Friedrich-Alexander-Universität
Technische Fakultät

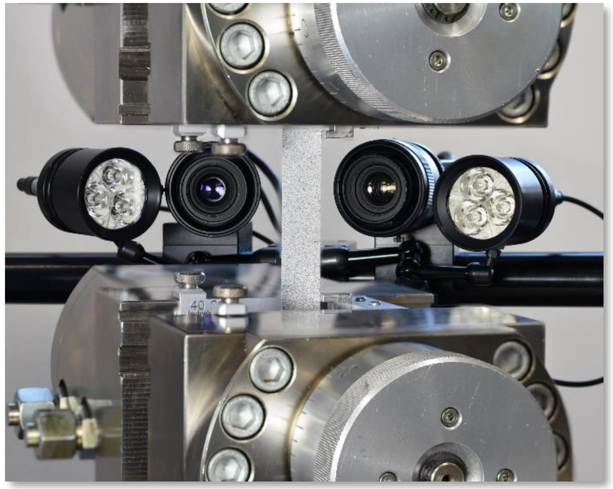
Institute of Manufacturing Technology
Friedrich-Alexander-Universität Erlangen-Nürnberg
Prof. Dr.-Ing. habil. Marion Merklein
Prof. Dr.-Ing. habil. Dipl.-Inf. Hinnerk Hagenah

Current challenges in sheet metal characterization

Martin Kraus M.Sc., Peter Hetz, M.Sc., David Naumann M.Sc.,
Prof. Dr.-Ing. habil. Marion Merklein

16.10.2023

- Motivation
- Overview sheet metal characterization
- Current research topics

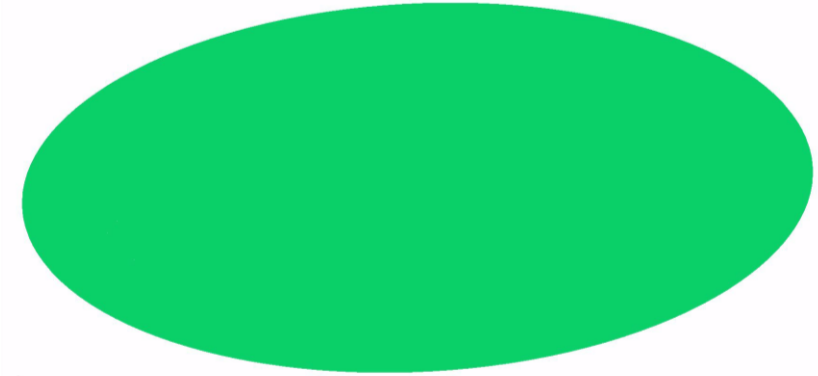


Tensile Test with ZwickRoell
and Zeiss GOM 3D-DIC

Motivation

What‘s the use of material characterisation?

- Improvement of the product quality
- Higher safety in case of car accidents
- Protection of the environment
  - Efficient use of material
  - Less consumption of resources
  - Fuel savings through lightweight design
  - Sustained reduction of CO_2-emissions in production and products



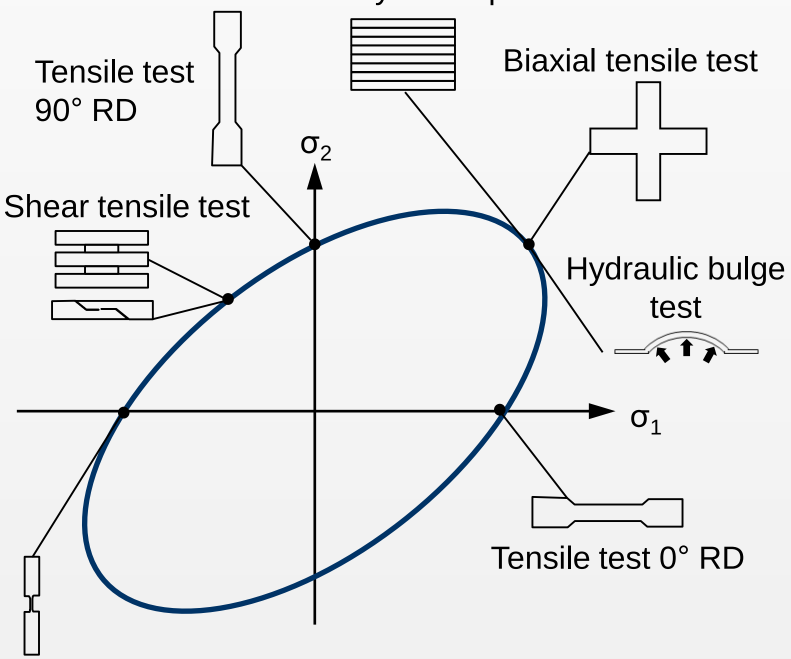
FEA of a deep drawing process

Overview sheet metal characterization

Yielding and Strain Hardening

Start of yielding

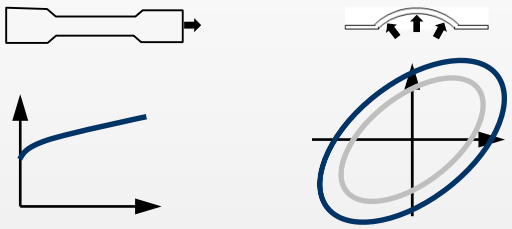
Layer compression test



Uniaxial compression test

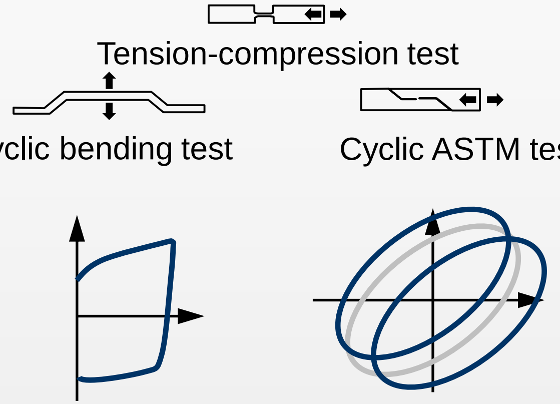
Yield locus curve

Isotropic hardening



Monotonous flow behavior

Kinematic hardening

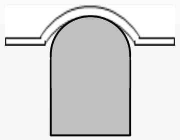


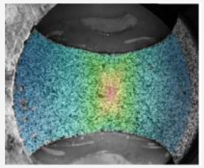
Yield locus translation (Bauschinger)

