Material and component behavior of light weight steels under complex loadings at high strain rates

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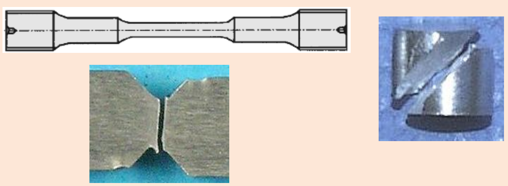
Outline

- Introduction
- Test equipement for characterization of advanced high strength steel sheets for automotive applications
  - at high strain rates and
  - multiaxial loading conditions
- Experimentally determined material data for simulation
- Modeling
  - Deformation behavior dependent on strain rate
  - Failure behavior dependent on stress state and strain rate
- Model validation with dynamic component tests
- Summary

Damage concept: multi step evaluation of crashworthiness

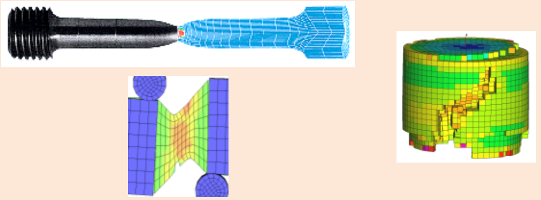
Material



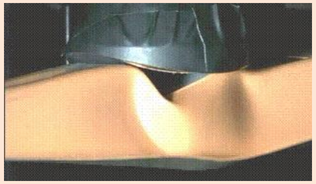
Tension-, compression-, shear-Tests
static, dynamic

Material models

Simulation of specimen tests



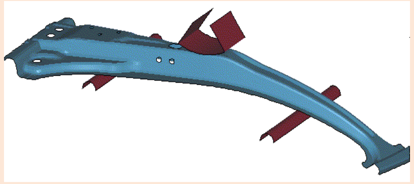
Component



Substructure crash test
(e.g.: B column)

Structural modeling

Simulation of component tests



Vehicle

Full scale test

Crashworthiness prediction

Simulation of Full-Scale Tests

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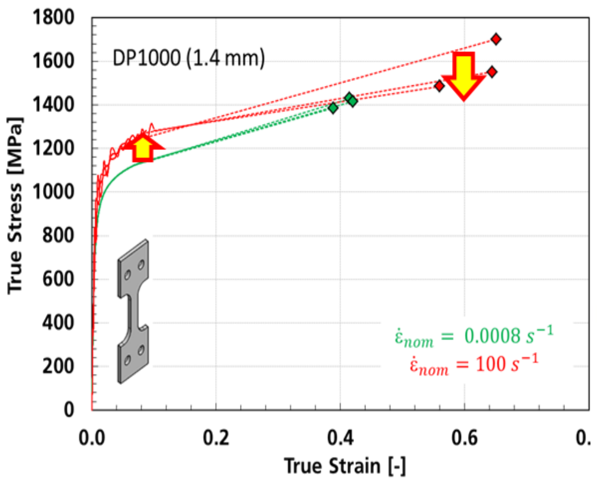
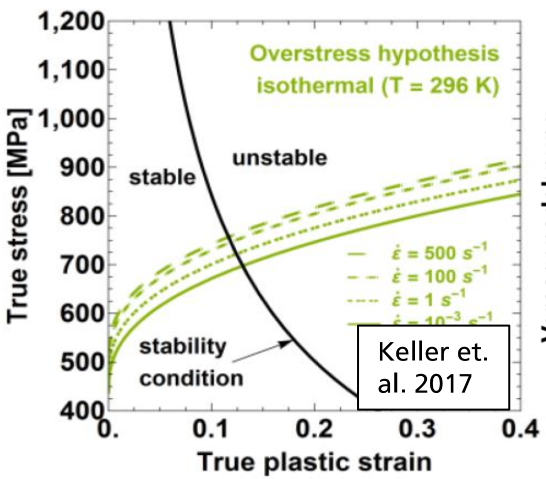
Influence of strain rate on deformation and failure of advanced high strength steel sheets

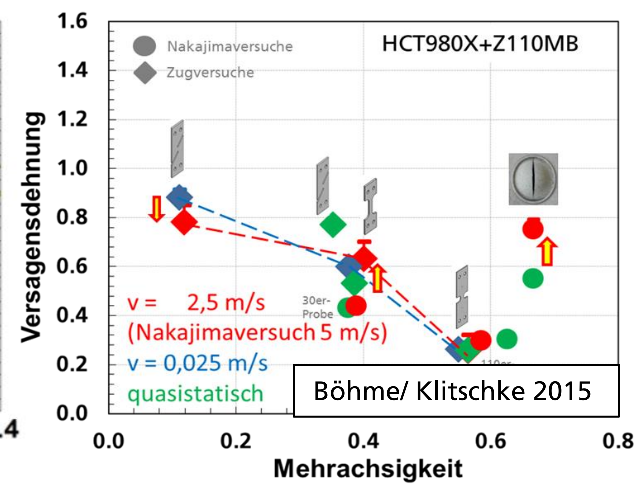
Influence of strain rate on <u>deformation behavior</u>:

Influence of strain rate on <u>onset of instability</u>:

Influence of strain rate on <u>failure behavior</u>:







<u>with increasing strain rate:</u>

- strain rate hardening
- adiabatic softening

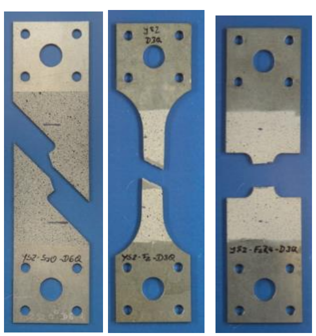
onset of instability at smaller strain values

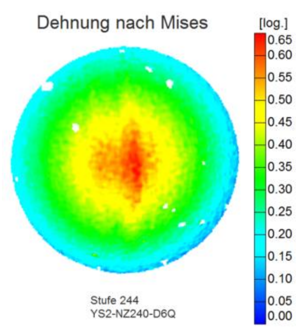
larger or smaller failure strains dependent on stress state

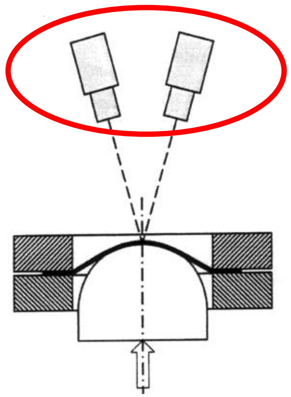
➔ Considering strain rate and stress state in simulation of dynamic loading situations

Test equipement for specimen tests at high strain rates and multiaxial loading situations

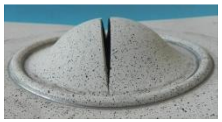
- Servohydraulic high speed testing machine (500 kN / 10 m/s)
- Clamping device for nakajima tests according to DIN EN ISO 12004
- 2 high speed video cameras for 3D-DIC (digital image correlation)







v = 6,25 m/s $\dot{\varepsilon} = 250\ s^{-1}$
v = 2,5 m/s $\dot{\varepsilon} = 100\ s^{-1}$
v = 0,025 m/s $\dot{\varepsilon} = 1\ s^{-1}$
v = 0,02 mm/s $\dot{\varepsilon} = 0{,}0008\ s^{-1}$



v = 0,0015 m/s

v = 5 m/s

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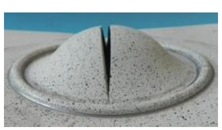
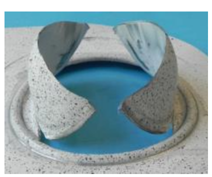
High speed infrared measurement for nakajima tests on high strength sheet metals at 5 m/s

