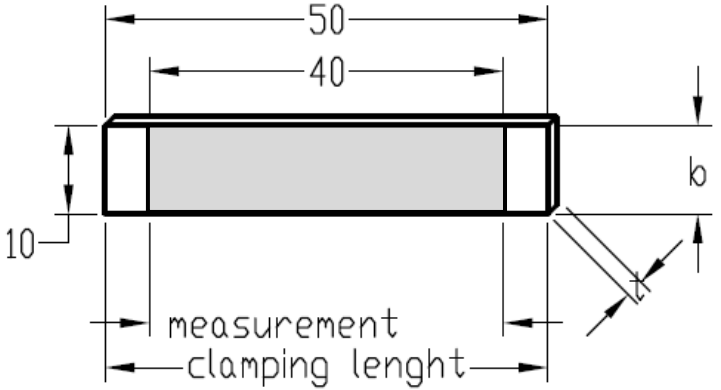
→ Easy description of important material behavior

Specimen

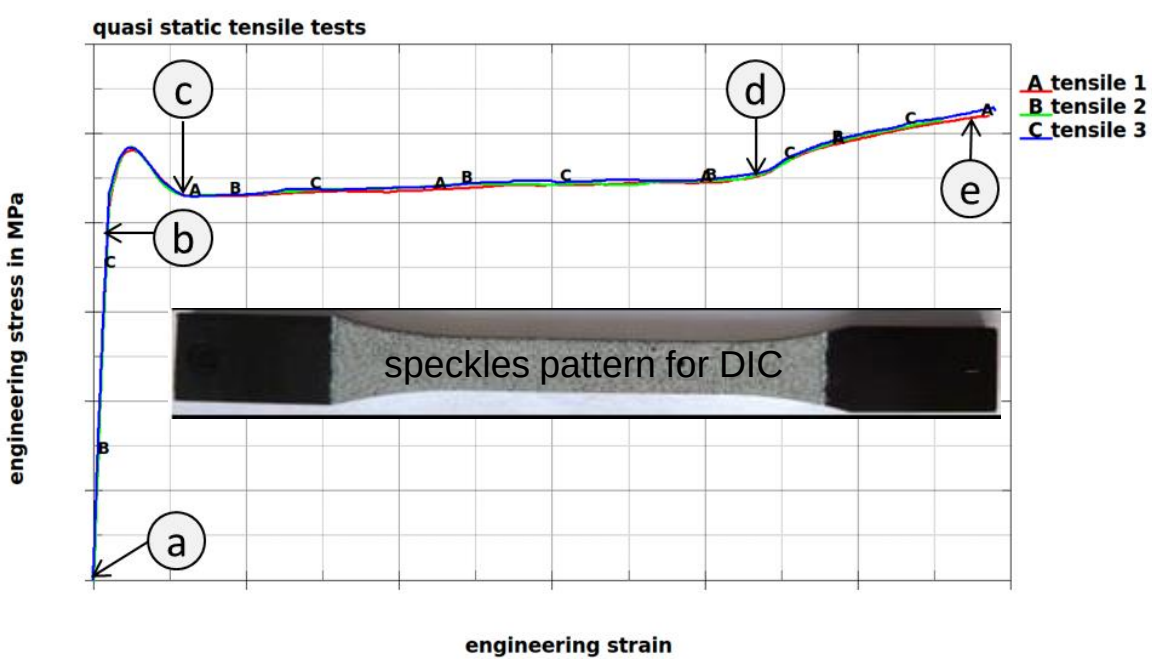
- Tensile specimen
  - static and dynamic tests
  - Strain via DIC
  - Engineering strain with l_0=30 mm
  - Target mesh size: 2mm
  - Milled specimen

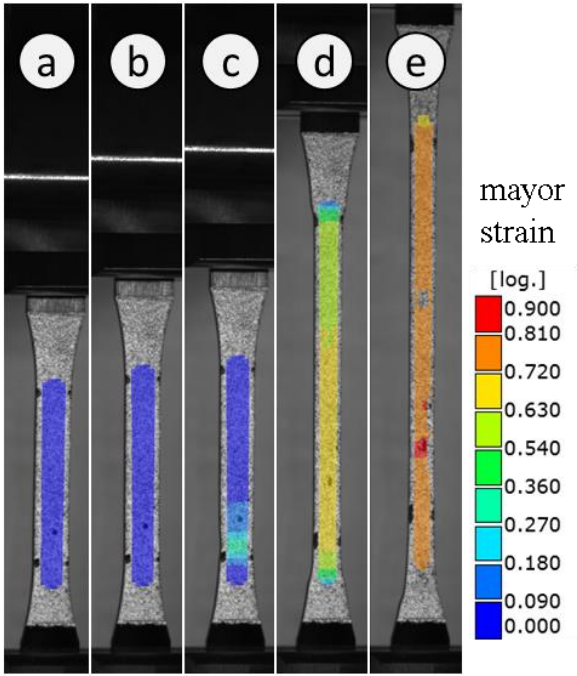


- 3 point Bending:
  - Static and dynamic tests
  - Milled specimen
  - Large of strain rates possible