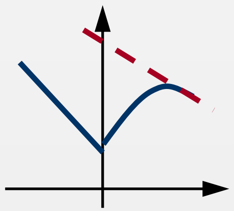
Failure

Forming limit

Nakajima



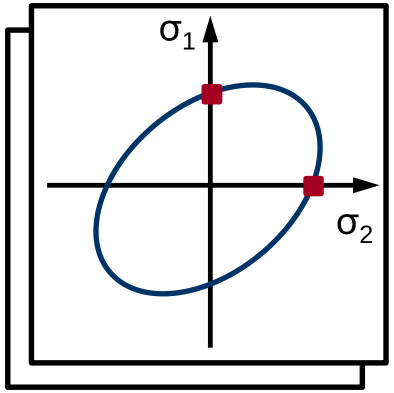


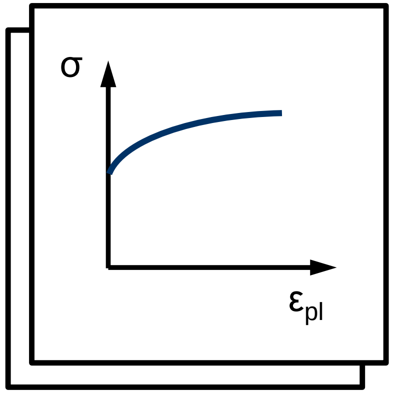


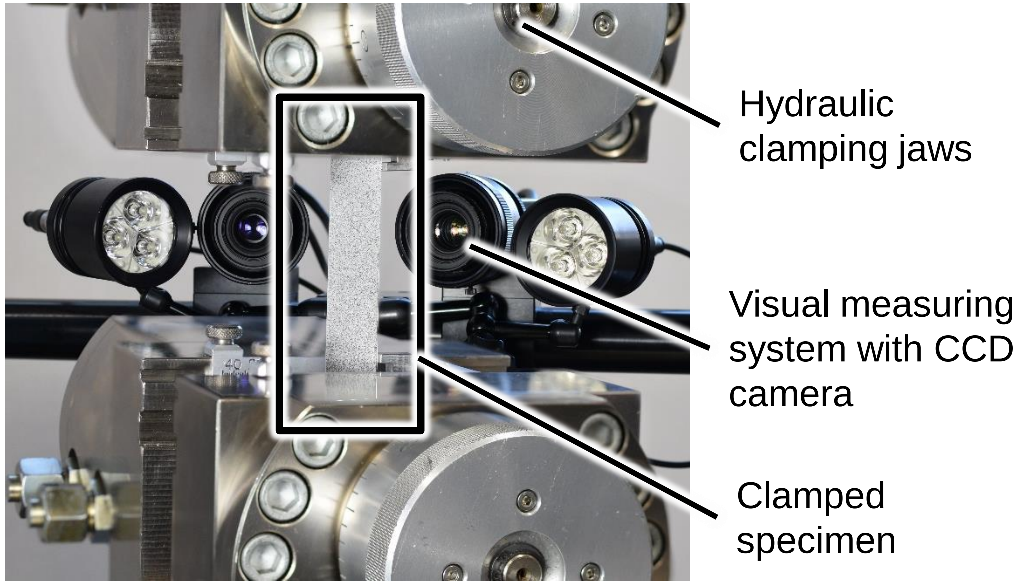
Uniaxial Tensile Test

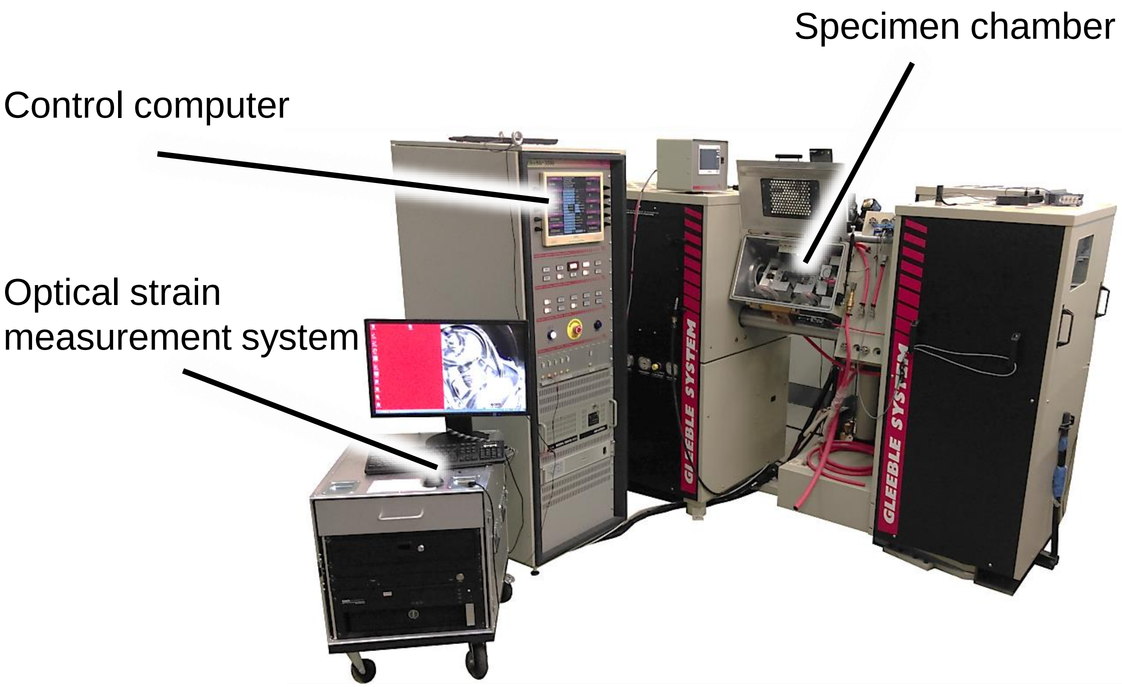
Characteristics

- According to ISO 6892
- Temperature up to 1000 °C and srain rates up to 50 1/s
- Standardized experimental set-up
- Simple stress state ($\sigma_1 \neq 0$, $\sigma_2 = \sigma_3 = 0$)
- Tests with constant rate of deformation
- Optical strain evaluation with DIC





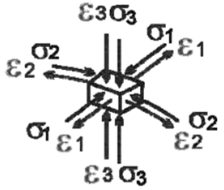


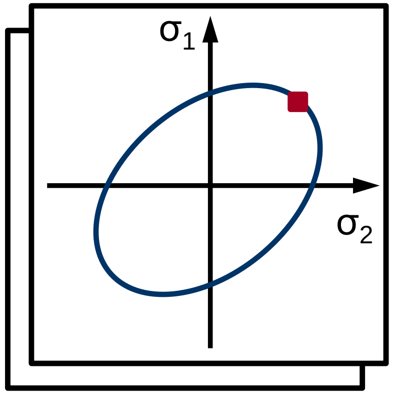


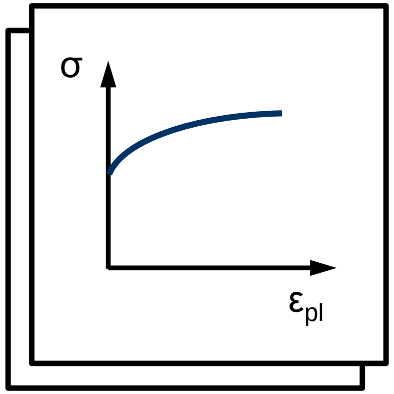
Layer Compression Test

Characteristics

- Following ISO 50106
- Biaxial loading
- Tests with constant rate of deformation
- Visual strain evaluation with two DIC systems
- High strain achievable

