Material characterization and modelling methods for the cryogenic forming of aluminium alloys

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#AAC Aerospace & Advanced Composites GmbH, Wiener Neustadt, AT

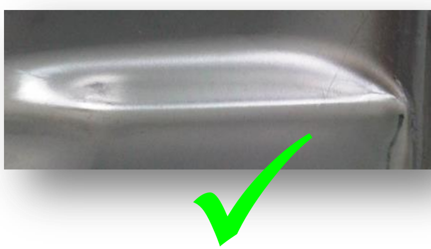
Joint and FFG-funded research by

Motivation

Preliminary experiments 5182 alloy:

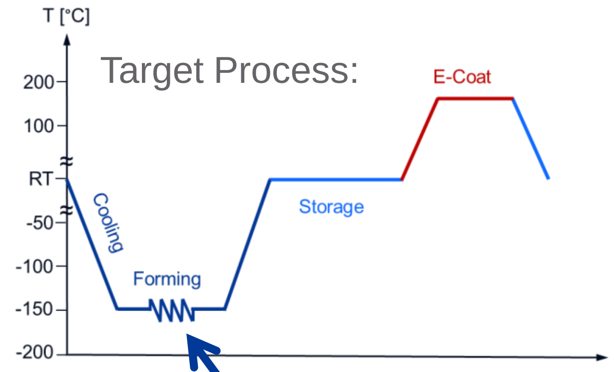
Forming at room temperature:

Cryogenic forming (-50° C cooled blank, Tool at RT) of the same component:

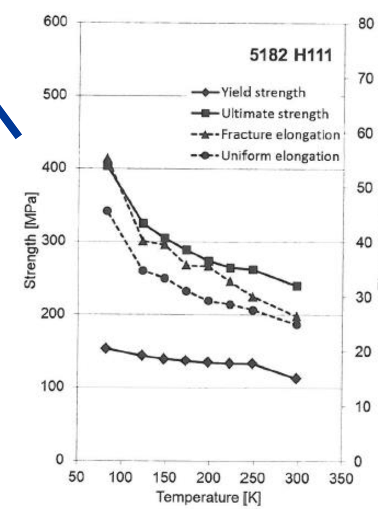


Quelle: voestalpine GmbH

Target Process:



Mechanical properties:



Source: R. Schneider et al.

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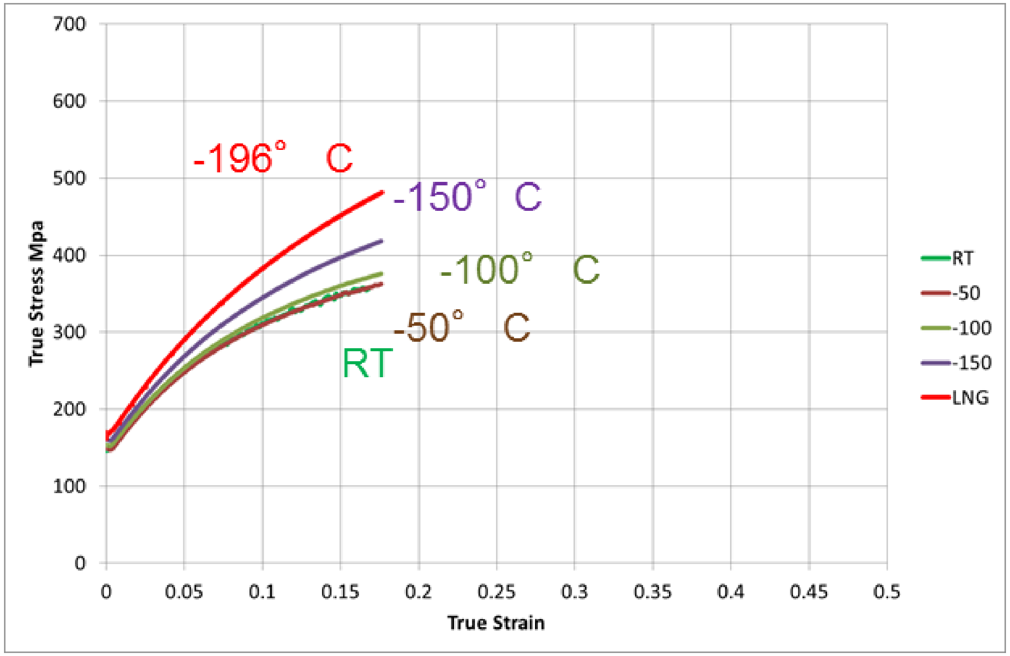
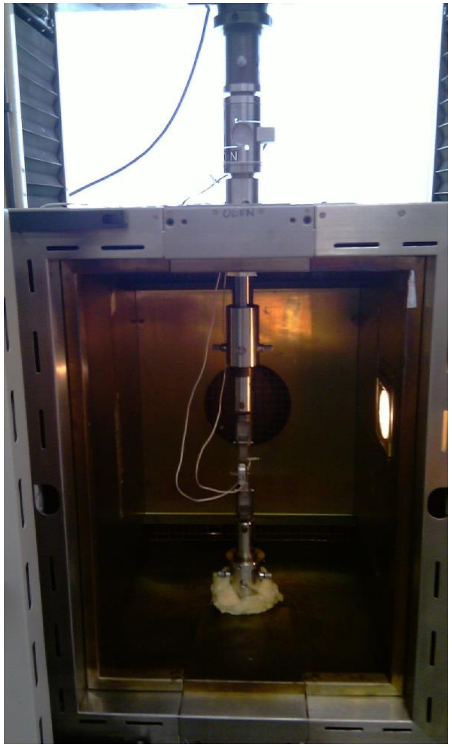
Agenda