High speed testing machine (500 kN/10 m/s):

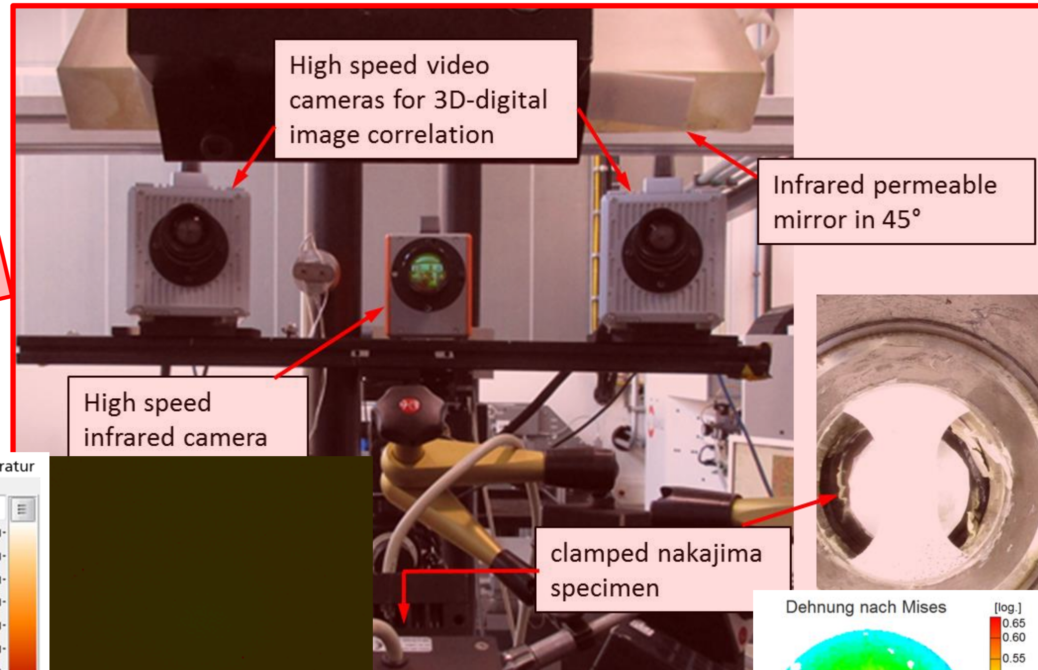


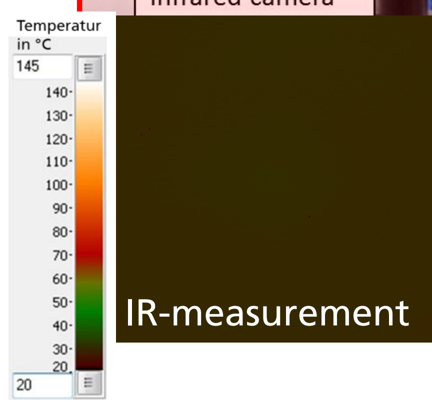
v = 0,0015 m/s

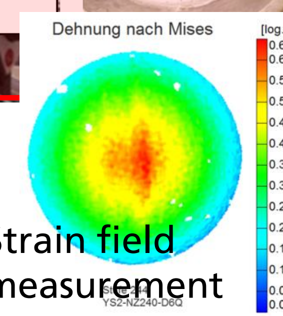


v = 5 m/s

High speed-3D-video recording and infrared measurement with 45° mirror:







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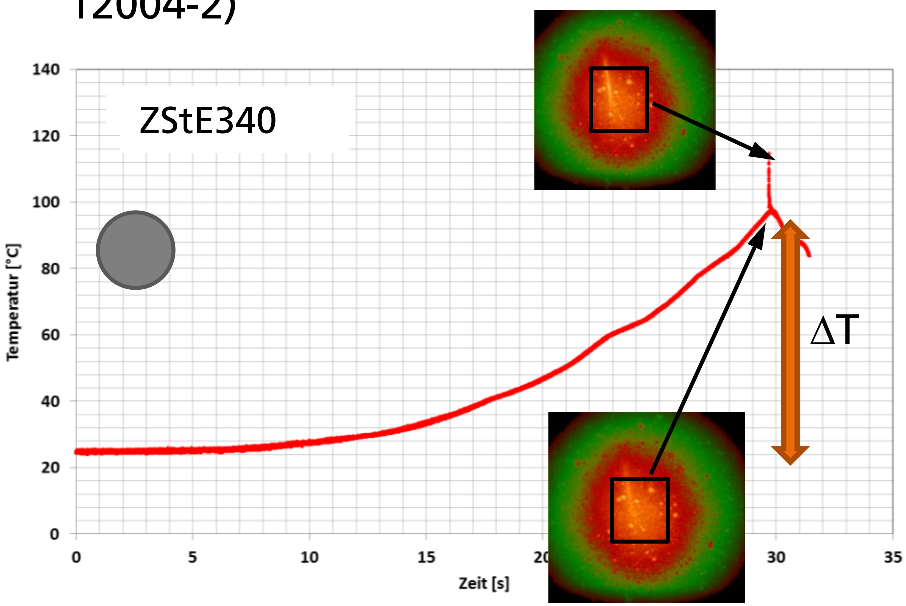
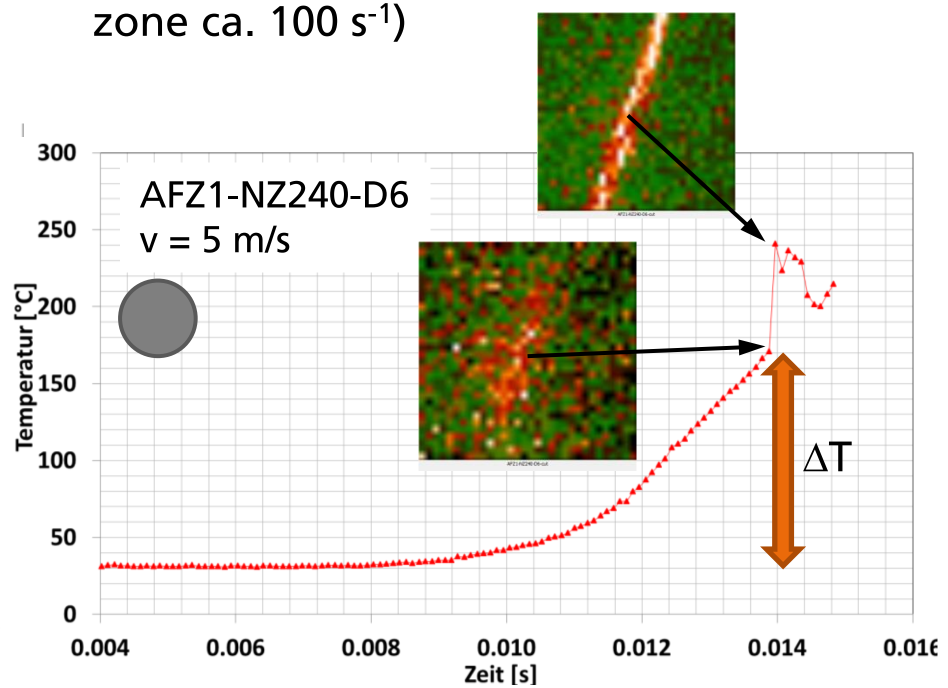
Adiabatic temperature rise for nakajima tests