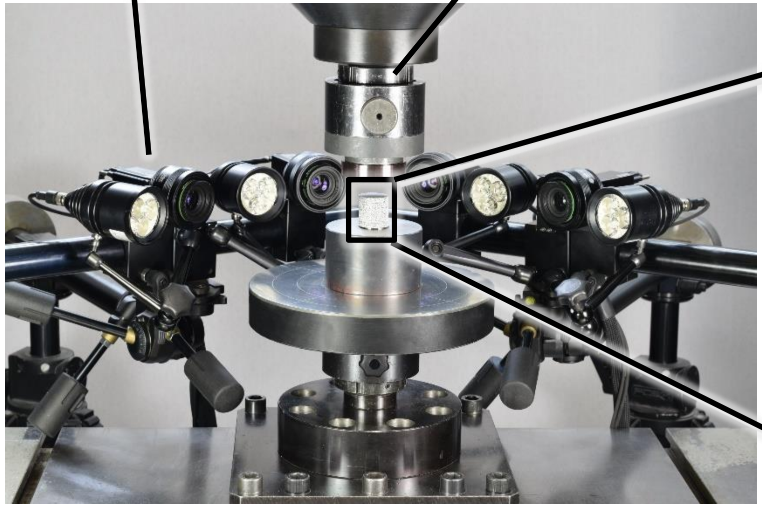






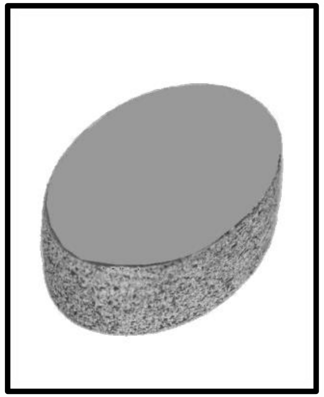
Visual measuring system with CCD camera

Load cell



Layer compression test set-up on a universal testing machine

Initial state



Final state

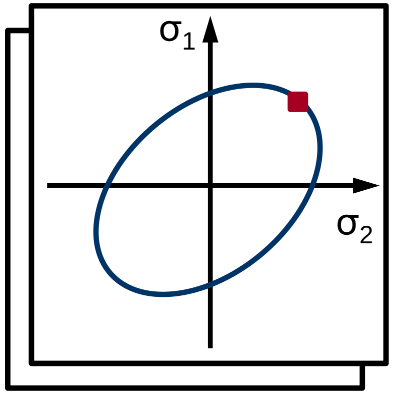
Applications

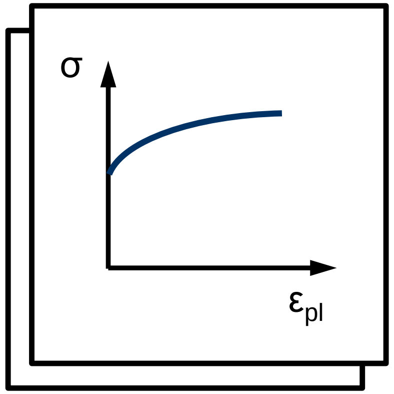
- Yield criterion: characterization of the behavior under biaxial load – yield locus definition (Y_b, r_b)
- Strain hardening law: support point for flow curve and isotropic hardening models

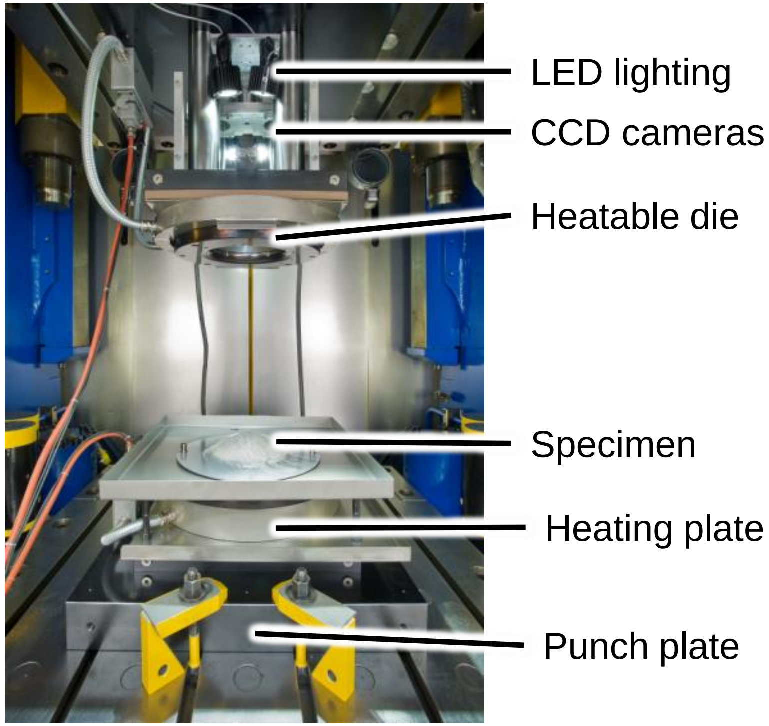
Hydraulic Bulge Test

Characteristics

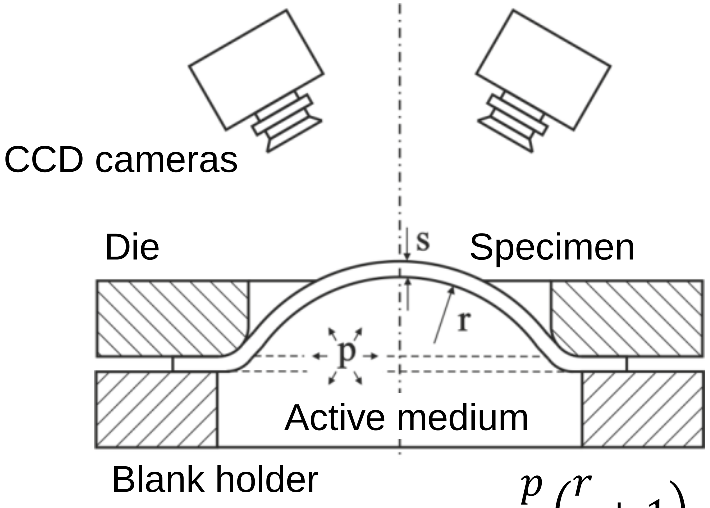
- According to ISO 16808
- Biaxal stress state (stretch forming)
- Tests with strain rate control over the entire test
- Visual strain evaluation with DIC
- High strain achievable