- Hardening behaviour – Flow curve
  - Experimental set-up
  - Flow curve extrapolation with physical motivation
  - Basic equations and temperature dependence
  - Results for AA5182
- Failure modelling with GISSMO
  - Identification of parameters
- Numerical and experimental determination of FLDs at low temperatures
  - Experimental set-up
  - Evaluation method
  - Results for AA5182
- Outlook: demonstator component B-Pillar
- Summary

Tensile tests





- Results for 5182
- PLC-Effect at RT vanishes at -50° C
- Data truncated at uniform elongation at RT

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Hardening behaviour

Physically motivated Modelling approach

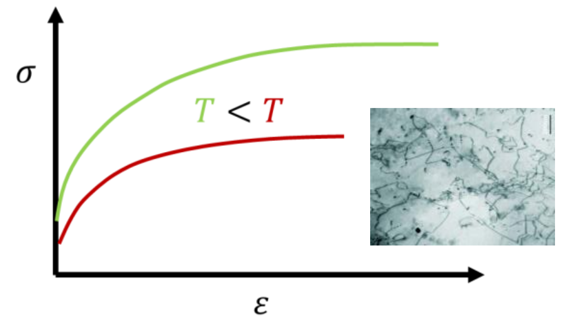
Yield stress:	$\sigma = \sigma_0 + 3Gb\sqrt{\rho}$
Evolution of dislocation density (Kocks-Mecking):	$\frac{d\rho}{d\varepsilon} = A\sqrt{\rho} - B\rho$
Thermally activated annihilation of dislocations:	$B = B(T) = B_0 \exp\left(-\frac{\Delta G}{k_B T}\right)$

Temperature dependent Parameters:

Initial yield stress	$\sigma_0 = \sigma_0(T)$	From tension tests
Shear modulus	$G = G(T)$	From literature

Temperature independent Parameters:

Burgers-vector:	b	
Effective activation energy:	ΔG	From tension tests
Material-parameter:	A, B_0	From tensile test at rooom temperature



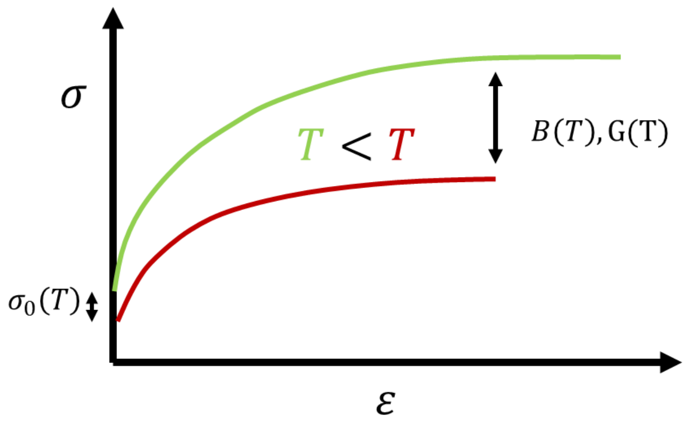
Hardening behaviour

Physically motivated Modelling approach

Integration yields Hocket-Sherby function: $\sigma(\varepsilon) = \sigma_0 + 3Gb\{\frac{A}{B} - (\frac{A}{B} - \sqrt{\rho_0})\exp(-\frac{B}{2}\varepsilon)\}$