ZStE340, v = 1.5 mm/s und 5 m/s

<u>v = 1.5 mm/s</u>
(Test speed for the determination of forming limits according to DIN EN ISO 12004-2)



<u>v = 5 m/s</u>
(local strain rates in the highly deformed zone ca. 100 s^{-1})



measured <u>maximal</u> temperatur rise in the highly deformed zone immediately before fracture: **70 K**

measured <u>maximal</u> temperatur rise in the highly deformed zone immediately before fracture: **140 K**

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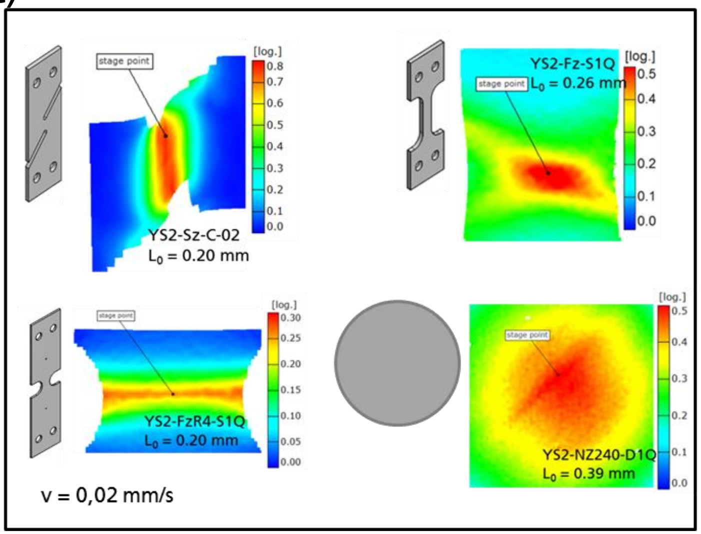
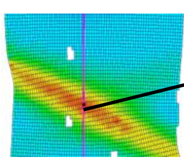
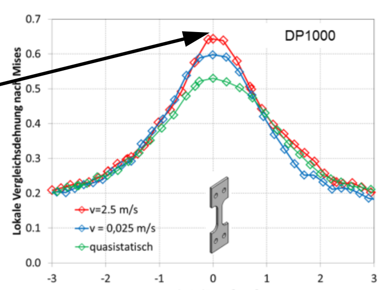
Influence of strain rate on material behavior under multiaxial loading situations

Failure strains determined by DIC

DP1000: Strain fields immediately before fracture (DIC)

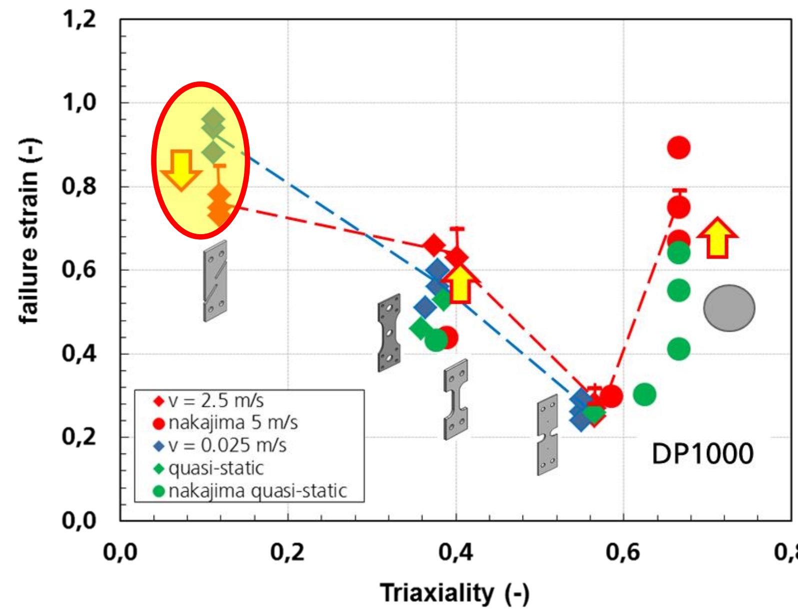






Evaluation of point with maximal strain before fracture

Experimentally determined failure strains:



Influence of strain rate on failure strains

Anmerkung: Triaxiality determined by FE-simulation

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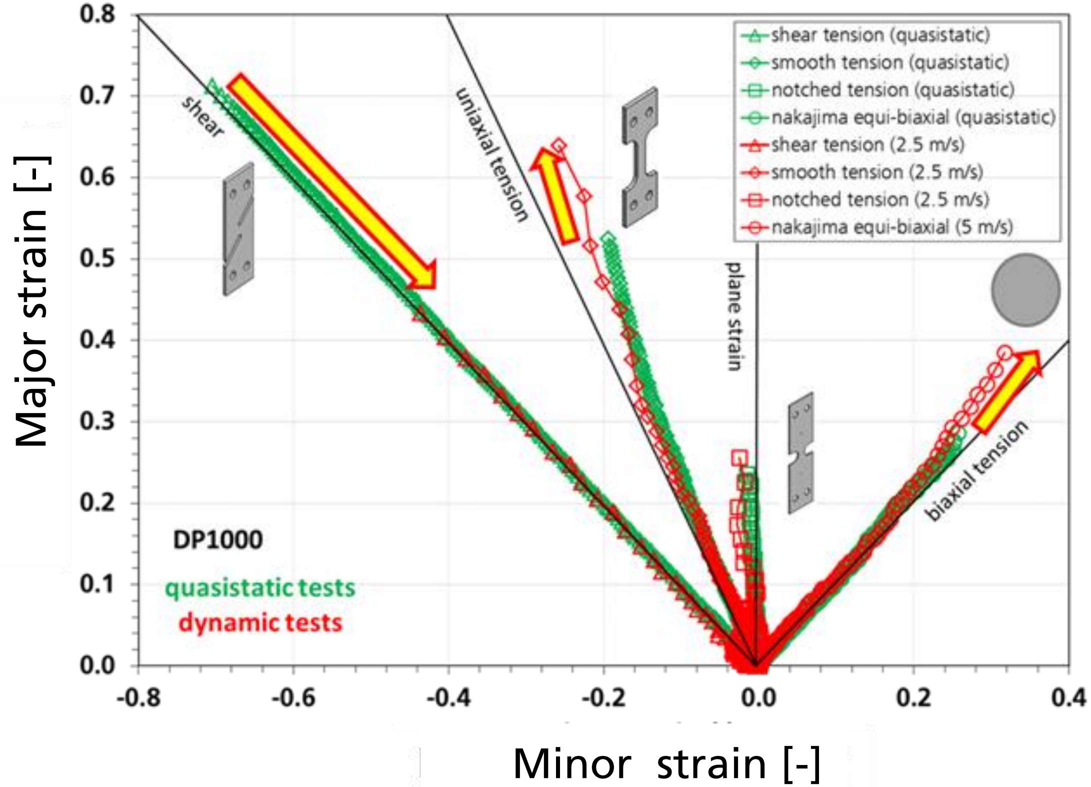
Influence of strain rate on material behavior under multiaxial loading situations
Strain paths up to fracture