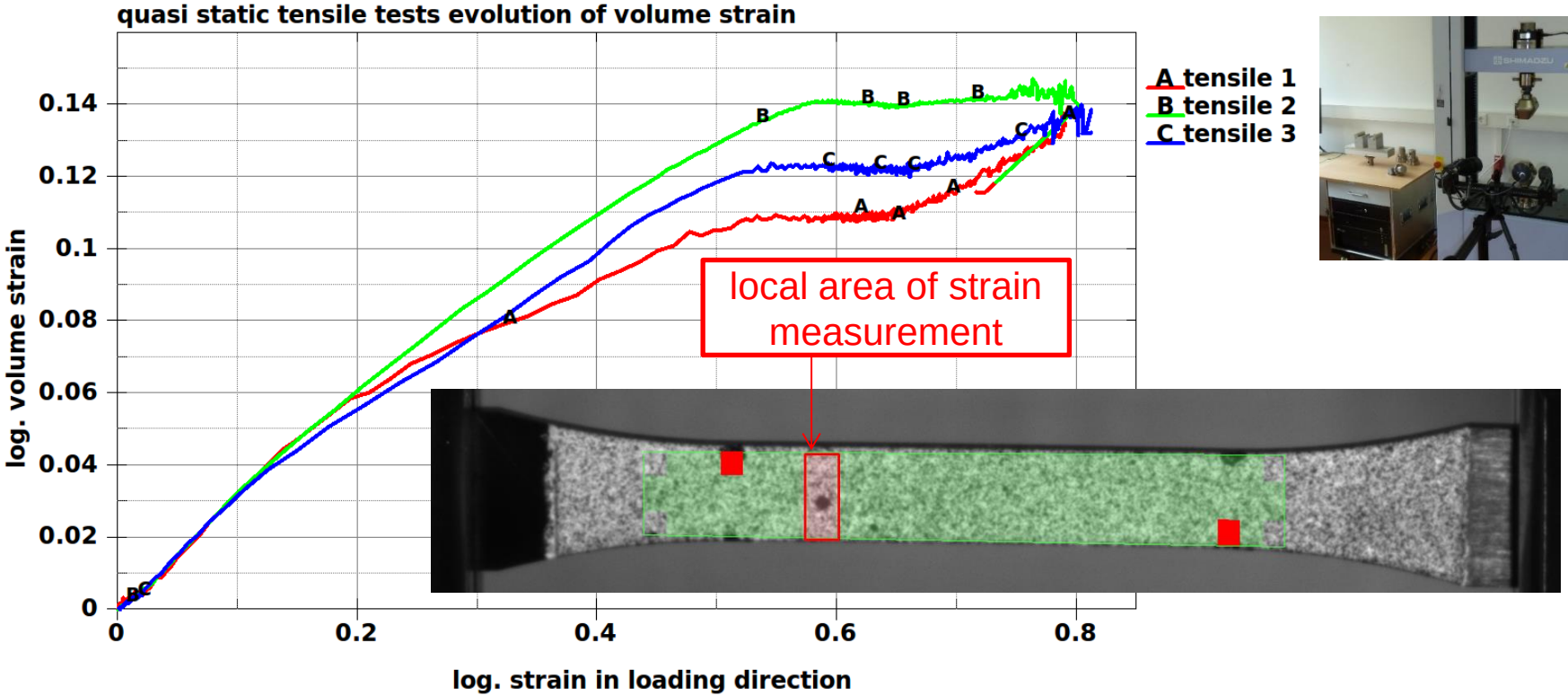


Deformation of tensile loaded PC/ABS

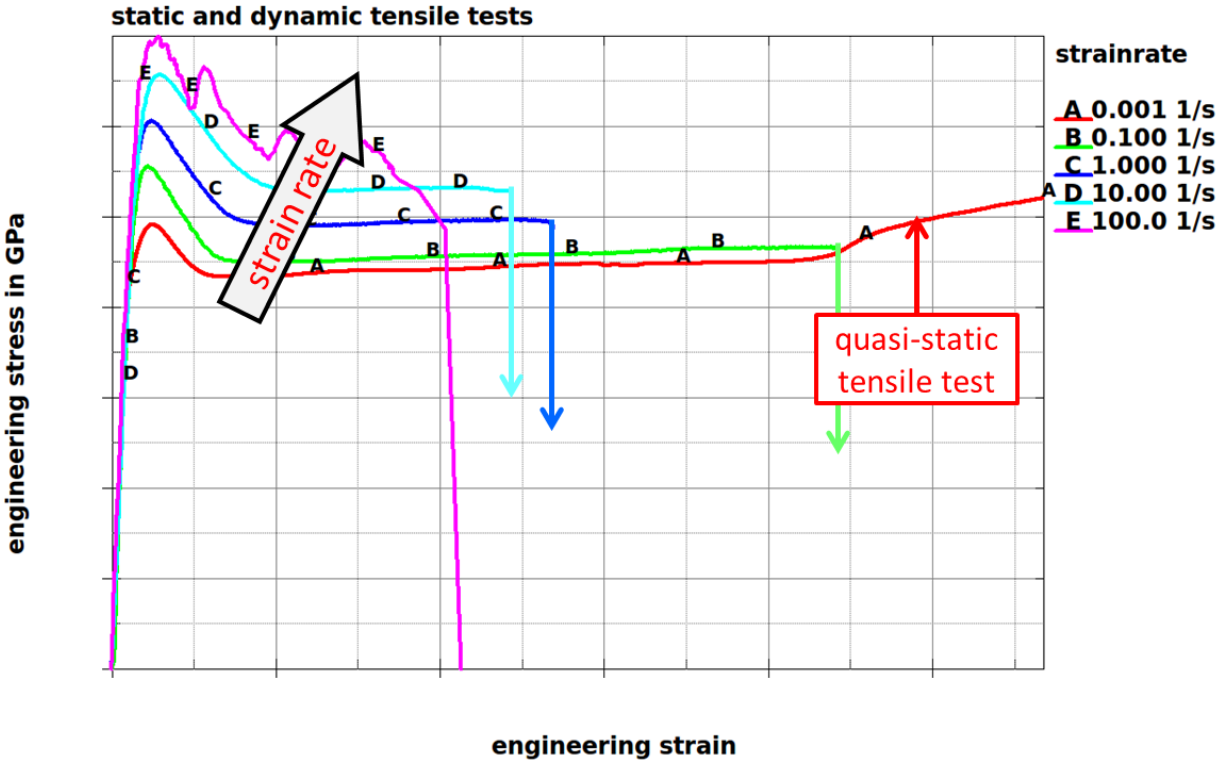




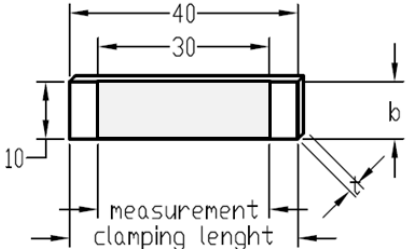
Local volume-strain measurement

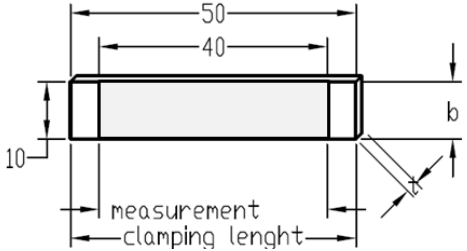


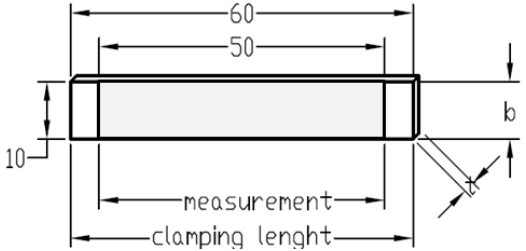
Dynamic tensile tests

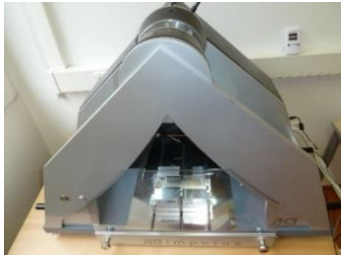


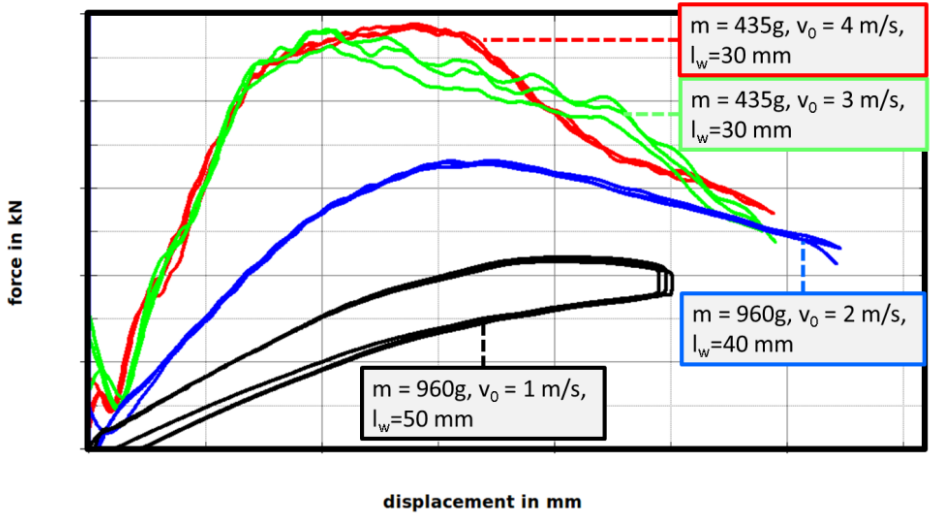
Dynamic three point bending tests

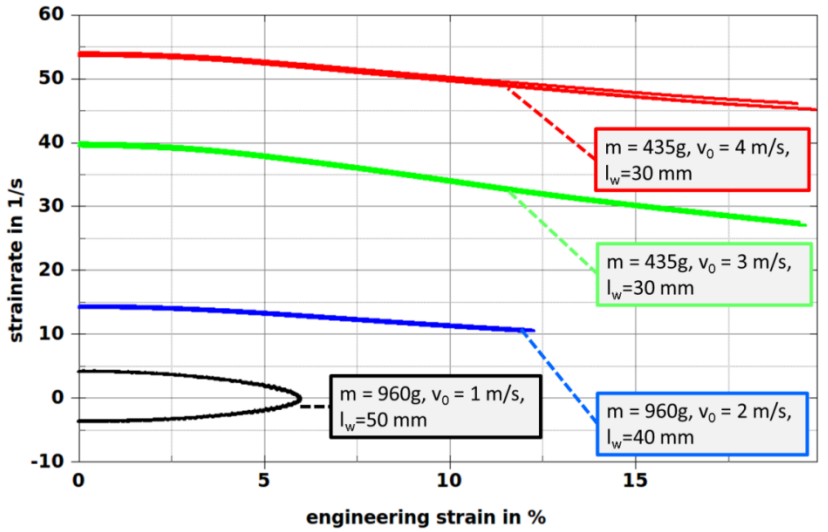










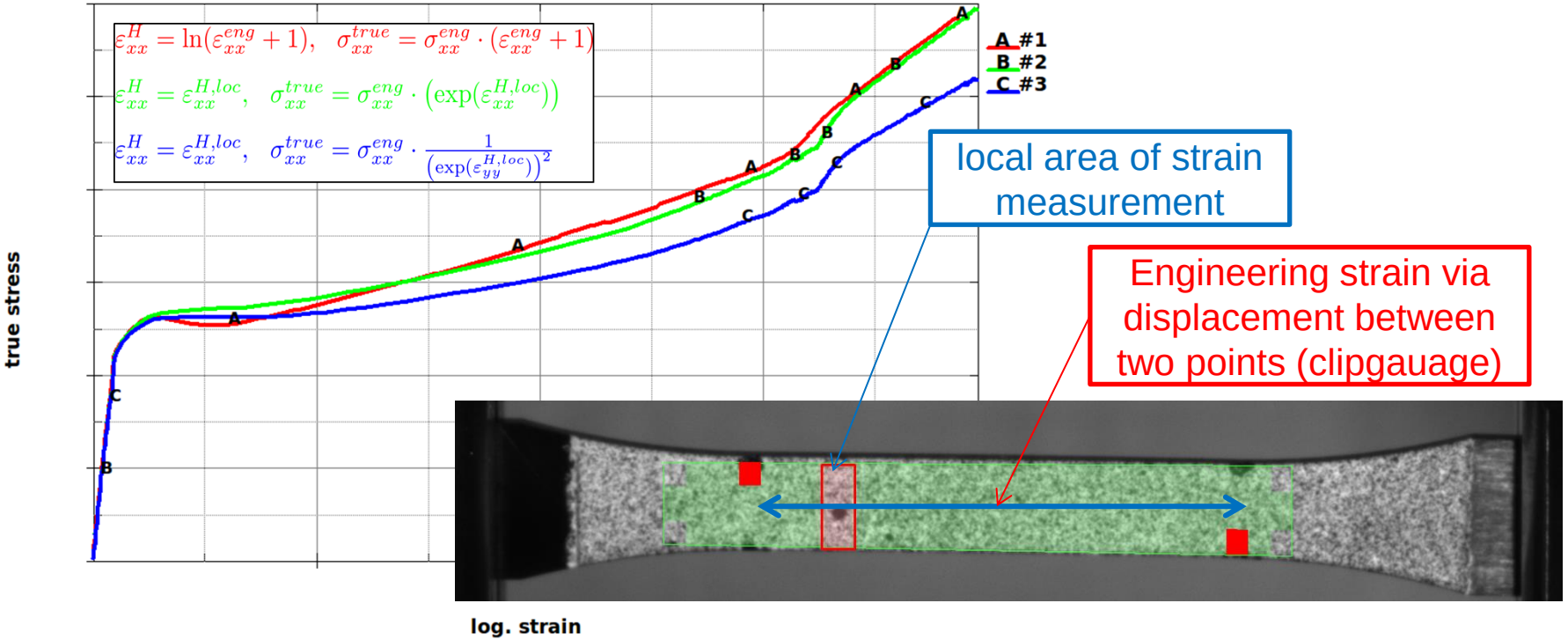


calculation of log. Strain vs. true stress