Saturation-stress $\sigma(\varepsilon \gg 0) = \sigma_0 + 3Gb\frac{A}{B}$

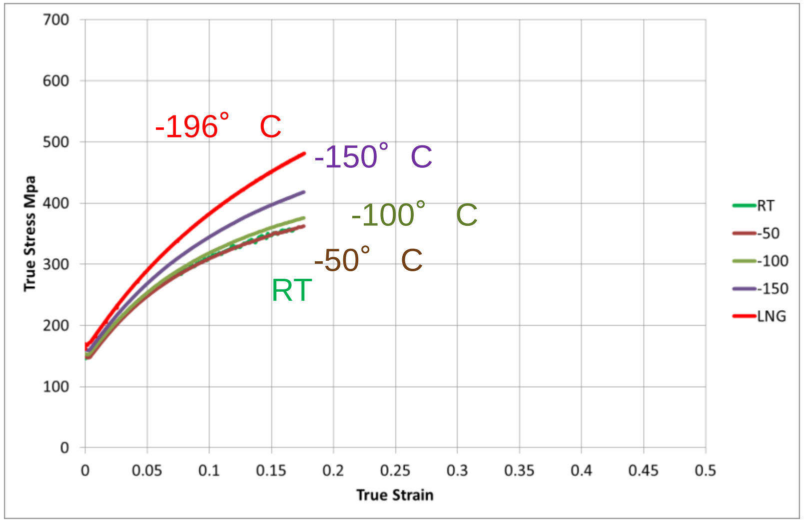
Dislocation annihilation $B = B(T) = B_0 \exp\left(-\frac{\Delta G}{k_B T}\right)$

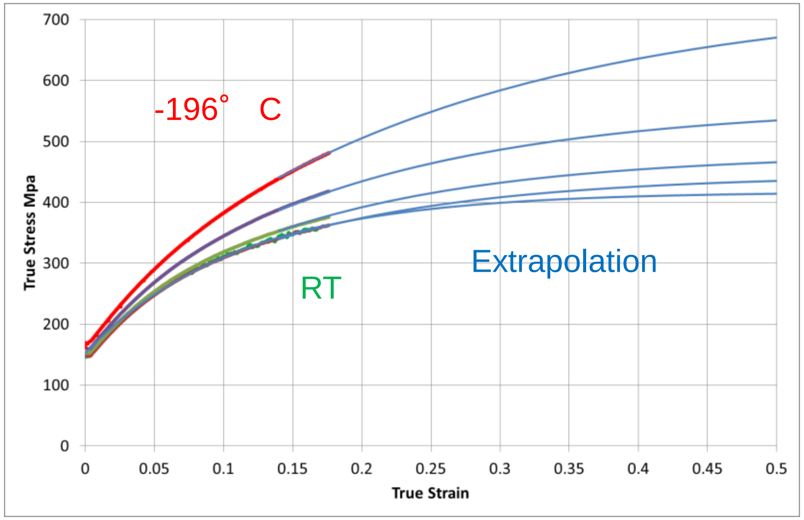


Yield curve extrapolation

Procedure:

- Extrapolation at RT by *Reverse Engineering* with FEM based on tensile test
- Fit of temperature independent model parameters at RT
- Fit of activation energy to cryogenic tensile tests





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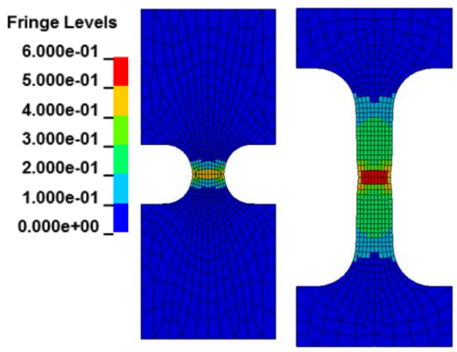
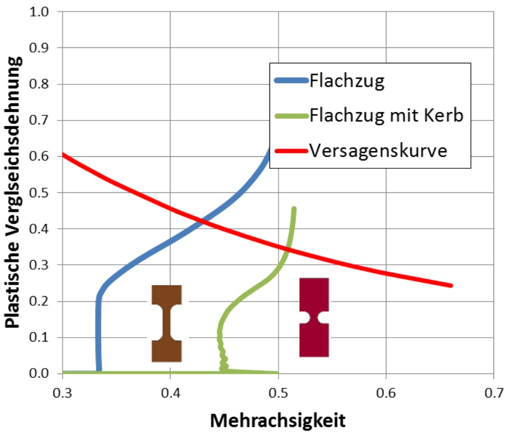
Failure modelling with GISSMO

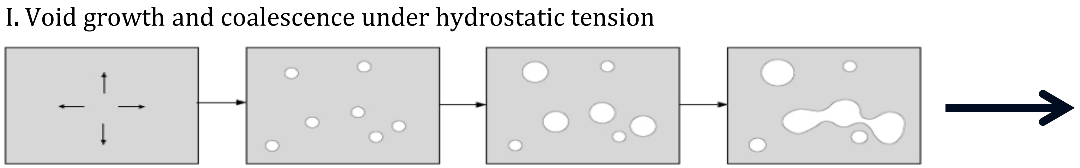
- Ductile failure for higher triaxialities
- Standard procedure at room temperature
- No notched tests at low temperatures
- Equibiaxial state from Round Nakajima test
- Results for AA5182



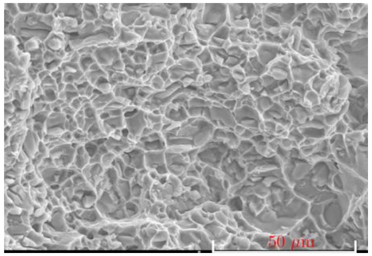
Plastic strain prior to fracture



Failure curve at room temperature



ENGELEN, R.A.B.: *Plasticity-induced Damage in Metals.* Habilitationsschrift, Technische Universität Eindhoven, Niederlande, 2005.