Bulge test set-up on a hydraulic press



$$\sigma_{pl} = \frac{p}{2}\left(\frac{r}{s} + 1\right)$$

Schematic layout

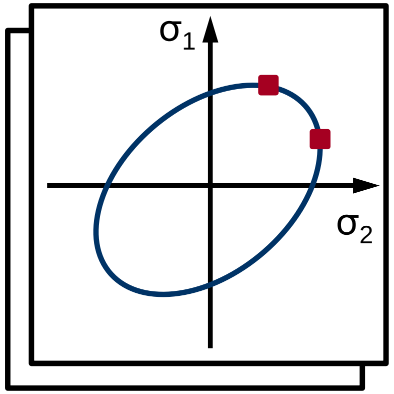
Applications

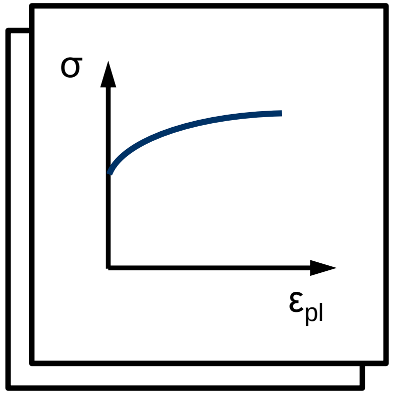
- Yield criterion: characterization of the behavior under biaxial load – yield locus definition (Y_b, r_b)
- Strain hardening law: support point for flow curve and isotropic hardening models

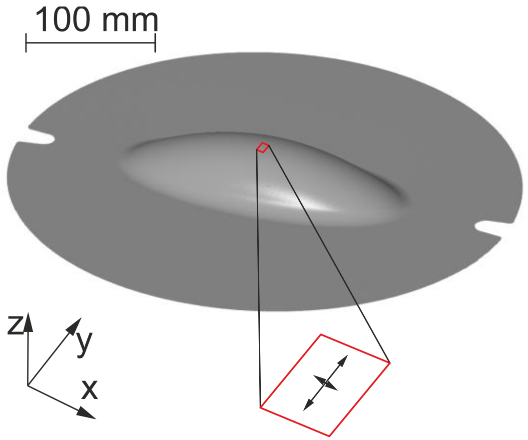
Hydraulic Bulge Test

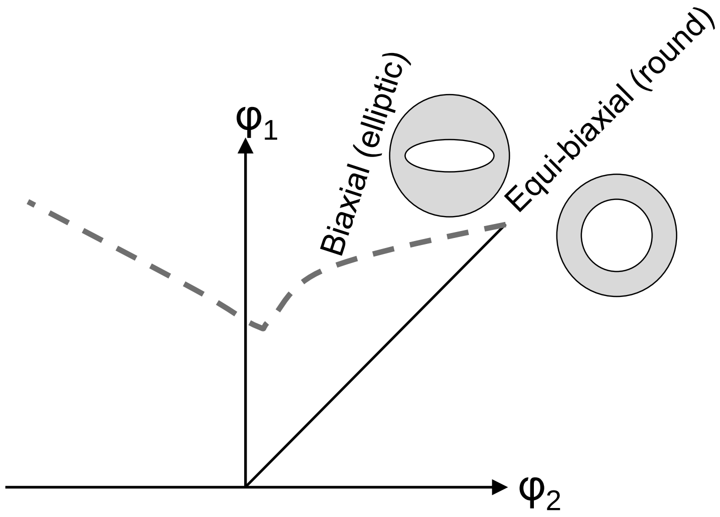
Characteristics

- Biaxal stress state (Ratio of the ellipse radii influences the ratio of major/minor strain)
- Stress state near plane strain representable
- High strain achievable









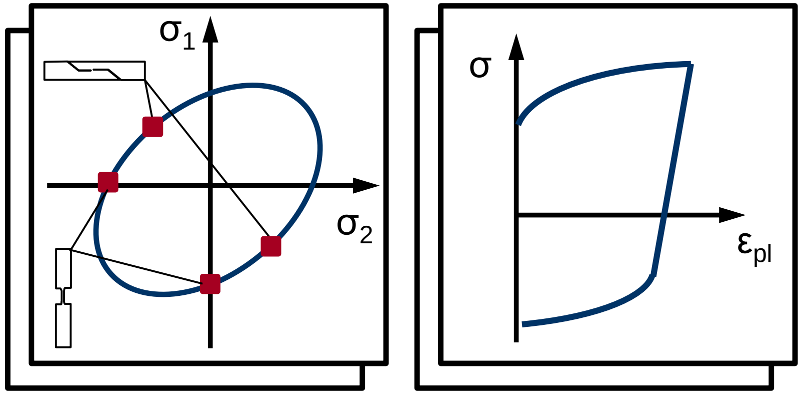
Applications

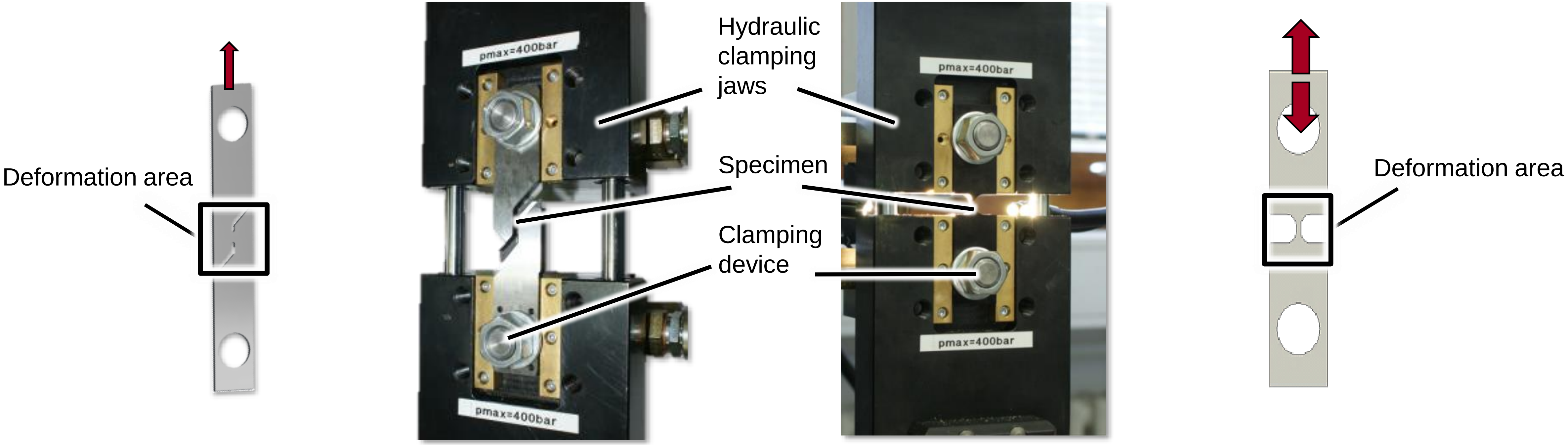
- Yield criterion: characterization of the behavior under biaxial load – yield locus definition (Y_b, r_b)
- Strain hardening law: support point for flow curve and isotropic hardening models
- Forming limit curve: support points with positive major and minor strain

Tension-Compression Test / Shear Test

Characteristics

- Uniaxial / Shear stress state (tension and compression)
- Monotonous and cyclic material testing
- Investigation of the Bauschinger effect
- Risk of buckling under compression stress
- Visual strain evaluation with DIC