Evaluation of the time dependent development of major and minor strain up to fracture for a point with maximal strain before fracture:



Influence of strain rate on failure strains

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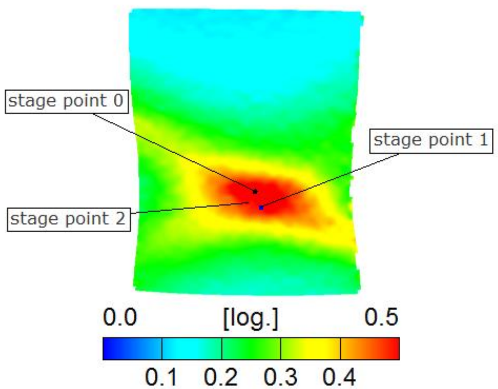
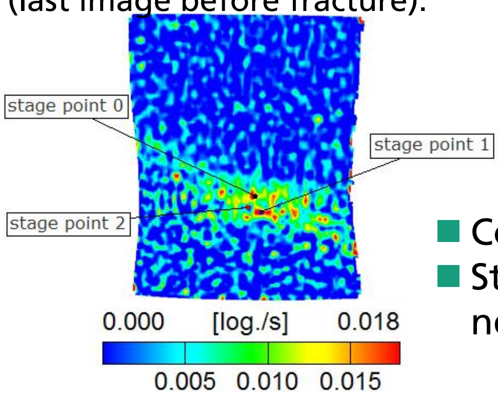
Influence of strain rate on material behavior under multiaxial loading situations

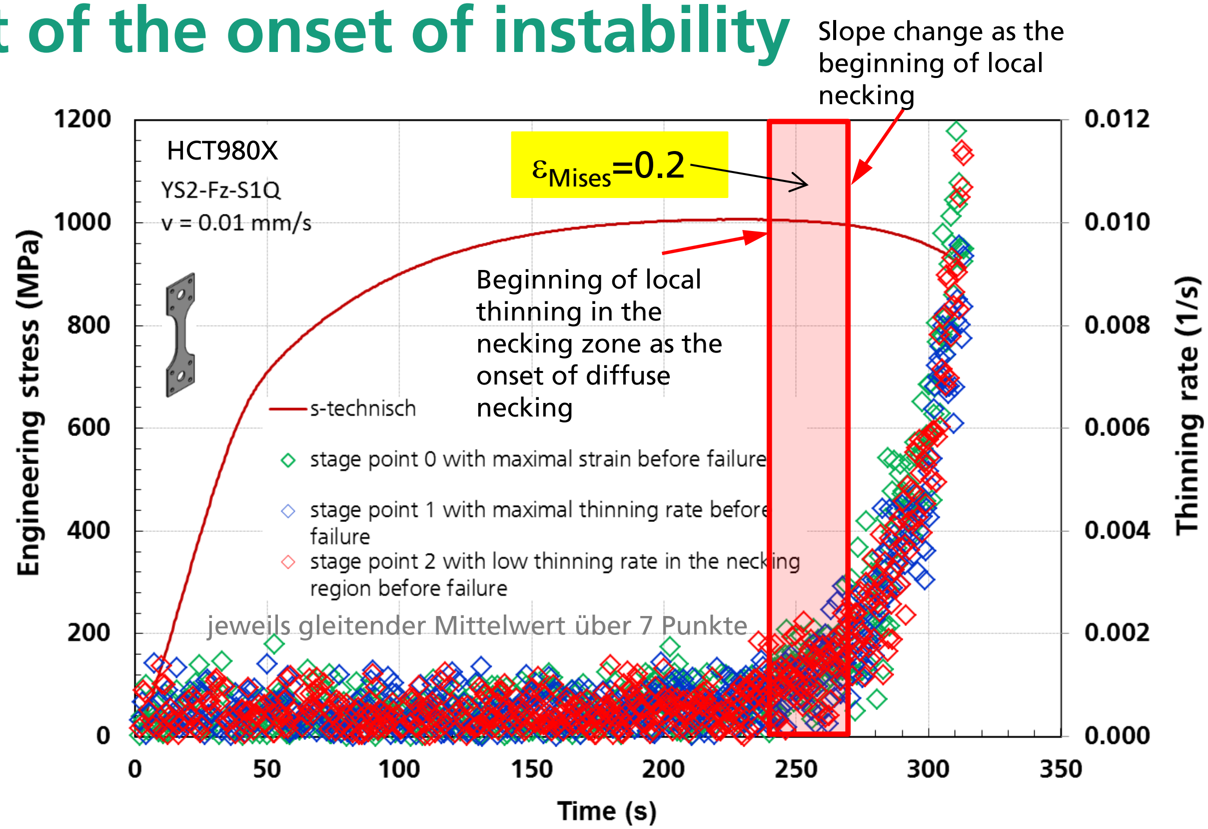
Evaluation concept of the onset of instability

<u>v. Mises equivalent strain</u>
(last image before fracture):



<u>Thinning rate</u>
(last image before fracture):





- Comparable curves for the different points in the necking zone
- Strain at the time of slope change is defined as the beginning of local necking and onset of instability