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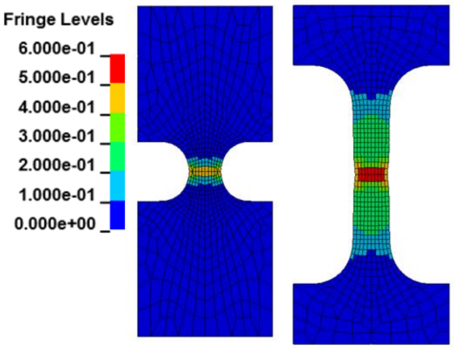

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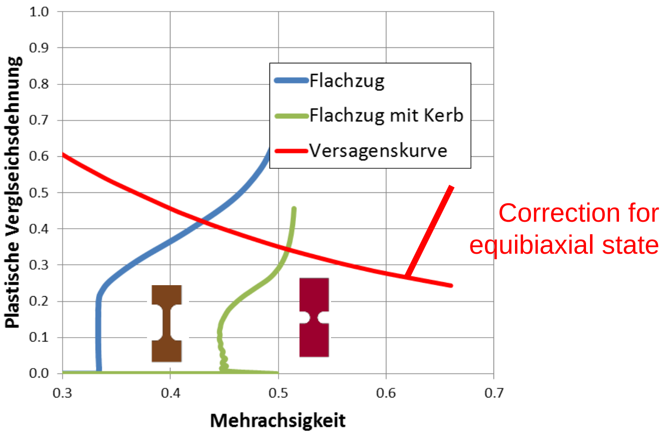
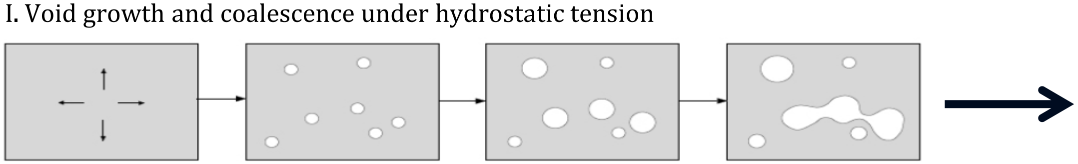


Failure curve at room temperature



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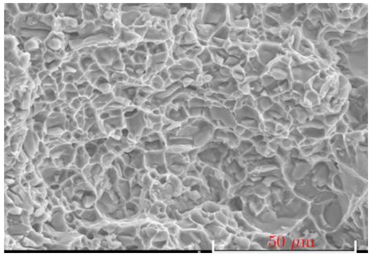

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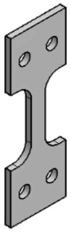
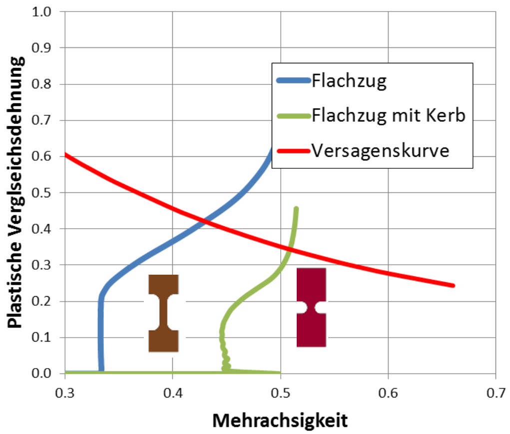
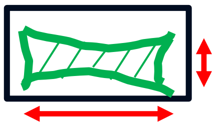
Parameteridentifikation GISSMO

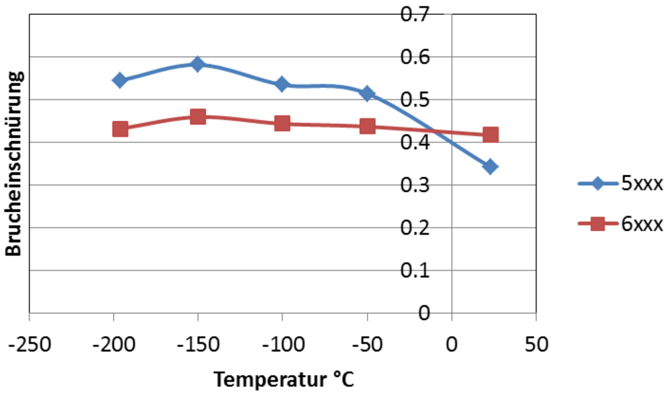
- Ductile failure for higher triaxialities
- Assumptions for low temperatures: Scaled failure curve
- Scaling factor determined from fracture surface
- Special behaviour of 5182 attributed to PLC-effect







