CHARACTERISATION AND MODELING OF THE CRASH BEHAVIOR OF DIFFERENT MATERIALS AND JOINTS WITH ASPECTS OF DIGITALIZATION

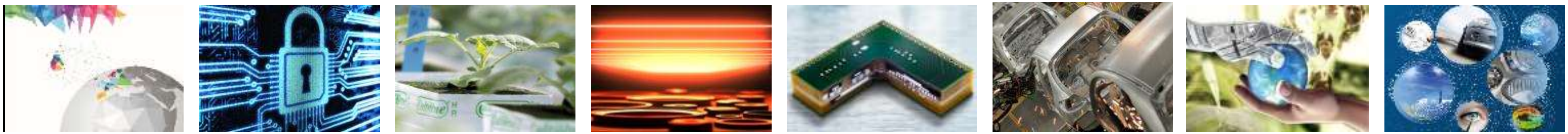
Silke Sommer

Fraunhofer
IWM

AGENDA

- Introduction of Fraunhofer IWM
- Characterization and Modeling the crash behavior of
  - of different materials and components
  - of different joints

Fraunhofer-Gesellschaft
Fraunhofer Groups: Pooling expertise



Institutes working in related subject areas cooperate in Fraunhofer Groups and foster a joint presence on the R&D market. They help to define the Fraunhofer-Gesellschaft’s business policy and act to implement the organizational and funding principles of the Fraunhofer model.

- Innovation Research
- Information and Communication Technology
- Life Sciences
- Light & Surfaces
- Microelectronics
- Production
- Defense and Security
- Materials and Components – MATERIALS

Fraunhofer Institute for Mechanics of Materials IWM

Directors

Prof. Dr. Peter Gumbsch
Dr. Rainer Kübler (Deputy Director), Prof. Dr. Chris Eberl (Deputy Director)

300 Employees – 20.3 Mio. Euro Budget – 46.4 % from Industry (K2018)

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Location Freiburg

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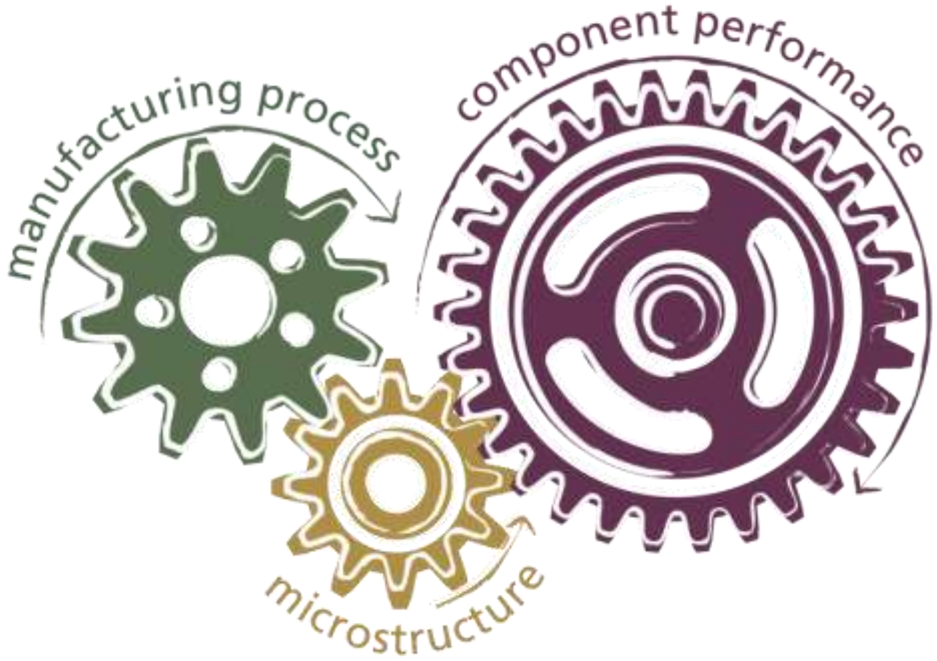
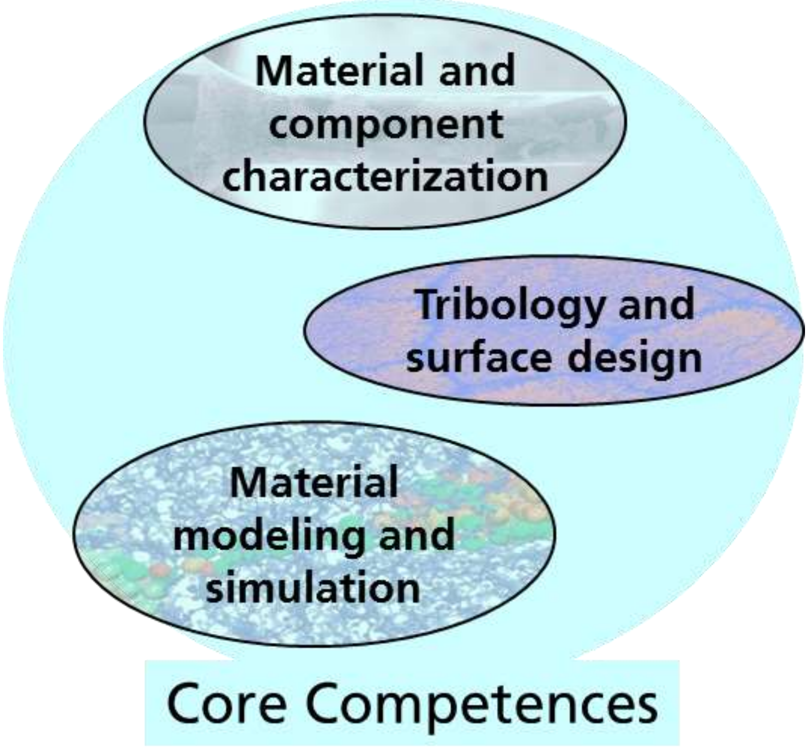
Location Karlsruhe