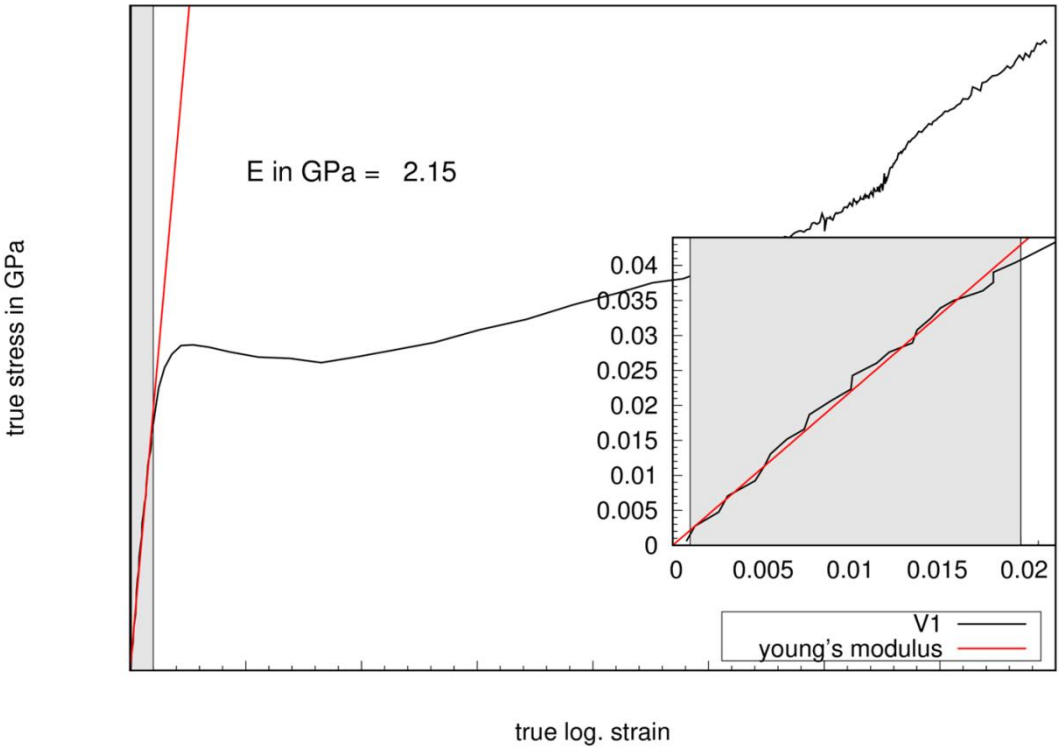
$$\varepsilon_{xx}^{H} = \ln(\varepsilon_{xx}^{eng} + 1), \quad \sigma_{xx}^{true} = \sigma_{xx}^{eng} \cdot (\varepsilon_{xx}^{eng} + 1)$$

$$\varepsilon_{xx}^{H} = \varepsilon_{xx}^{H,loc}, \quad \sigma_{xx}^{true} = \sigma_{xx}^{eng} \cdot \left(\exp(\varepsilon_{xx}^{H,loc})\right)$$

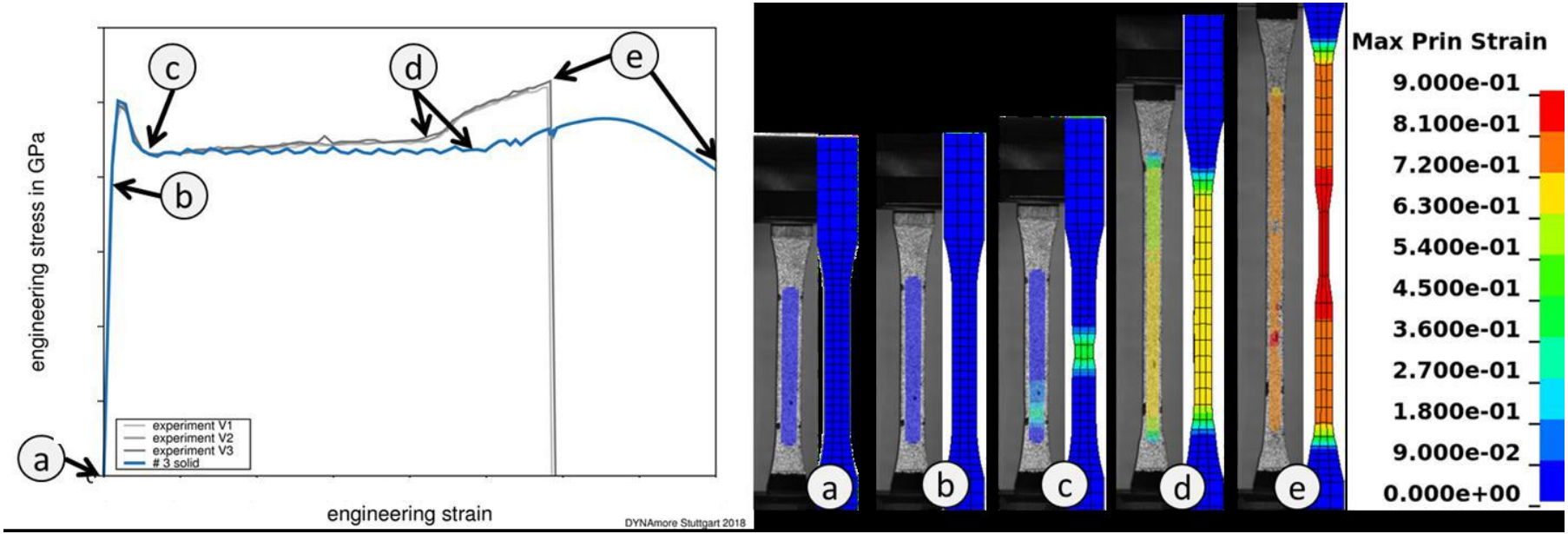
$$\varepsilon_{xx}^{H} = \varepsilon_{xx}^{H,loc}, \quad \sigma_{xx}^{true} = \sigma_{xx}^{eng} \cdot \frac{1}{\left(\exp(\varepsilon_{yy}^{H,loc})\right)^2}$$