$$Z = \ln \frac{A_0}{A}$$



Measured necking strains in dependence of the temperature

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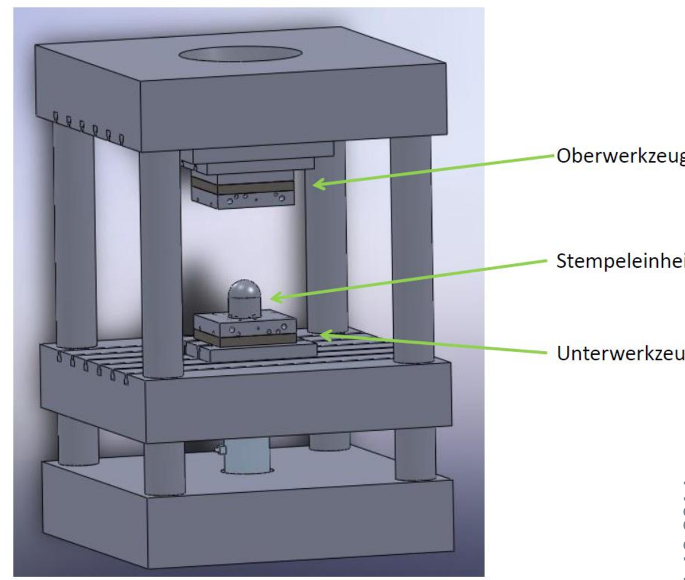
Experimental Set-up of Nakazima-test at low temperatures

- Cooling of die punch and blankholder with liwuid nitrogen
- High-precision control of nitrogen flow: ±2° C
- Optical strain measurement of strains with ARAMIS
- Reliable results until -100° C. For lower temperatures lubrication system is being optimized currently
- For lower temperatures: use numerical predictions

Aramis-System

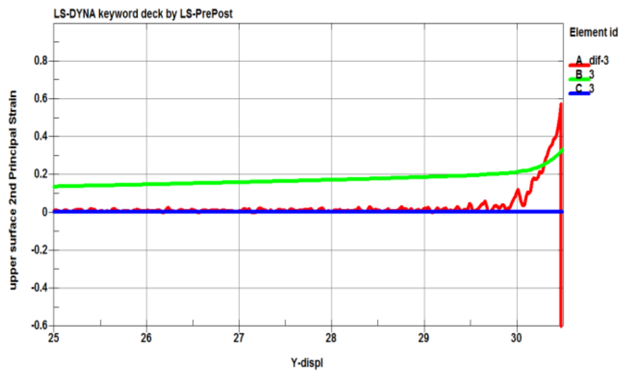
Steuerung der Kühlung



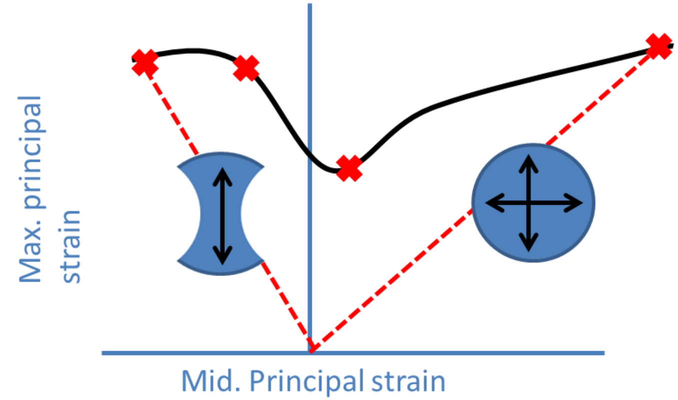
Source: AIT-LKR, Linde Gas GmbH

FE-Modelling of Nakazima-Tests

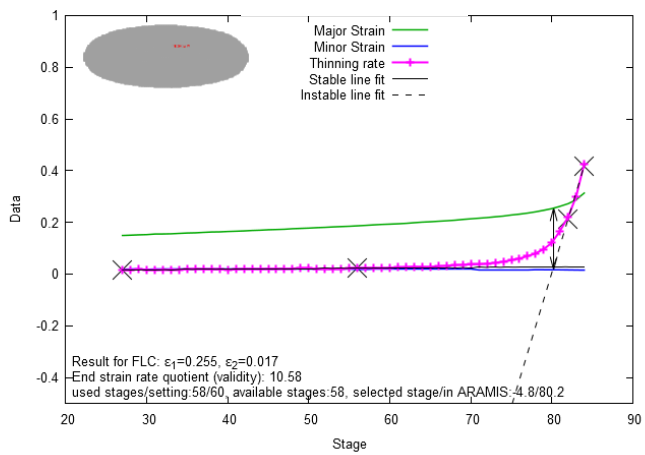
Evaluation with „Time-Method“



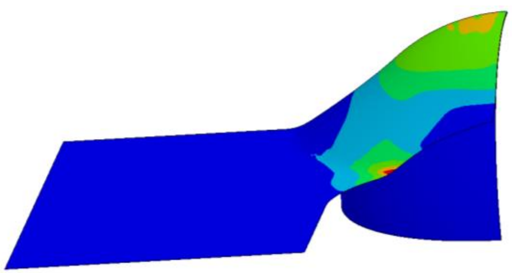
Thinning rate, principal strains from simulation