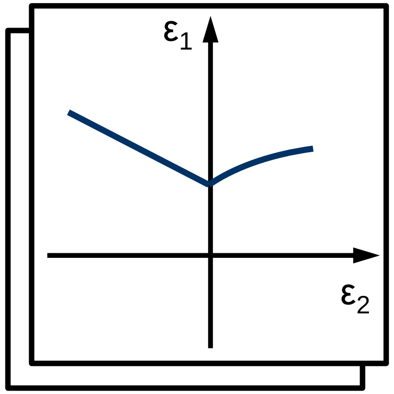


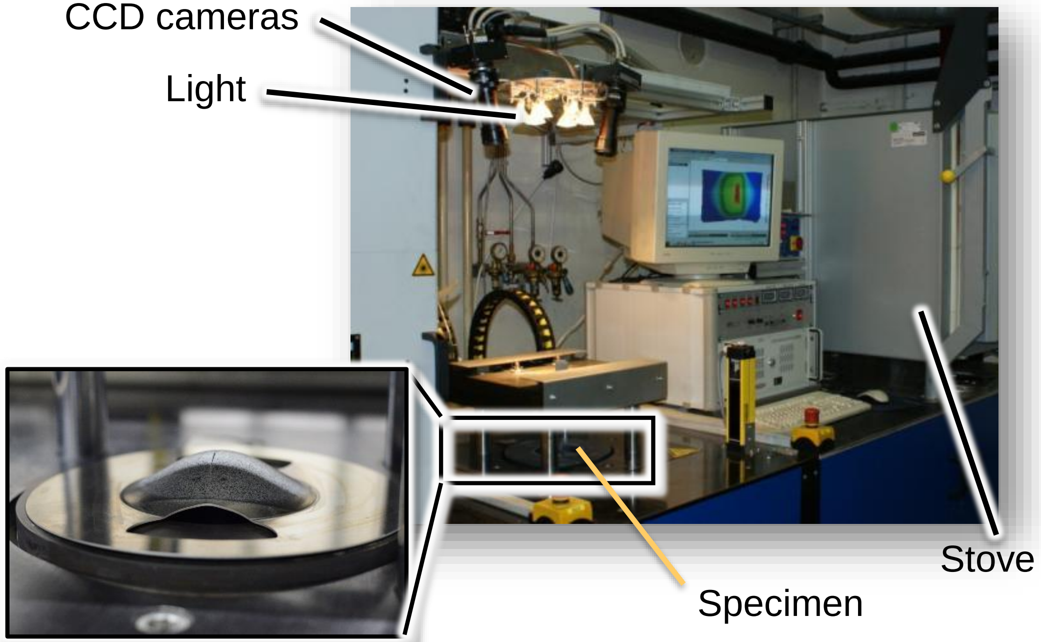


Nakajima Test

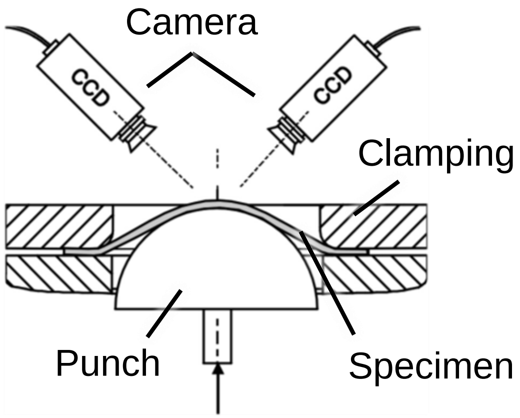
Characteristics

- According to ISO 12004-2
- Modification to Marciniak test possible
- Analysis of different strain paths by variation of the sample geometry
- Visual strain evaluation with DIC





Schematic test setup



Application

Failure criterion: characterization of the forming limits under various stress states – forming limit curve definition

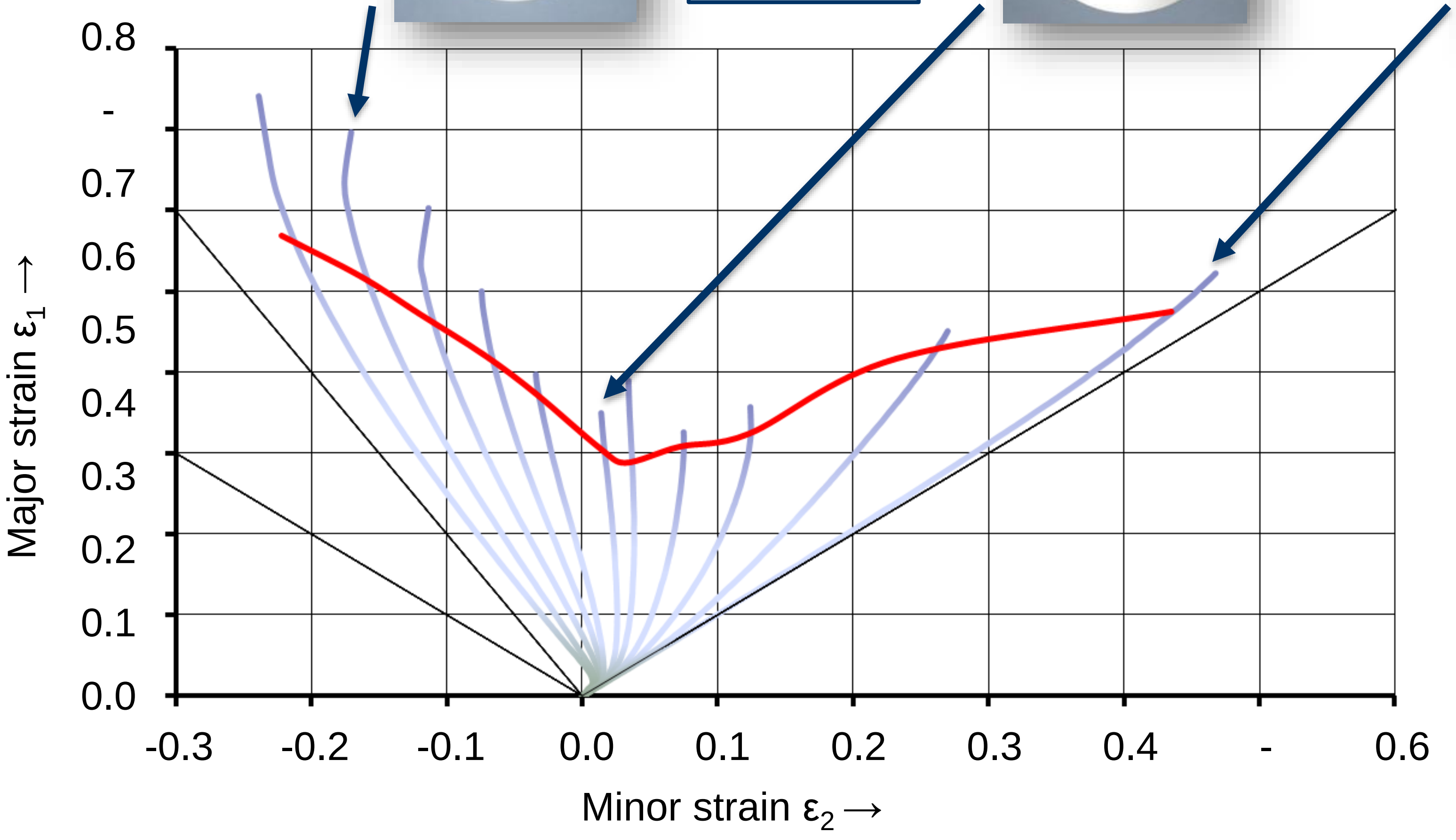
Nakajima Test

Forming limit curve determined from Nakajima tests with various specimen geometries