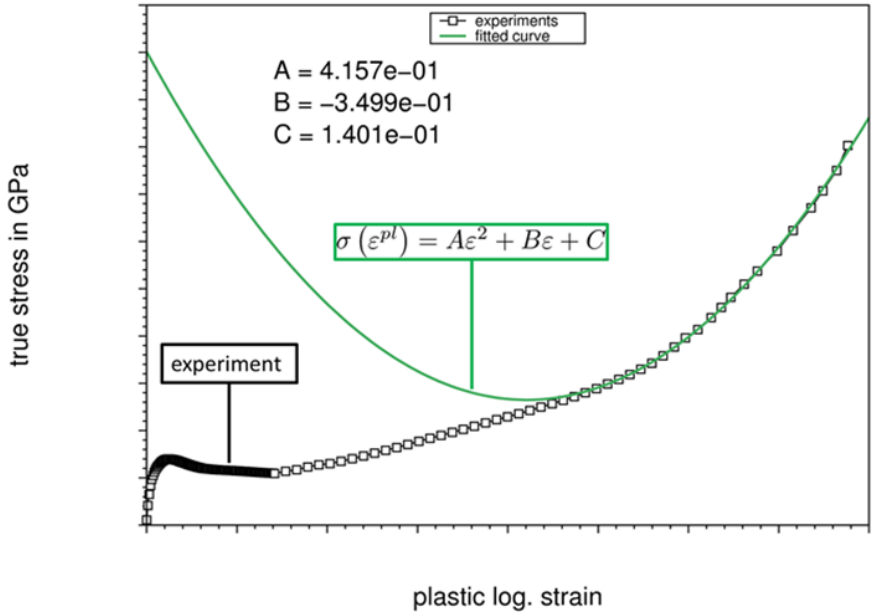
Determination of young‘s modulus

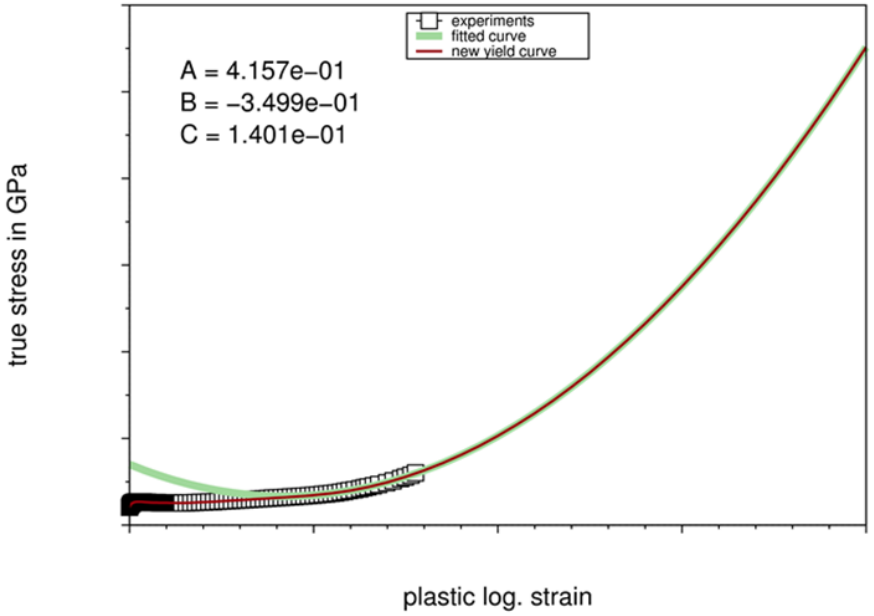


Simulation with measured yieldcurve

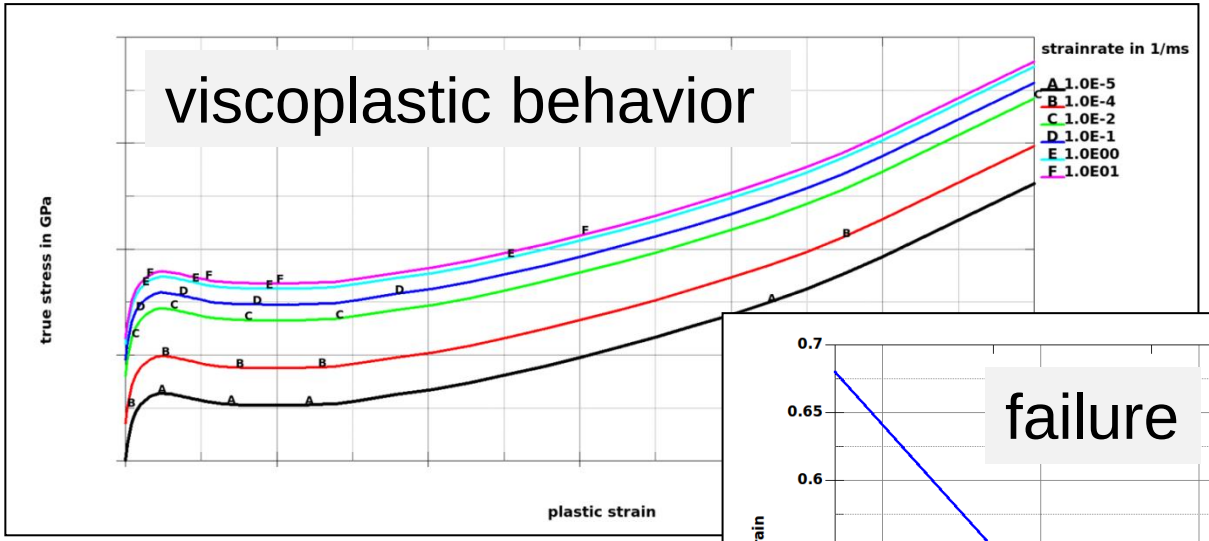


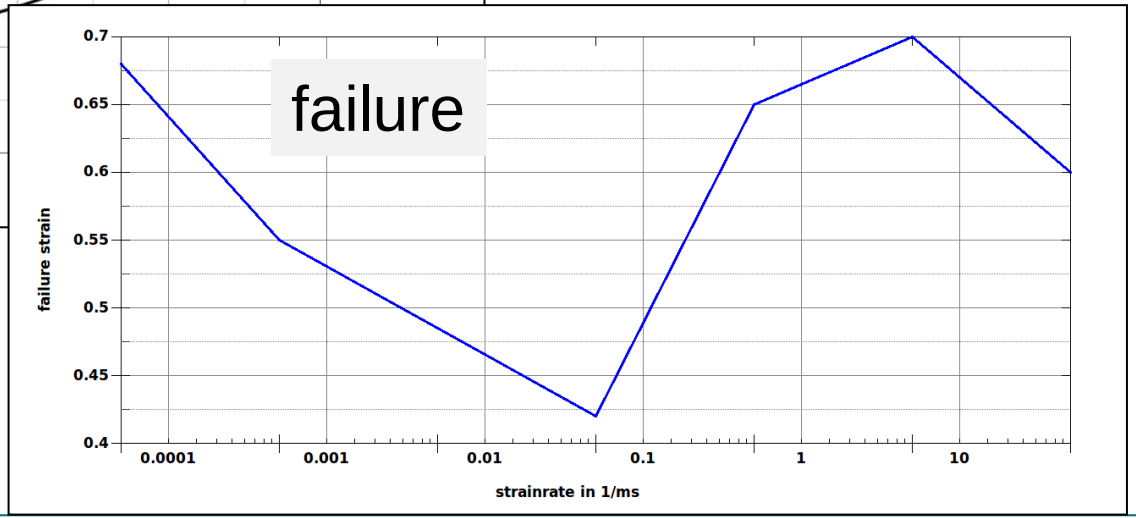
Yieldcurve extrapolation



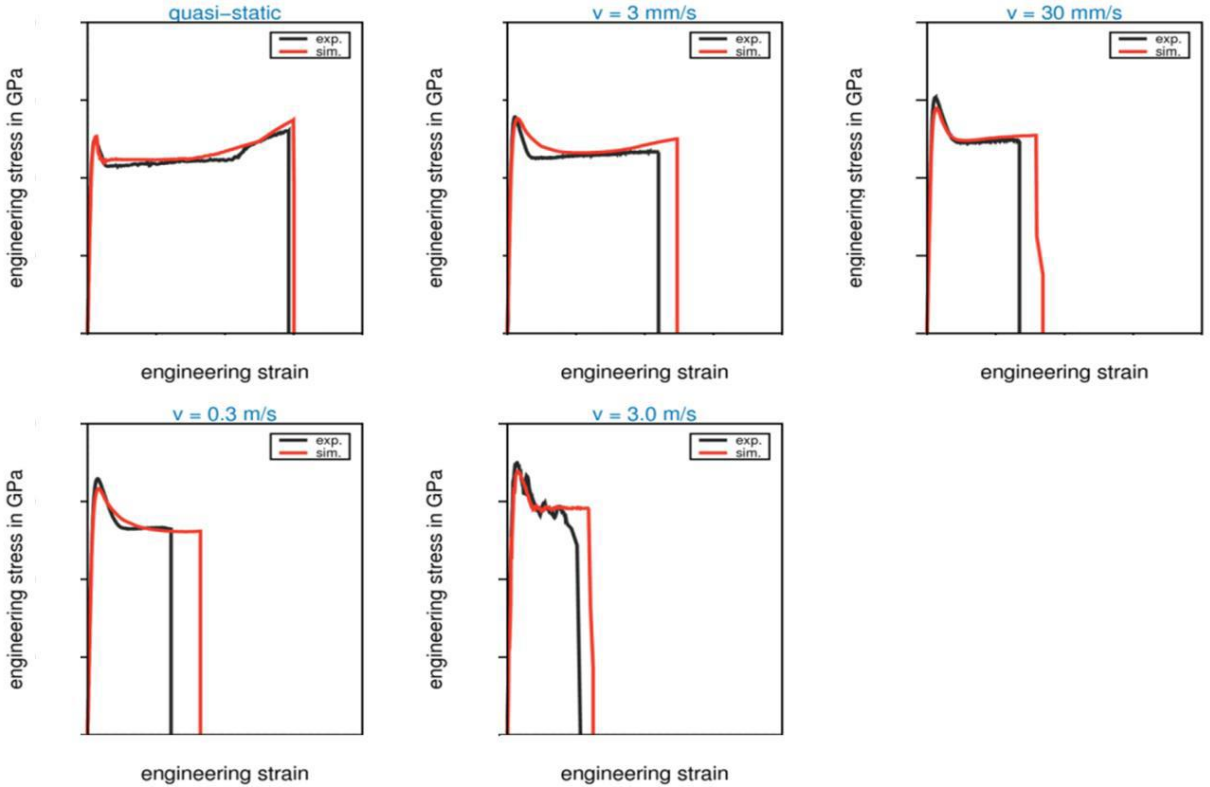


Strainrate dependency

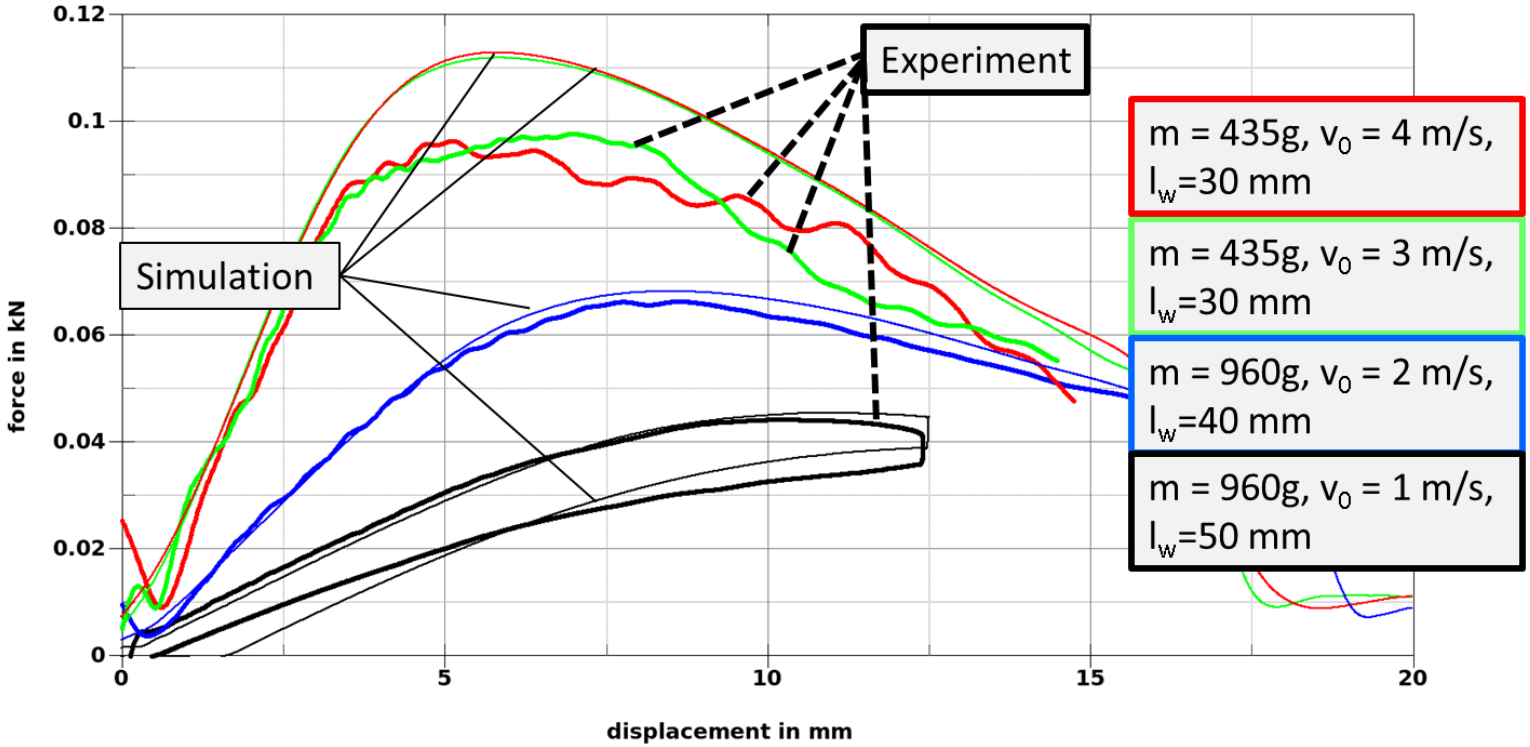