Nakazima-Test Schematisch



Thinning rate, principal strains from experiment



FE-Model (Blankholder and die not depicted)

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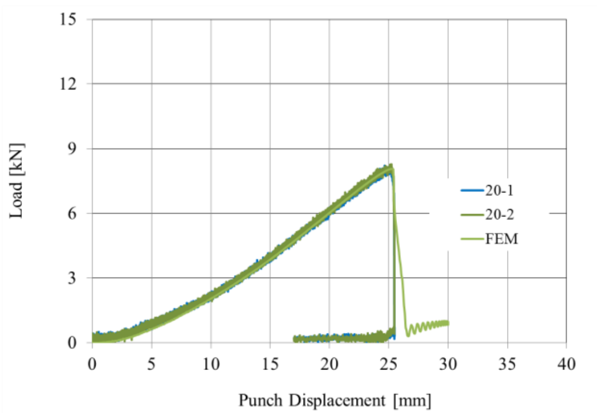
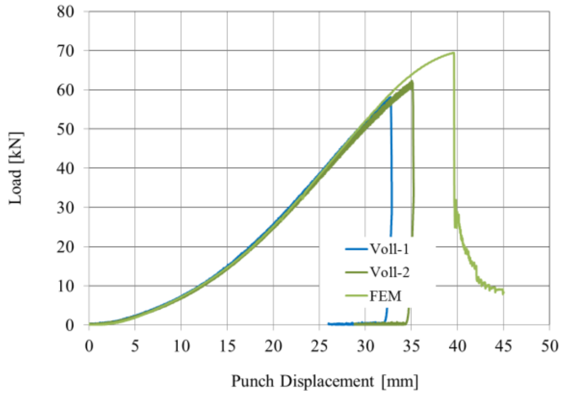
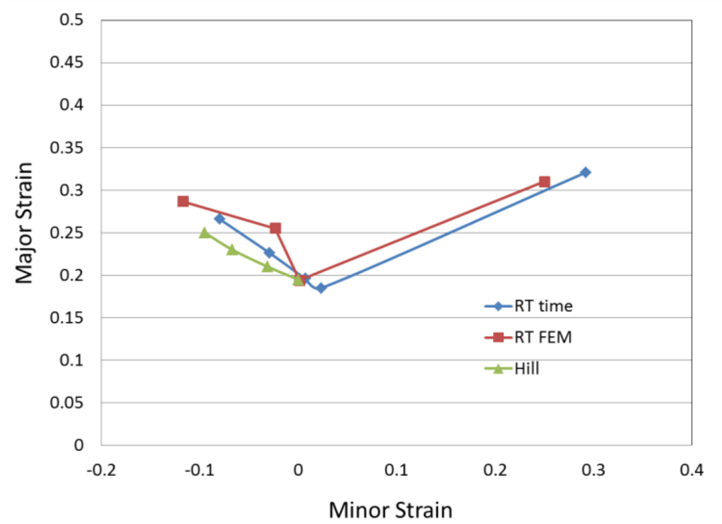
Nakazima-Tests at room temperature, Validation

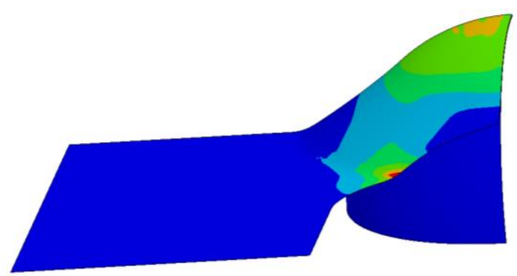


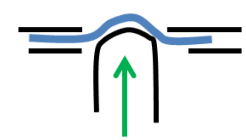


Force-displacement curves from experiment and simulation for 5182 at room temperature