Specimen width 50 mm

Specimen width 100 mm

Full specimen



Current reasearch topic: Local material characterization

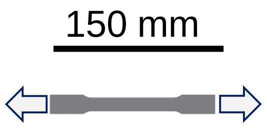
Analysis of the material behavior from formed sheet metal products

Clutch disc

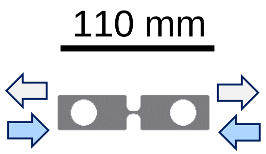
Middle segment of a B-pillar

Rim manufactured by hydroforming

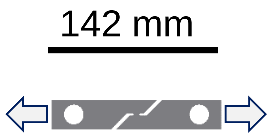
Conventional tests for sheet metal material characterization



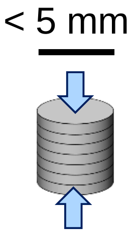
Tensile test
(standardized)



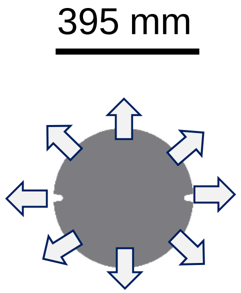
Tensile test/
Compression test
(not standardized)



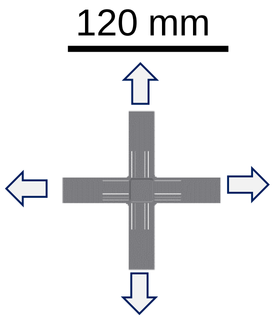
Shear tensile test
(not standardized)



Layer compression test
(not standardized)



Hydraulic bulge test
(standardized)



Cross tensile test
(standardized)

Challenges in the characterization of local material properties with conventional tests

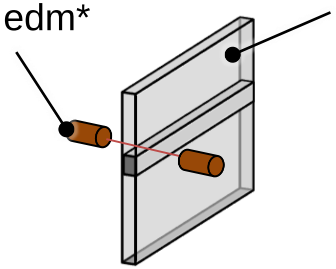
Specimen manufacturing of miniaturized upsetting specimens

Schematic procedure for specimen manufacturing

*electro discharge machining

Wire edm*

Sheet blank

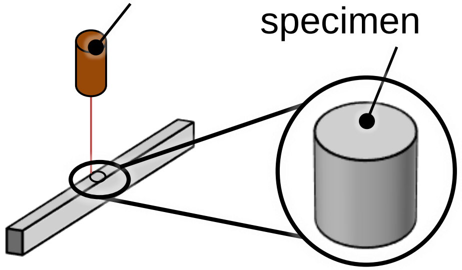


Cutting a strip from a sheet metal blank

Wire edm* machine:
AgieCharmilles CUT 2000

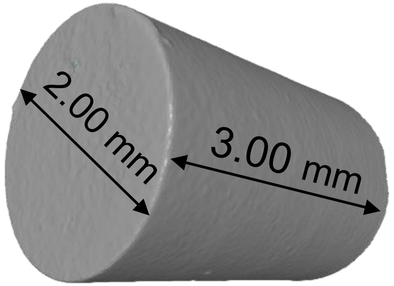
Micro edm*

Miniaturized specimen



Extraction of the sample from the strip

Micro edm* drilling machine:
Sarix SX-200-HBM



Ra < 0.2 µm

Optical measurement of the specimens

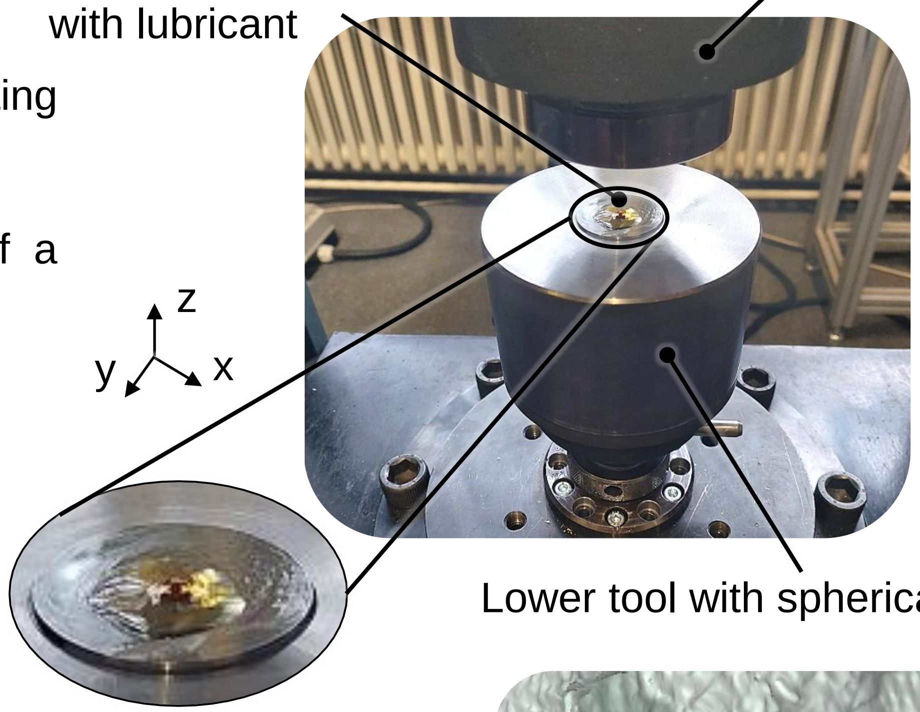
Optical measurement system:
InfiniteFocusG5

Accurate specimen manufacturing with a good surface quality to reduce the influence of friction

Upsetting test setup and evaluation

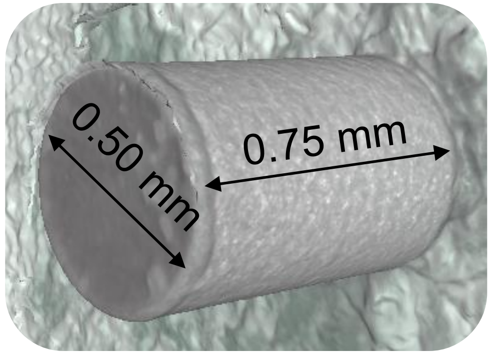
Test setup

- Performance of the upsetting tests on a Z10 universal testing machine (ZwickRoell AG)
- Ensuring the parallelity of the upsetting paths by means of a spherical cap
- Lubricant used to reduce friction influence