Results of MAT_024 + GISSMO card: tensile tests

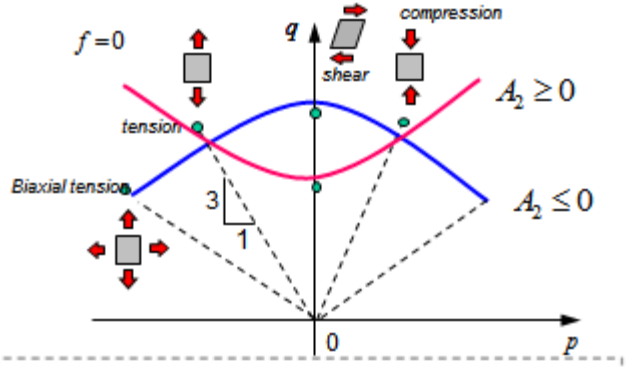


Results of MAT_024 + GISSMO card: bending tests



Material modelling of polymers in LS-DYNA

Isotropic plasticity with SAMP-1 (*MAT_187)

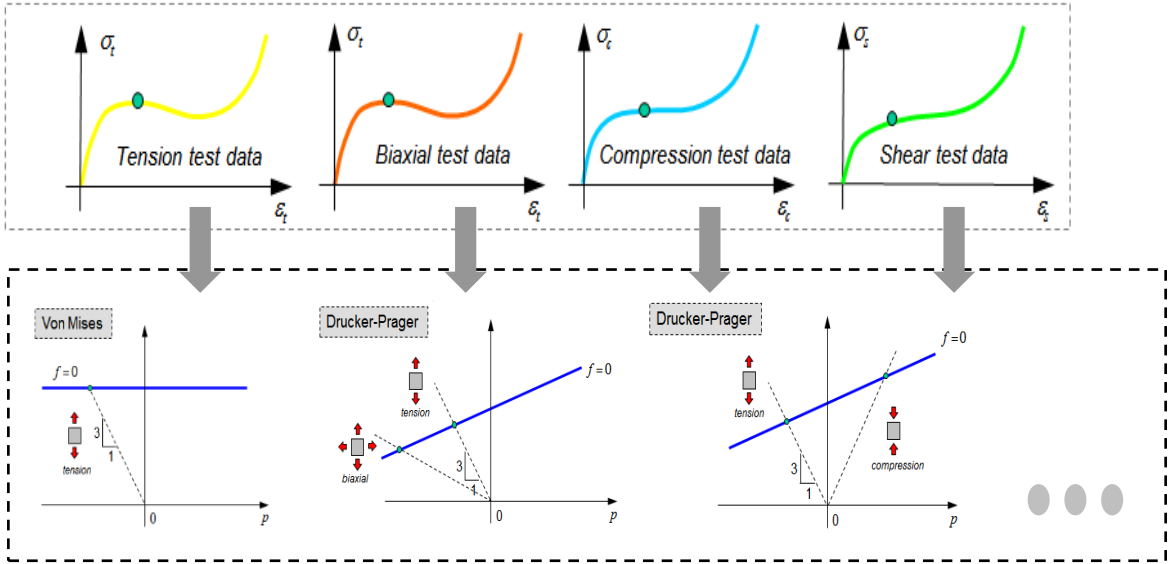


Yield surface:

$$f(p,\sigma_{vm},\bar{\varepsilon}^{pl}) = \sigma_{vm}^2 - A_0 - A_1 p - A_2 p^2 \le 0$$