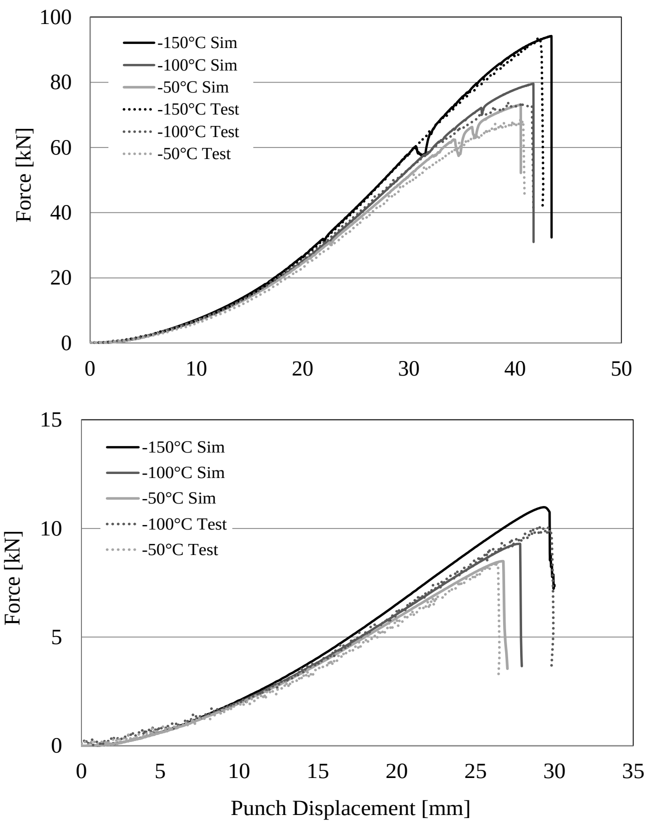
Forming Limit Diagram, Experiment and Simulation at room temperature



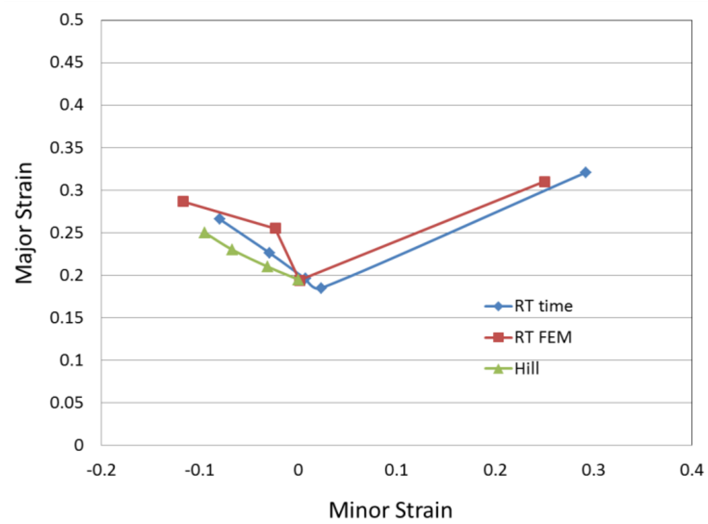


FE-Model
(Blankholder and die not depicted)

Nakazima-Tests at low temperatures validation



Force-displacement curves from experiment and simulation for 5182



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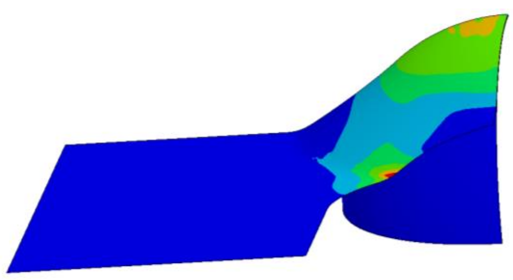
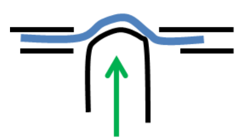


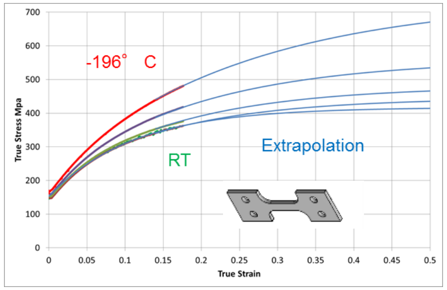


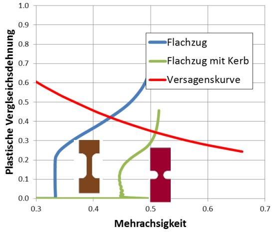
FE-Model
(Blankholder and die not depicted)

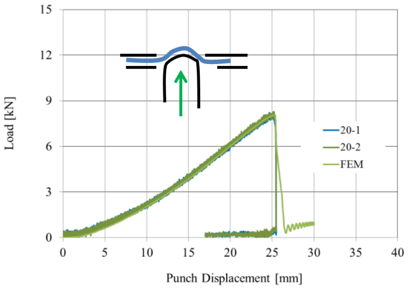
Materialmodellierung and caharacteriaztion for the cryogenic forming of aluminium sheets

Summary

- Physically motivated yield description was developed and validated
  - Flow-curve extrapolation for low temperatures
  - Allows description of non-isothermal proceses
- Calibration of failure curve GISSMO
  - Fracture curve for low temperatures scaled with simple assumtion
  - Used to predict FLDs at low temperatures
- Numerical prediction of FLDs at low temperatures
  - Use of novel time-dependent evaluation method
  - Good agreement (Force-displacement curves)
  - Allows predistion of missing experimental data
- Outlook
  - Demonstrator B-Pillar
  - Automatized Process