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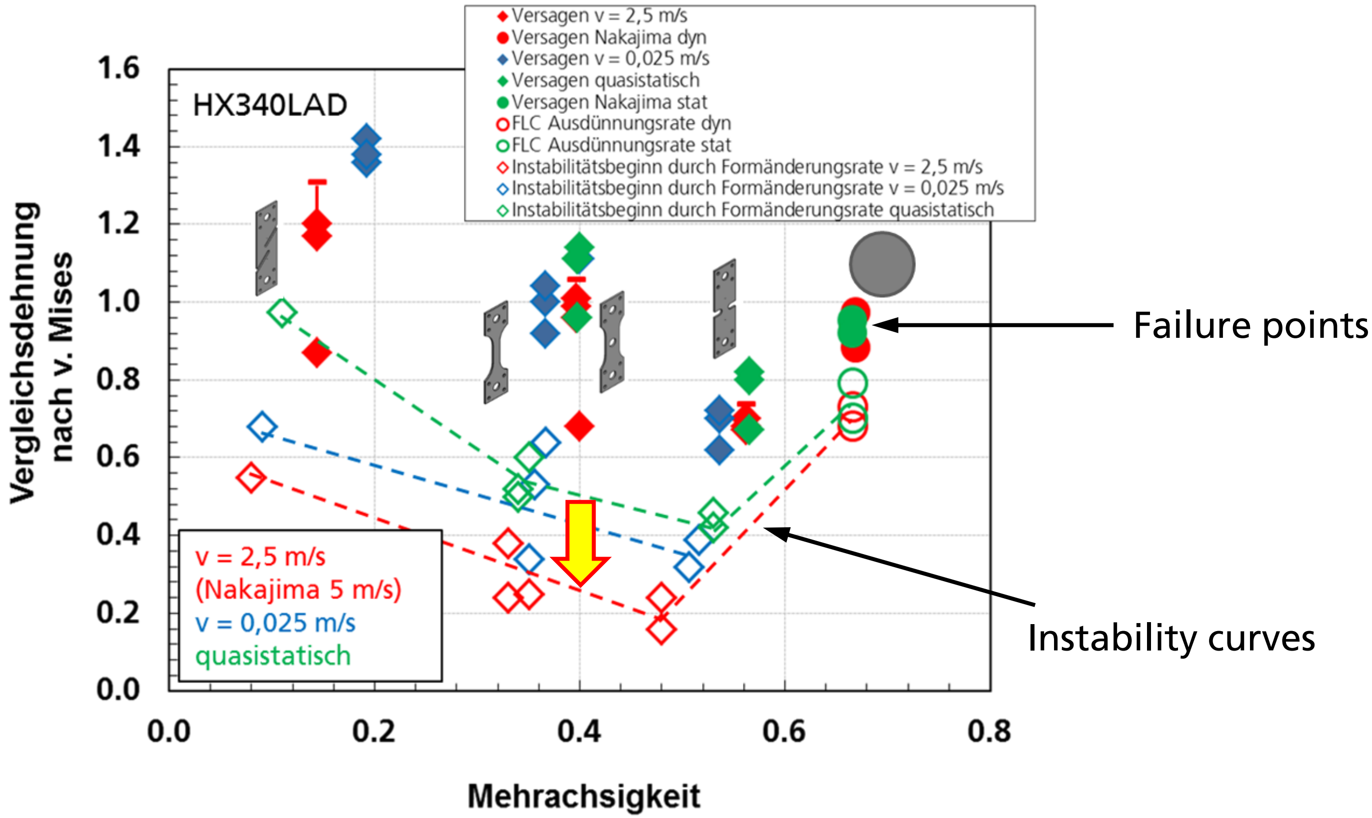
Influence of strain rate on material behavior under multiaxial loading situations

Influence of strain rate on the onset of instability



Under dynamic loading tendency of smaller values for strains at the onset of instability compared with quasistatic loading

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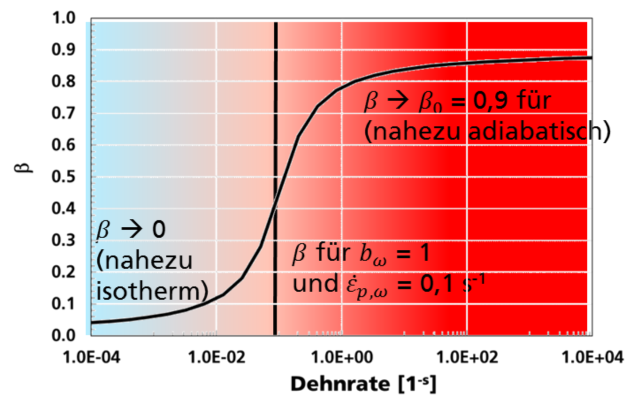
FE-Simulation: Considering influence of strain rate and stress state on material behavior

Adiabatic softening (MAT_TABULATED_JOHNSON_COOK)

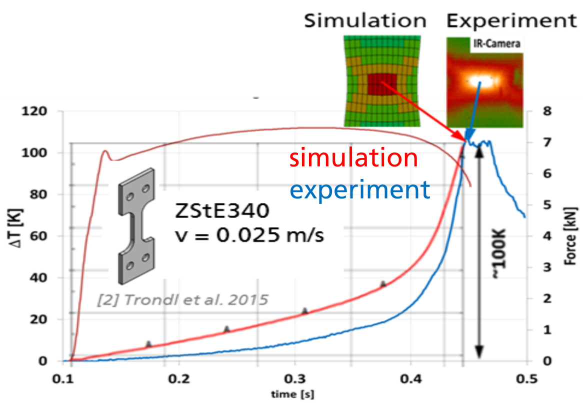
- Avoiding thermomechanical coupling in simulation with pseudothermomechanical material model
- isotropic thermo-viscoplastic material model with adiabatic softening dependent on strain rate (LS-Dyna, MAT_224)
- Johnson-Cook-approach: $\sigma = s(\varepsilon_p, \dot{\varepsilon}_p) \cdot g(T)$

  with $s(\varepsilon_p, \dot{\varepsilon}_p)$: isothermal flow curves

  g(T): softening function
- Temperature calculation: $\dot{T} = \frac{\partial T}{\partial t} = \beta(\dot{\varepsilon}_{pl})\frac{\sigma \dot{\varepsilon}}{\rho c_p}$



b_ω - width of the transition region
$\dot{\varepsilon}_{p,\omega}$ - "transition strain rate"



- non-isothermal strain rate range: good prediction of material behavior for uniaxial tension
- Influence on stress state on adiabatic softening will be considered in the future

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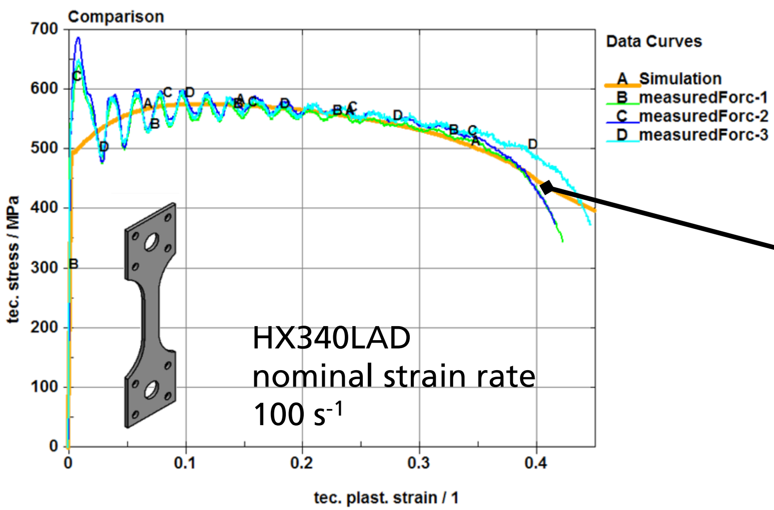
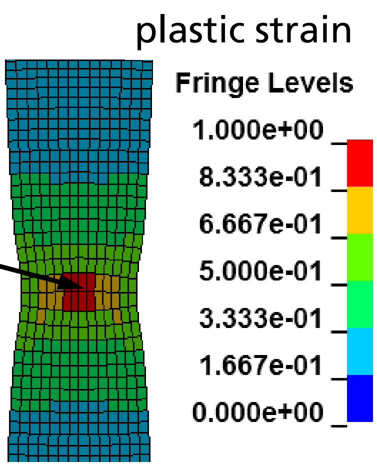
FE-Simulation: Considering influence of strain rate and stress state on material behavior