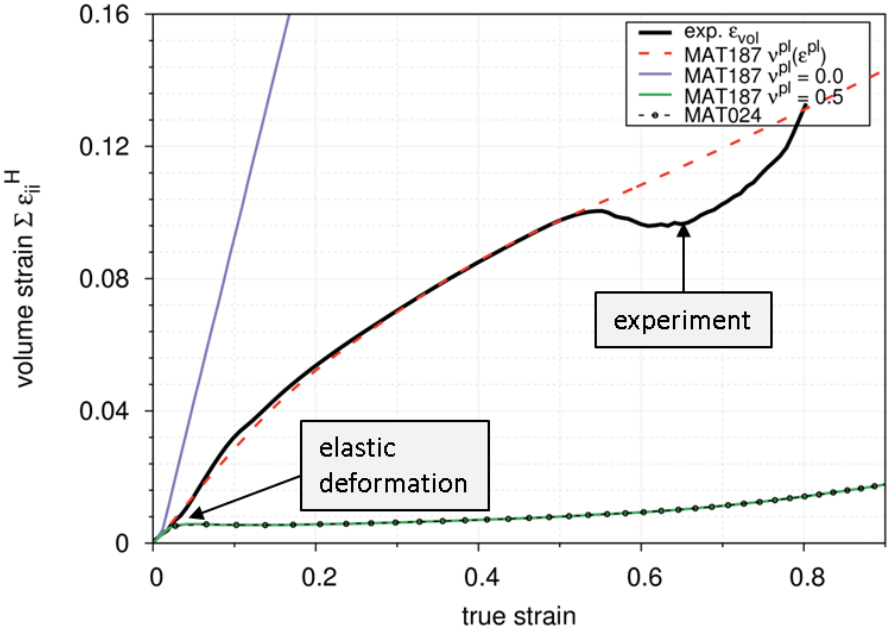
Condition for convexity :

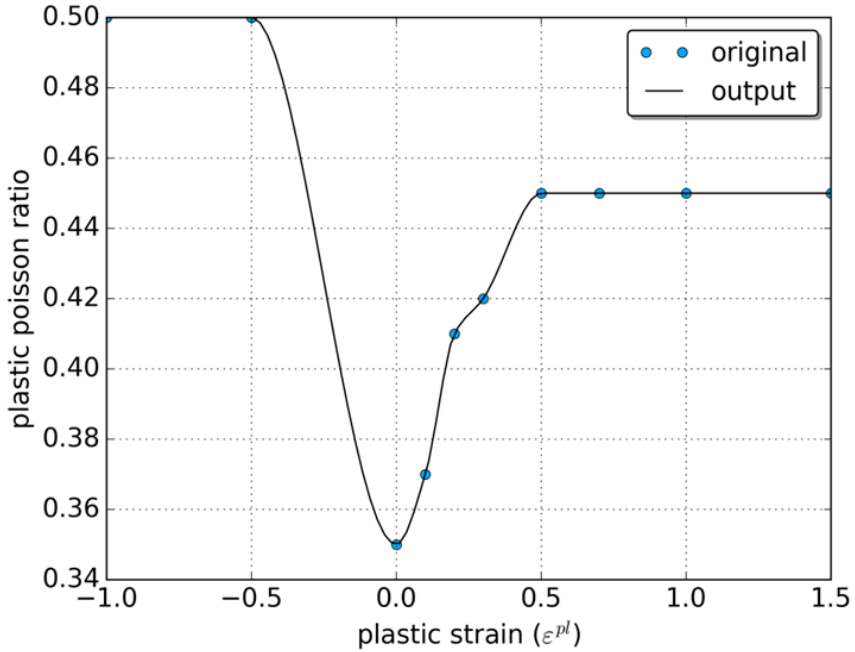
$$A_2 \le 0 \Leftrightarrow \sigma_s \ge \frac{\sqrt{\sigma_t \sigma_c}}{\sqrt{3}}$$