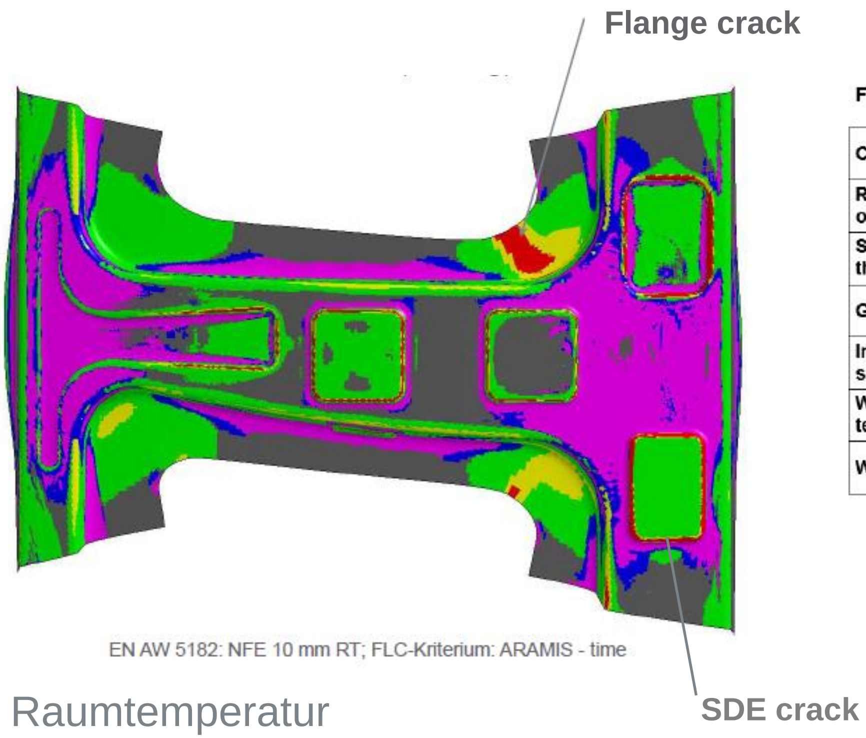






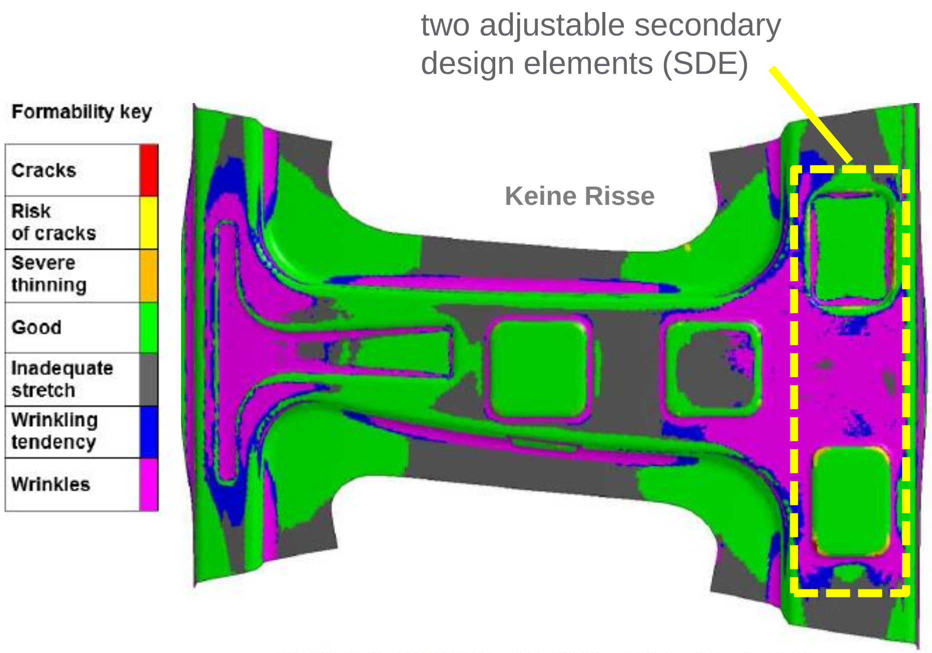
Demonstrator tool: scaled B-Pillar

FE-Modelling based on FLD-Criterion using numerical predictions



EN AW 5182: NFE 10 mm RT; FLC-Kriterium: ARAMIS - time

Raumtemperatur



EN AW 5182: NFE 10 mm 77K; FLC-Kriterium: CrachLab - ELS

Kryogene Umformung bei -196°

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Pressenaufbau und Automatisierung der B-Säule am LKR Ranshofen

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#AAC Aerospace & Advanced Composites GmbH, Wiener Neustadt, AT

Vielen Dank für Ihre Aufmerksamkeit

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