Evaluation

- Acquisition of the force and displacement measurement data
- Determination of strains in x- and y-direction under assumption of an isotropic deformation based on the z-strain using the approach of volume constancy



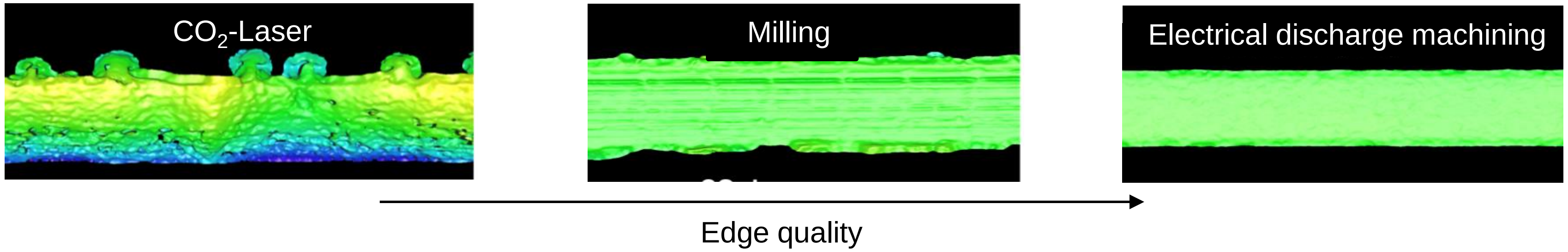
Miniaturized upsetting specimen

Determination of the flow behavior in the uniaxial compression stress state

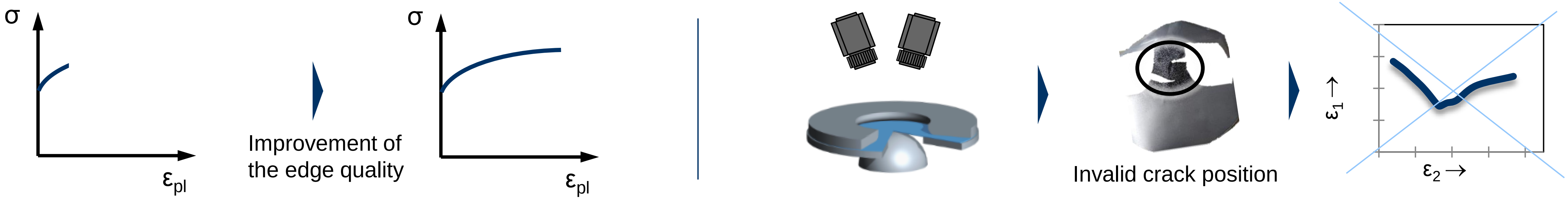
Current research topic: Metal foil characterization

Current challenges in the characterization of foil materials

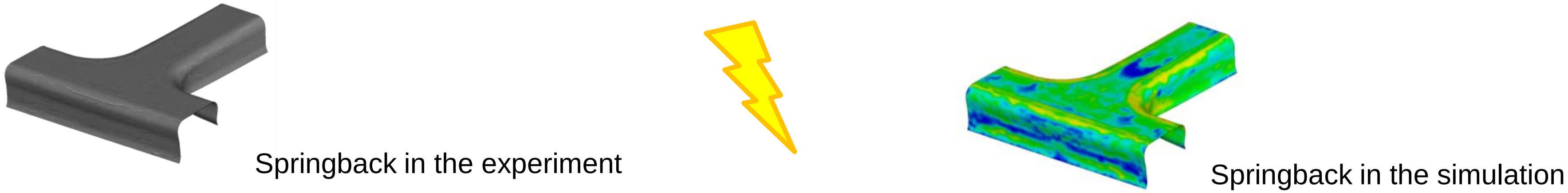
- High sensitivity of the material parameters with regard to the edge processing of test specimens



- No suitable test methods for determining the forming limit

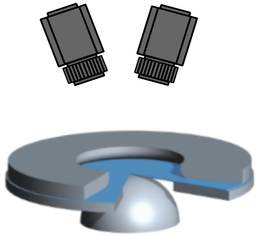


- Insufficient numerical mapping accuracy of springback behavior for industrial application



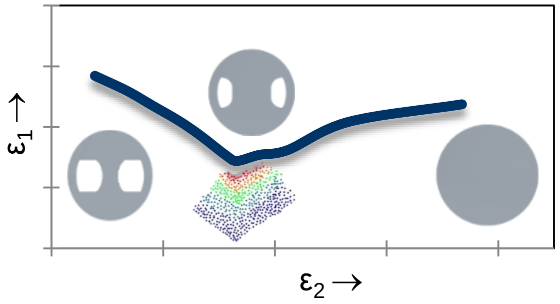
Improvement of the failure characterization for metal foils

Conventional determination of the forming limit of sheet materials



Nakajima test
(DIN EN ISO 12004-2)

Conventional forming limit curve

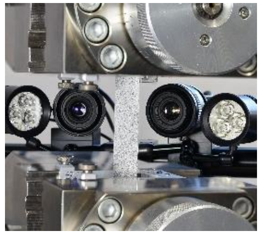


Current challenges

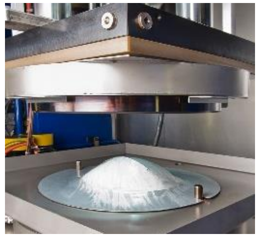
- Limited testing of sheet thicknesses below 0.3 mm
- Not strain controlled
- Frictionally sensitive

(Crack location with metal foils often not sufficient for a valid test according to standards)

Alternative approach based on the tensile test and the hydraulic bulge test (HBT)

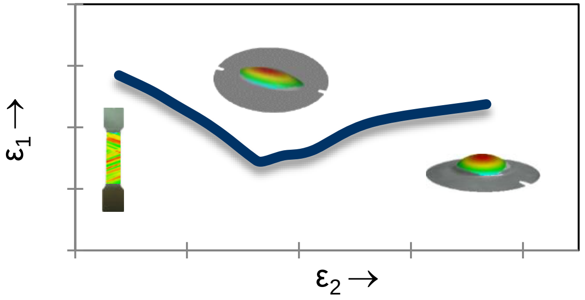


Tensile test
(DIN EN ISO 6892-1)



HBT
(DIN EN ISO 16808)

Alternative forming limit curve



Advantages compared to the state of the art

- Valid tests also with metal foils (sheet thickness $s_0 < 25$ µm)
- Strain-rate-controlled
- Almost no influence of friction
- No influence of edge machining by HBT