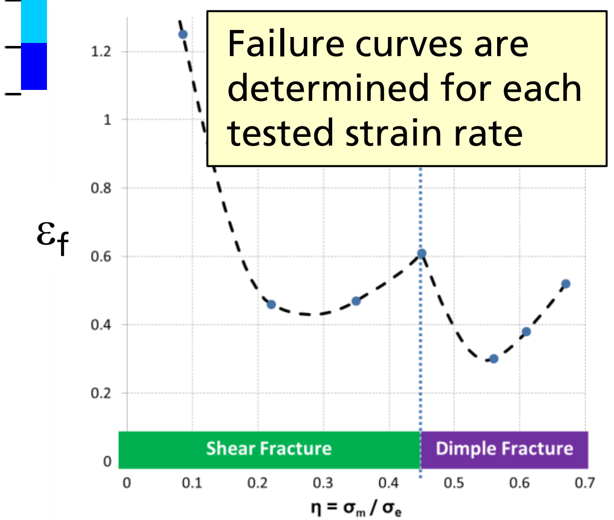
Failure, damage (MAT_ADD_EROSION, GISSMO)

1. Simulation of specimen tests





Failure strains determined by simulation



2. Failure curves

two spline-interpolations for

two damage areas of the failure curves (shear failure and dimple fracture)

Comment: Gissmo = Generalized Incremental Stress State dependent damage model (Haufe et. al. 2011)

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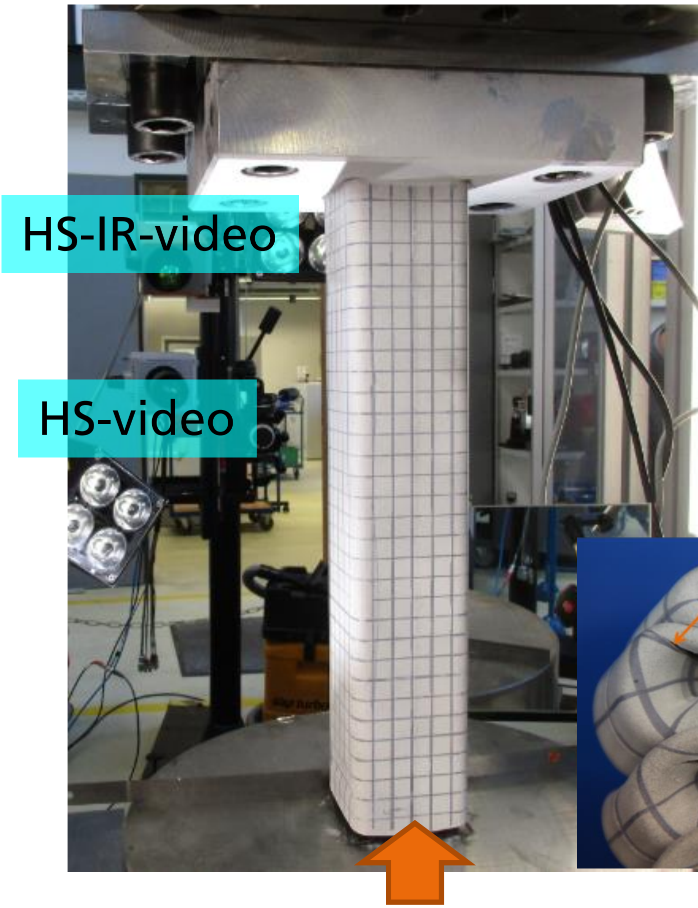
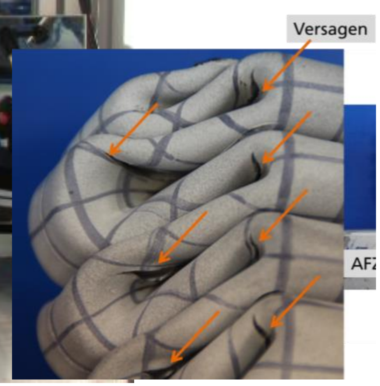
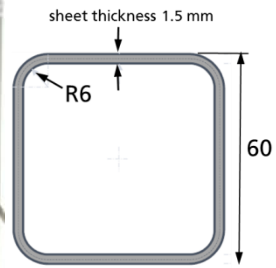
Modelvalidation

Dynamic component tests (v = 5 m/s)