➢ Dependency of plastic poisson ratio

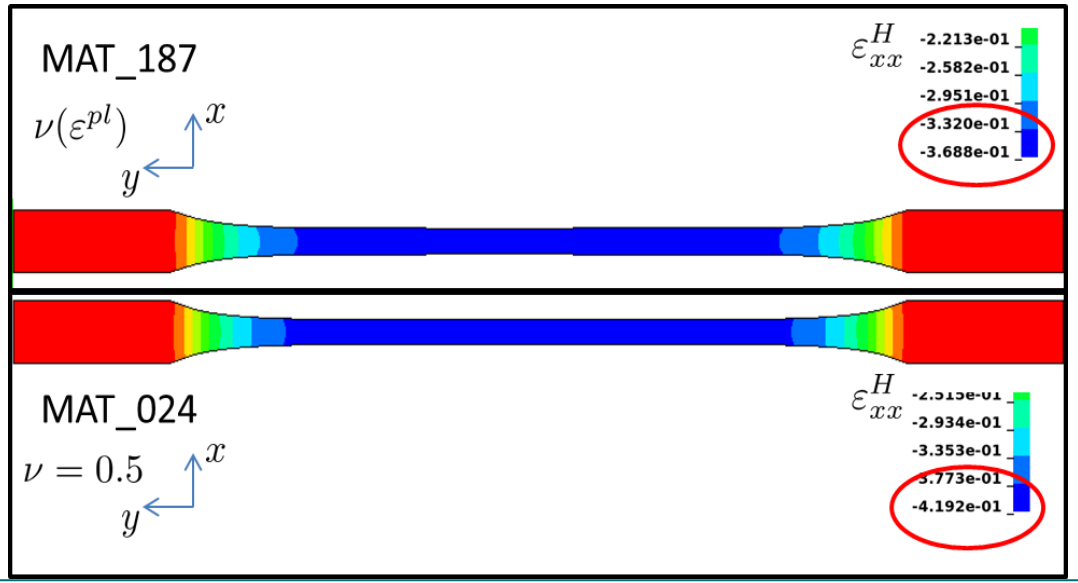
SAMP#1: plastic poisson‘s ratio



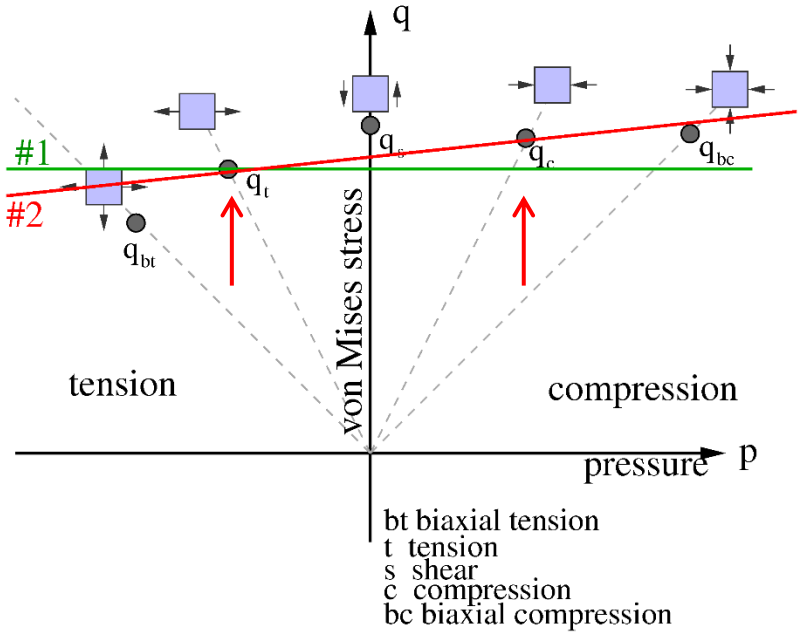


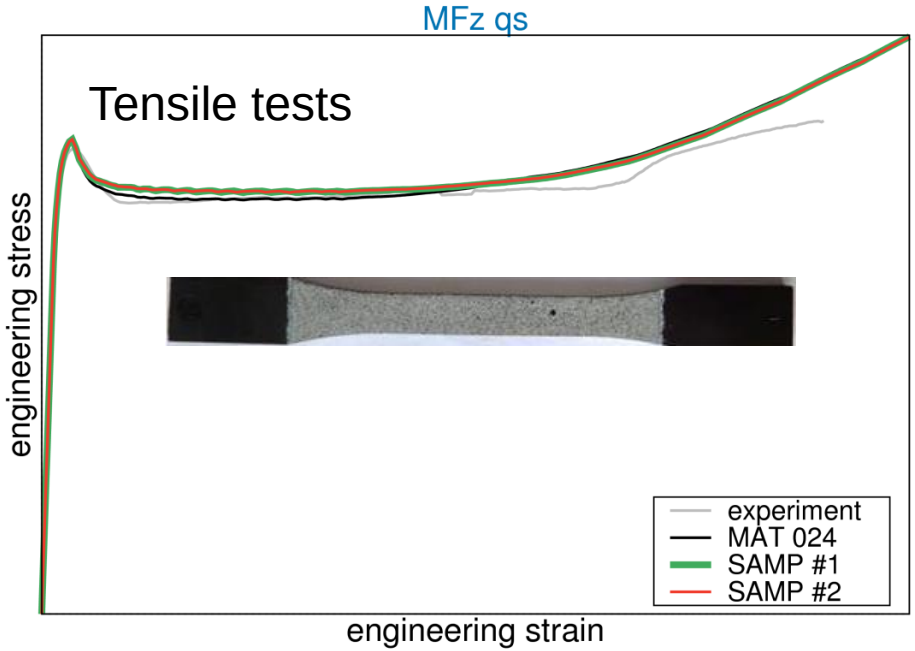
SAMP#1: plastic poisson‘s ratio

- Taking ratio into account:
  - influence on strain transversal to loading direction
  - influence plastic strain at notch tip
  - important for complex FE-models

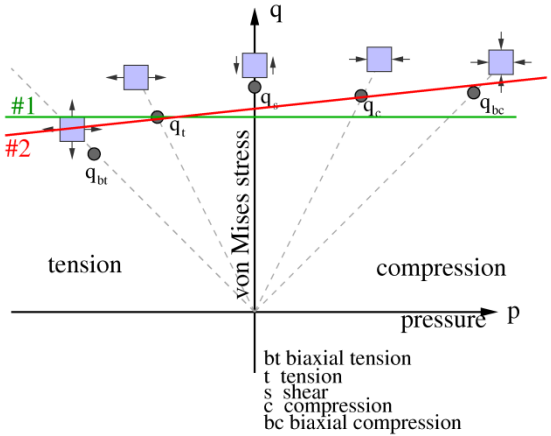


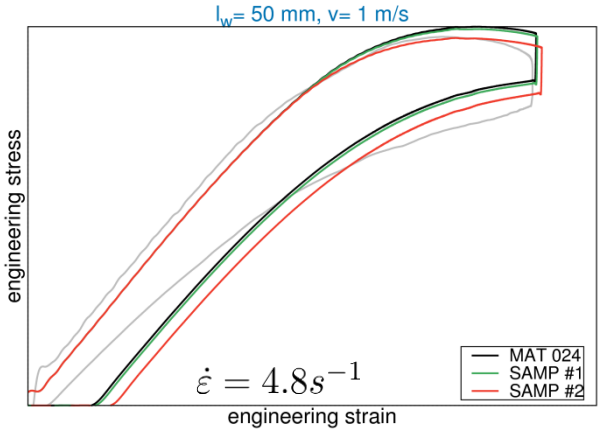
SAMP #2: taking compression into account

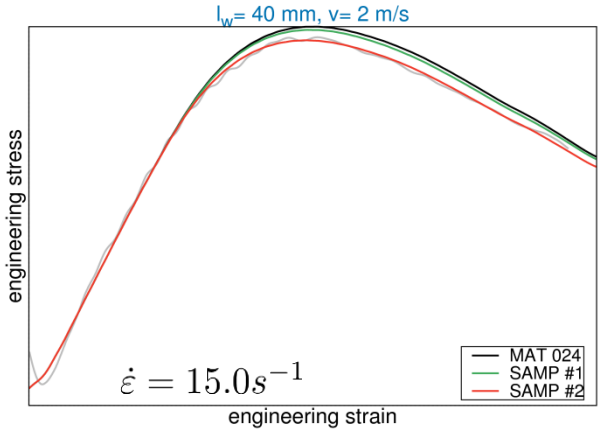


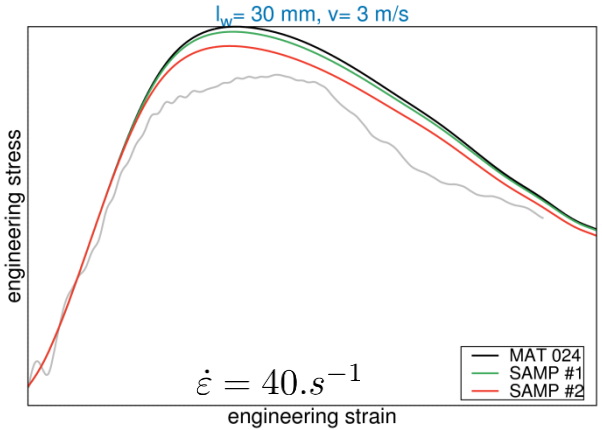


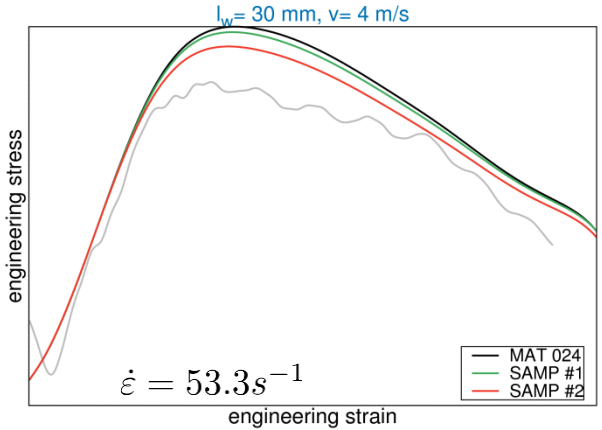
Bending results:











Summary

- Short overview of crazing at rubber toughened polymers
- Experimental characterization of an PC/ABS blend
  - Tensile tests with DIC
  - Evolution of volume-strain
  - Dynamic tensile tests
  - Dynamic bending tests
- Yield-curve determination from local strain measurement
- Determination strainrate dependency and failure
- MAT_024 card under dynamic bending load
- Enhanced modelling with GISSMO
  - Consideration of plastic Poisson’s ratio
  - Consideration of yielding under pressure load

OUTLOOK: Material modeling in LS-DYNA

Isotropic plasticity (*MAT_187)
Volumetric/deviatoric damage (*MAT_ADD_GENERALIZED_DAMAGE)

- SAMP has been used as plasticity model, calibrated for PC ABS
- GGDM in MAT_ADD_GENERALIZED_DAMAGE is used for damage with PDDT=2 and HISV1=0 (deviatoric straining) and HIS2=6 (volumetric straining)

```
*MAT_SAMP-1_TITLE
PC ABS
$      MID        RO      BULK     SHEAR      EMOD       NUE    RBCFAC
         1    1.0E-6       0.0       0.0       2.2       0.4         1         0
$   LCID_T    LCID_C    LCID-S    LCID-B     RNUEP    LCID-P    INCDAM
       100                                                501         0         0
$   LCID_D    EPFAIL    DEPRPT  LCID_TRI   LCID_LC
         0                0.0         0         0
$  MAXITER      MIPS             INCFAIL     ICONV      ASAF    IPRINT     NHISV
         0        20         0         0         0       0.0
$--------1---------2---------3---------4---------5---------6---------7---------8
*MAT_ADD_GENERALIZED_DAMAGE
$      pid      idam    dmgtyp      refsz    numfip                  PDDT      nhis
         1         1         1                   1                     2         2
$     his1      his2      his3     iflg1     iflg2     iflg3
```