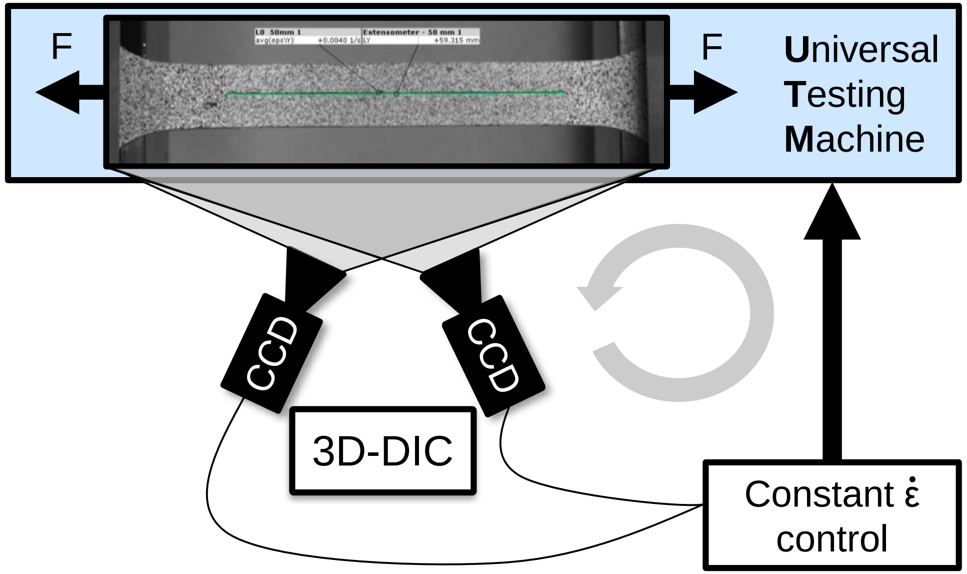
Enabling the forming limit determination of metallic foils

Optical strain rate control (OSRC)

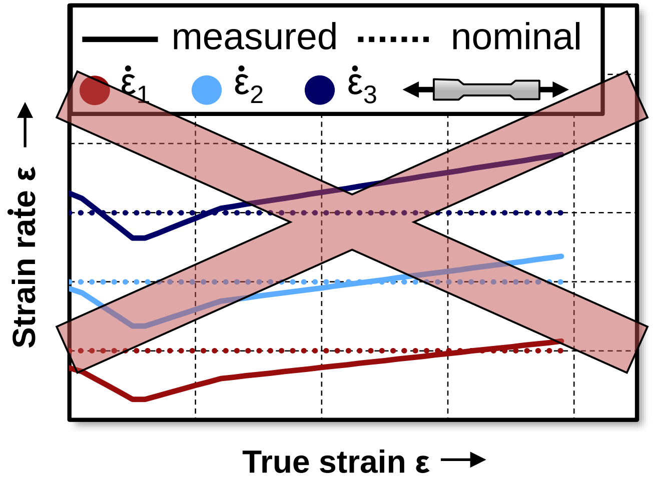
Challenges

- Current testing procedures obtain incoherent material data for FEA due to inconstant strain rate (up to failure)
- Strain rate increases significantly in the necking area

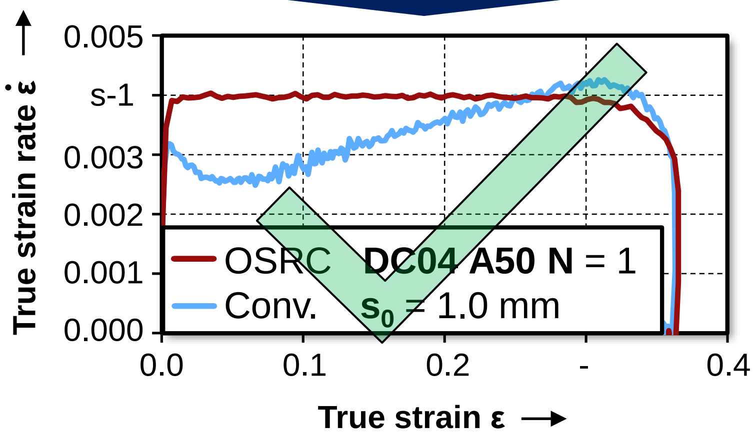
Optical closed loop strain feedback control (tensile test)



Determination of the flow behavior at constant true strain rate up to the failure strain in the region of necking



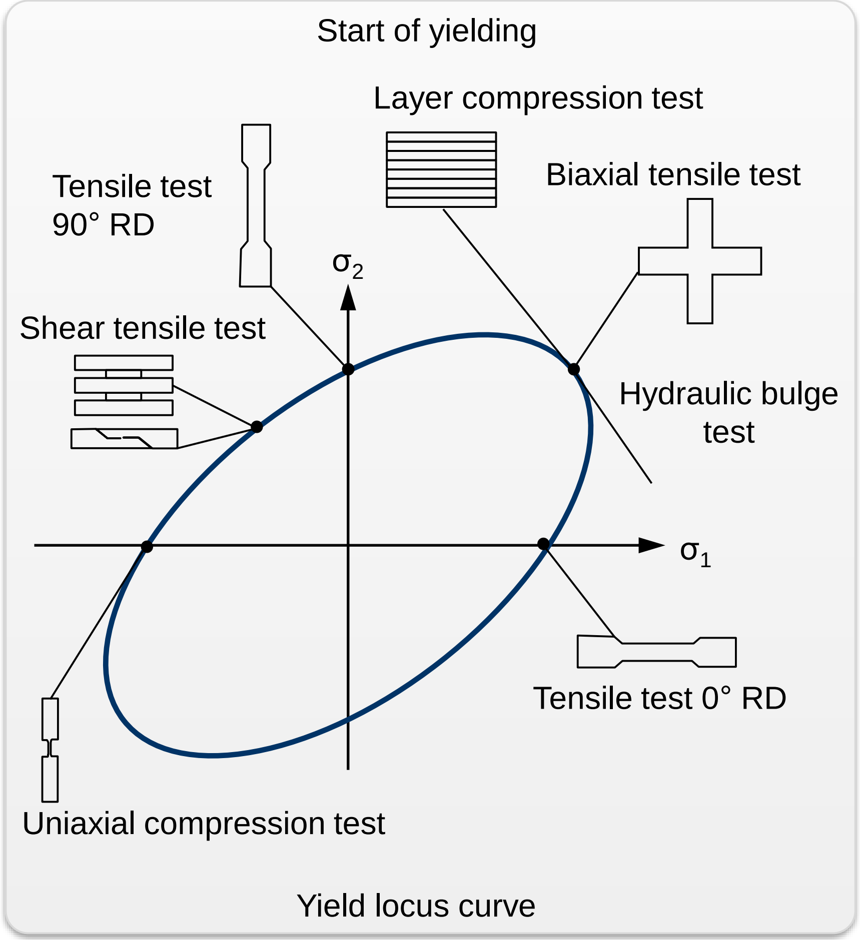
Closed-Loop-Control
ZwickRoell ↔ DIC



Summary

- Material characterization is still important in forming technology
- Large portfolio of test setups for characterization of forming and failure behavior
- Trend towards the use of foil materials and miniaturization of components creates new challenges
- Continuous improvement of current experiments e. g. by optical strain rate control

1 cent coin | Miniaturized upsetting specimen | Conventional upsetting specimen



Shaping ideas into solutions