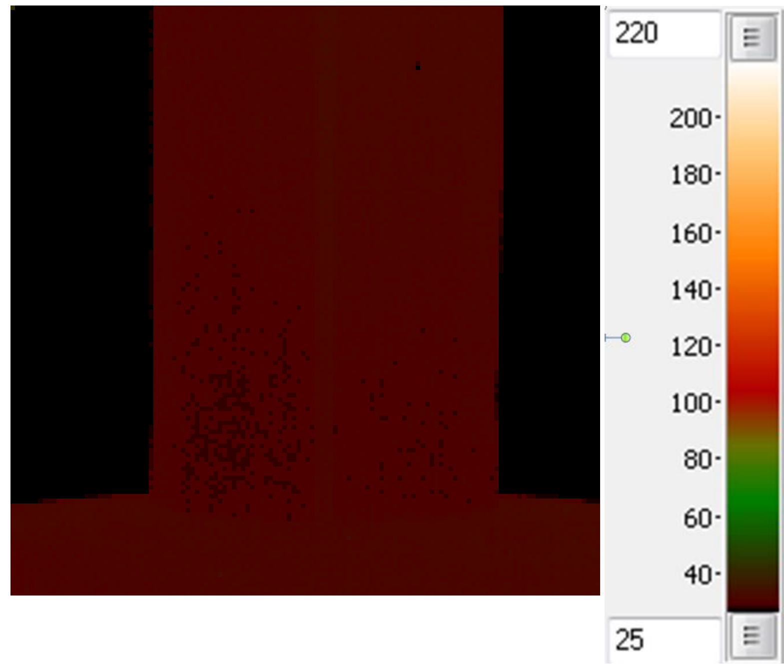
DP1000



Measurement of force deformation behavior

High speed infrared measurement

temperatur in °C



Measurement of temperature development

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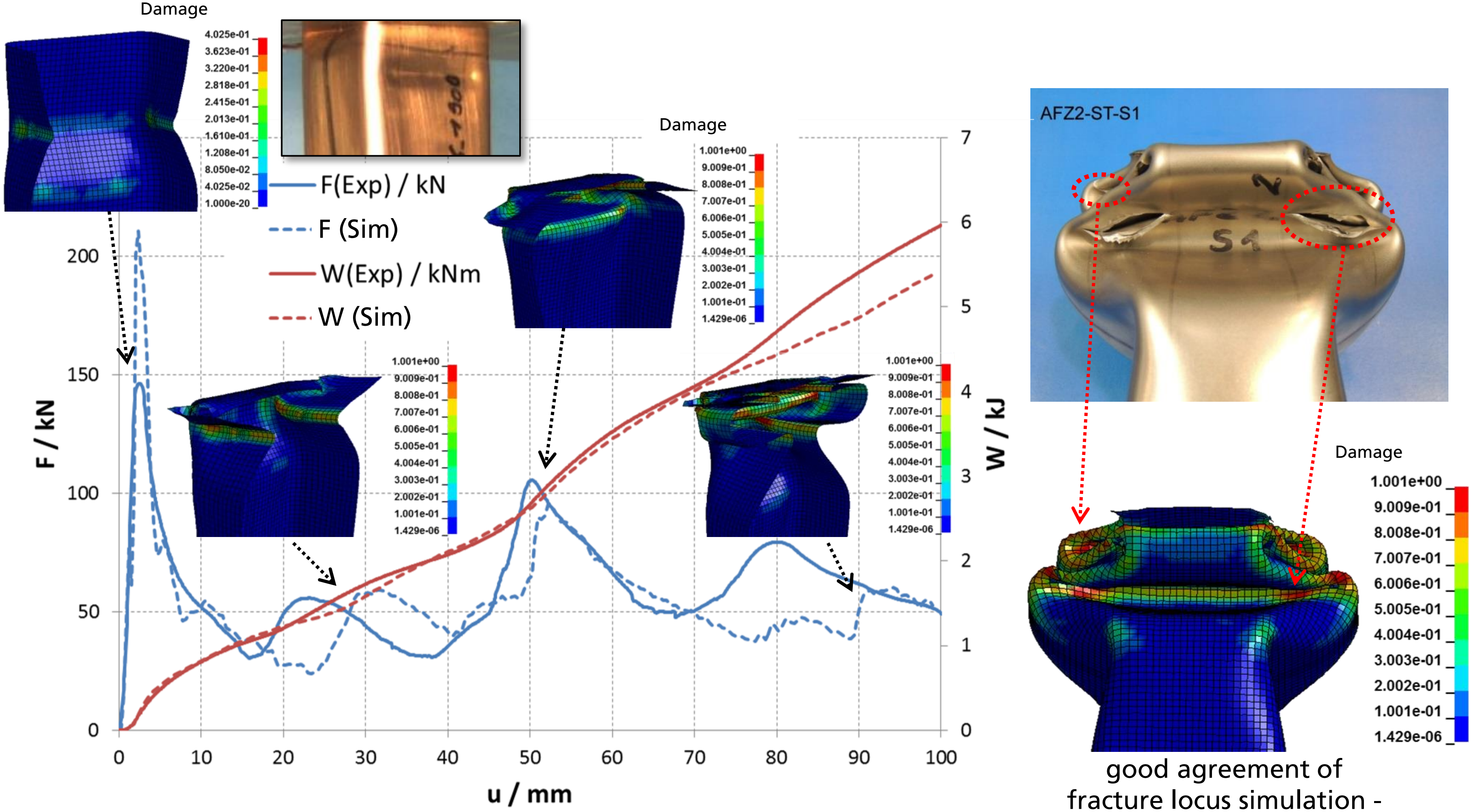
Component tests and simulation

HCT980X, Force-displacement, local damage, static



good agreement of fracture locus simulation - experiment

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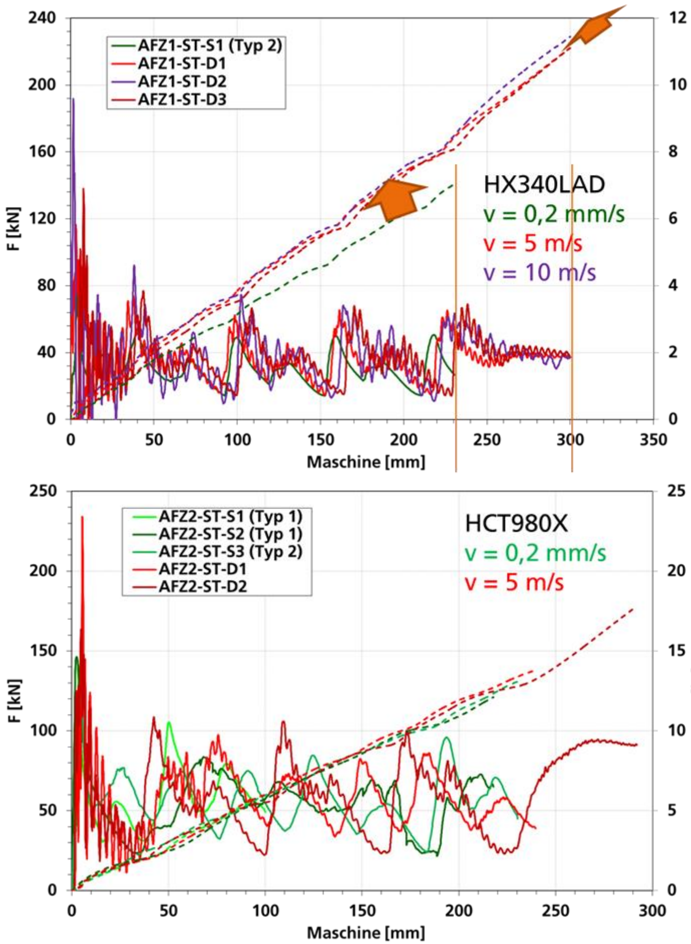
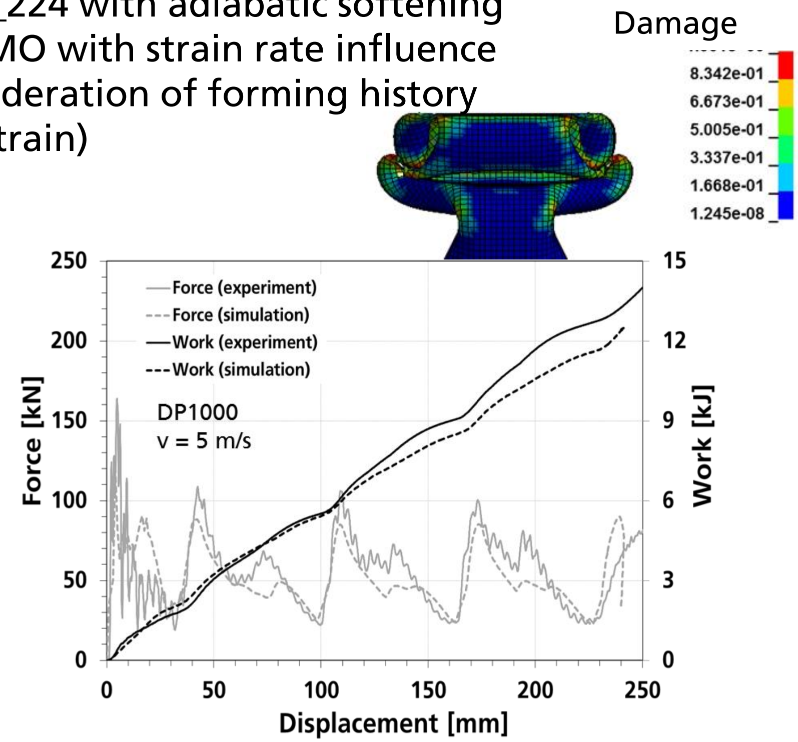
Modelvalidation
Energy absorption of dynamically tested component

experiment



simulation

Example for
- MAT_224 with adiabatic softening
- GISSMO with strain rate influence
- Consideration of forming history (prestrain)



Under dynamic loading material dependent higher energy absorption compared to quasistatic loading!