OUTLOOK: Material modeling in LS-DYNA

Isotropic plasticity (*MAT_187)
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- SAMP has been used as plasticity model, calibrated for PC ABS
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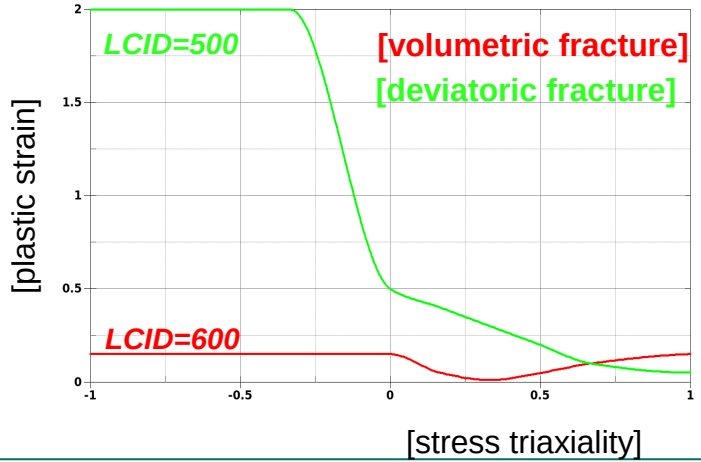
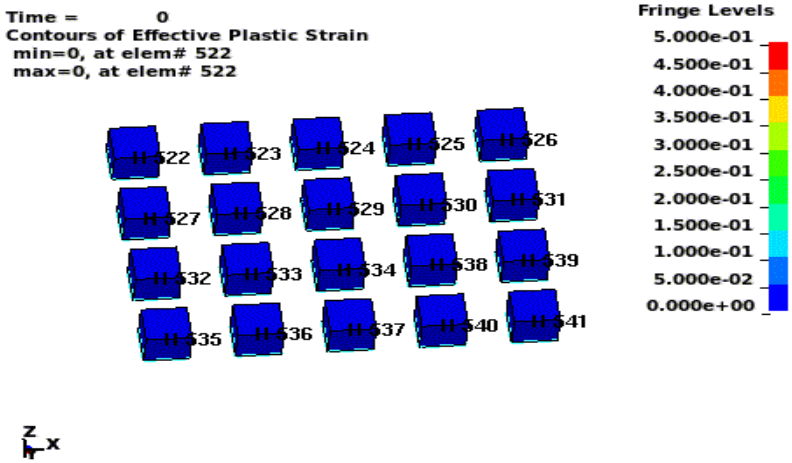
```
$--------1---------2---------3---------4---------5---------6---------7---------8
*MAT_ADD_GENERALIZED_DAMAGE
$       pid       idam     dmgtyp      refsz     numfip                 PDDT       nhis
          1          1          1                    1                    2          2
$      his1       his2       his3      iflg1      iflg2      iflg3
           0          6                     0          0          0
$     dam11      dam22      dam33      dam44      dam55      dam66

$     dam12      dam21      dam24      dam42      dam14      dam41

$     lcsdg      ecrit     dmgexp      dcrit     fadexp     lcregd
        500       -500        2.0                  1.0
$     lcsrs       shrf      biaxf

$     lcsdg      ecrit     dmgexp      dcrit     fadexp     lcregd
        600       -600        2.0                  1.0
$     lcsrs       shrf      biaxf
```

OUTLOOK: Material modeling in LS-DYNA

Isotropic plasticity (*MAT_187)
Volumetric/deviatoric damage (*MAT_ADD_GENERALIZED_DAMAGE)

- The classical multiaxial (numerical) test for one element has been modified for 3D elements
- SAMP has been used as plasticity model, calibrated for PC ABS
- GGDM in MAT_ADD_GENERALIZED_DAMAGE is used for damage with PDDT=2 and HISV1=0 (deviatoric straining) and HIS2=6 (volumetric straining)

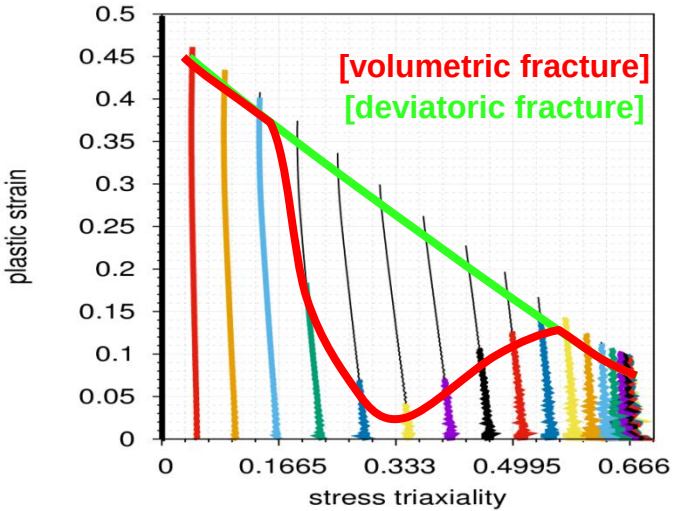


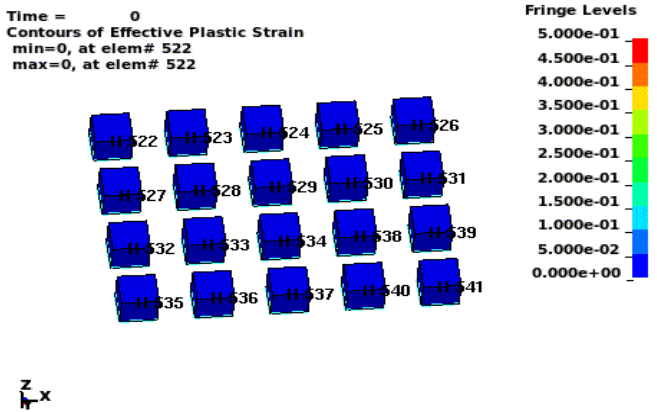


OUTLOOK: Material modeling in LS-DYNA

Isotropic plasticity (*MAT_187)
Volumetric/deviatoric damage (*MAT_ADD_GENERALIZED_DAMAGE)

- The classical multiaxial test for one element has been modified for 3D elements
- SAMP has been used as plasticity model
- GGDM in MAT_ADD_GENERALIZED_DAMAGE is used for damage with PDDT=2 and HISV1=0 (deviatoric straining) and HIS2=6 (volumetric straining)





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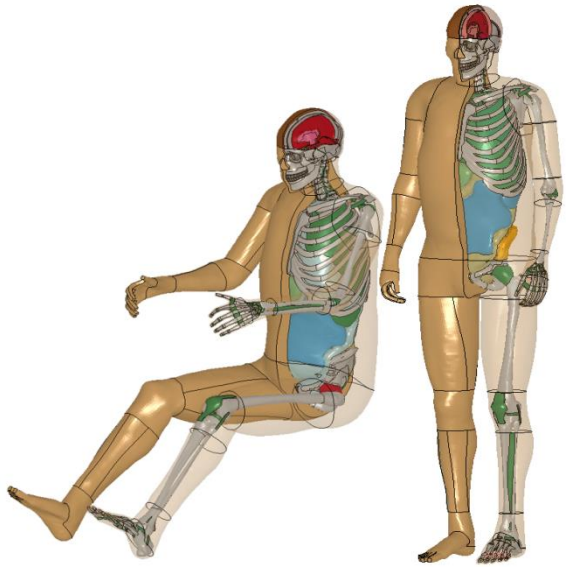

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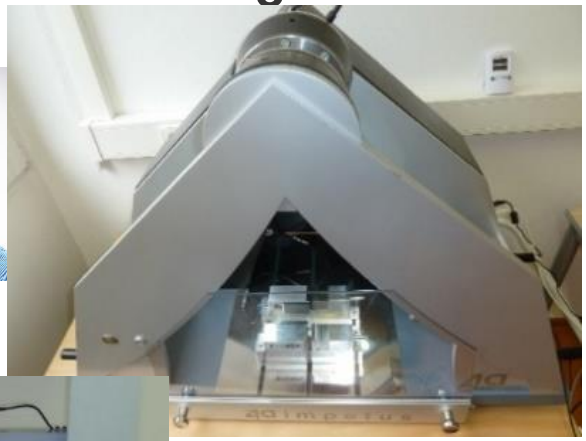

- Services
  - Material deformation characterization and LS-DYNA material model calibration for: **Polymers, Foams, Metals**
  - Experiments
    - Tensile, bending, compression, punch test
    - Component testing
    - Local strain analysis with DIC
  - Damage and fracture characterization and calibration for GISSMO and MAGD models