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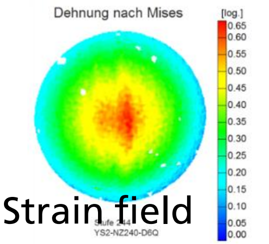
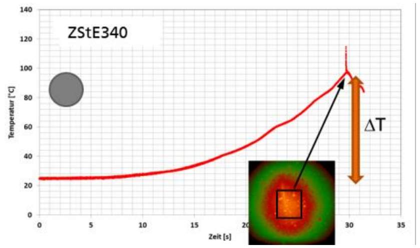
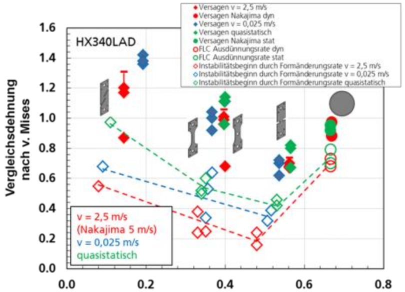
Summary

- Specimen tests at high strain rates and different loading situations
  - Strain and temperature field measurement

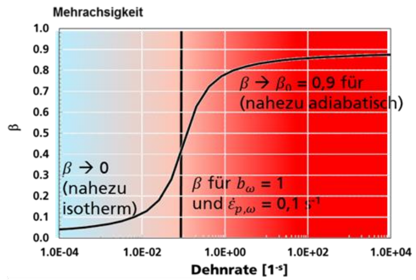


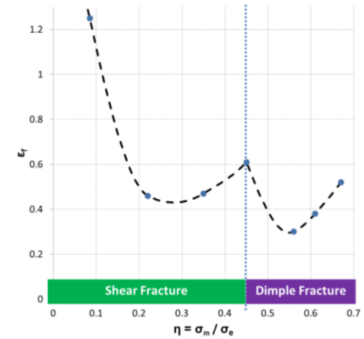
- Material data for simulation



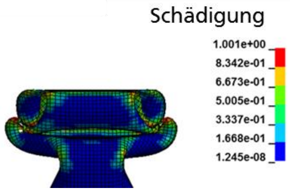


- Modeling
  - Johnson-Cook-model
  - Gissmo-failure model





- Modelvalidation



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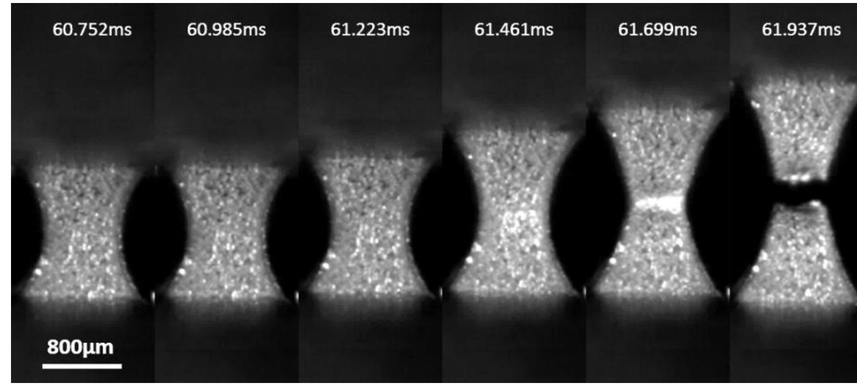
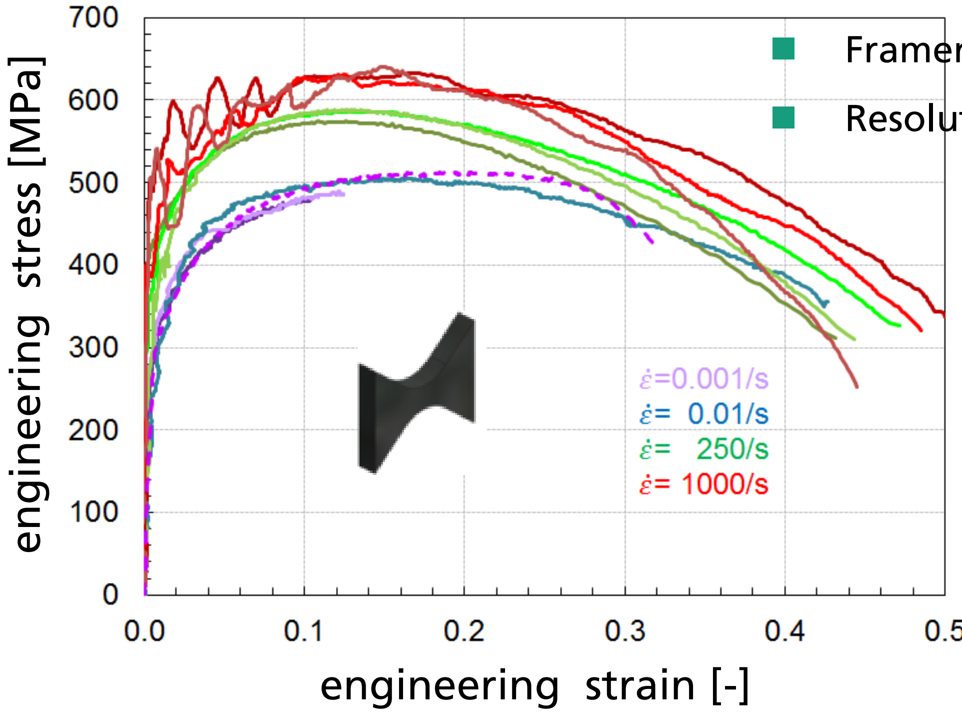
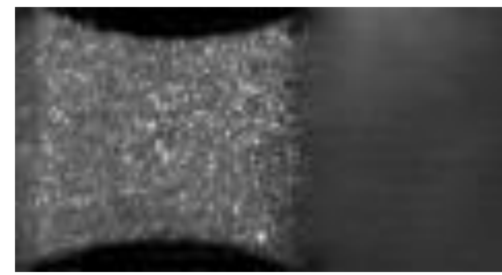
Perspective: Micro Testing over 5 Strain Rate Decades

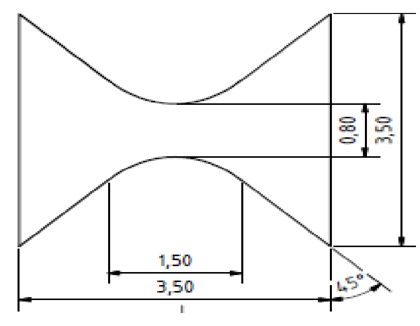
- Velocity of testing: 1 m/s
- Acceleration: 50 m/s²
- Framerate: 300.000 fps





- Framerate: 200.000 fps
- Resolution: 256x64 pixel





Geometry of tested specimen

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Acknowledgements

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