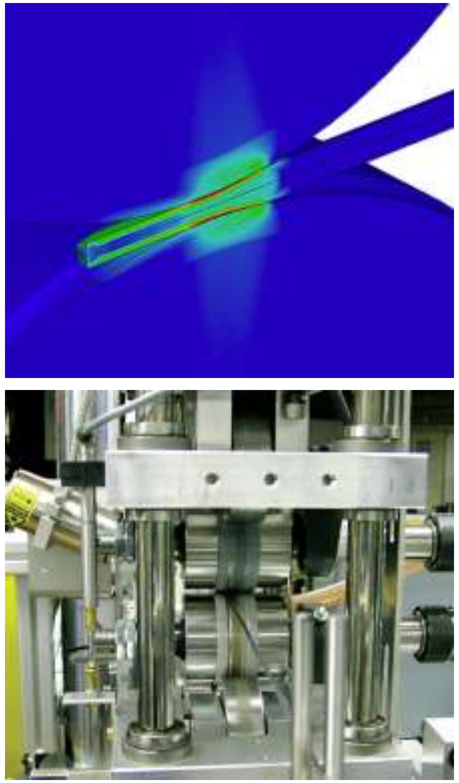
Mechanics of Materials

- How do materials behave in components?
- How do material properties evolve during manufacture?
- How can material properties be accurately adjusted?

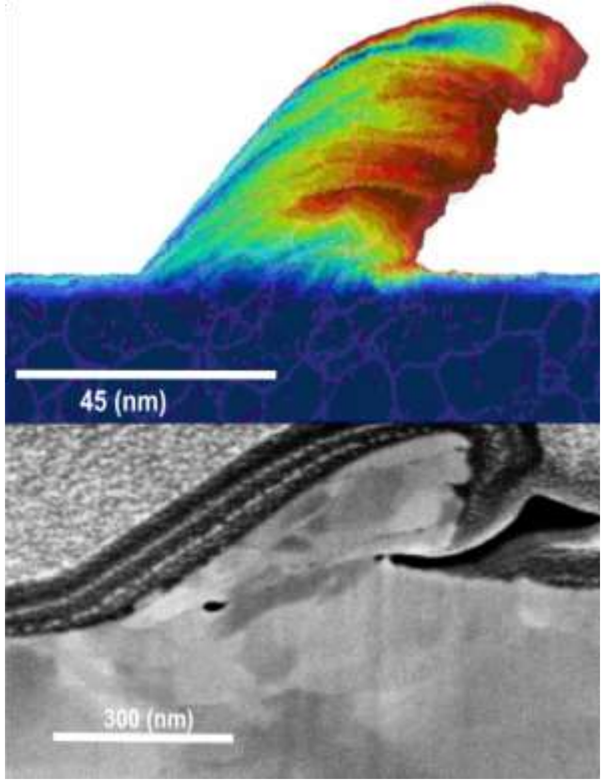




Combining experiment and simulation

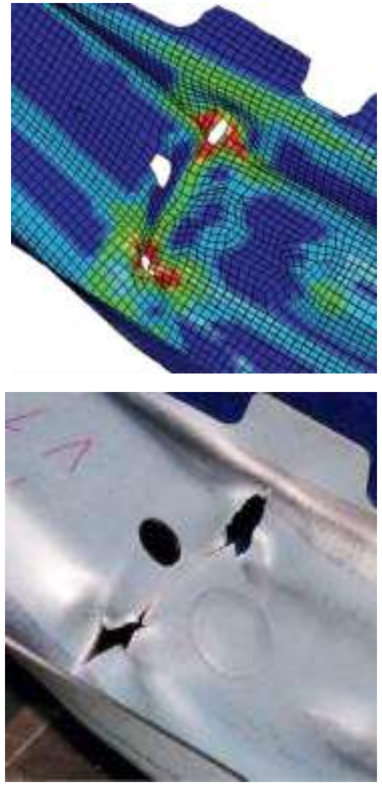


material substitution

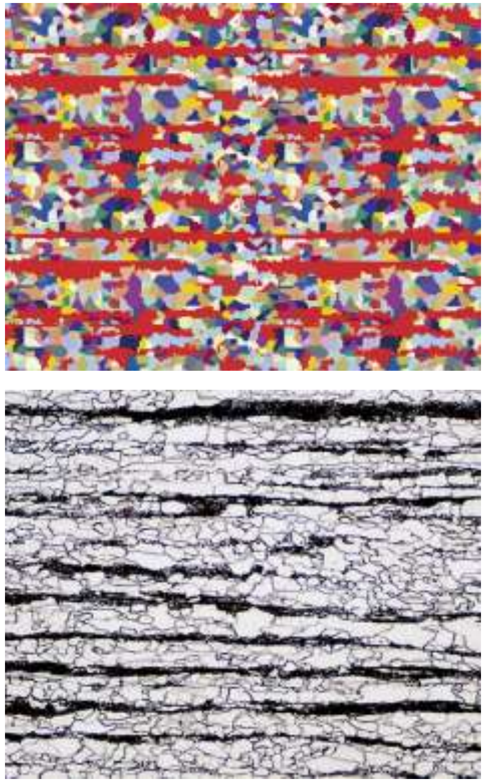


wear

lifetime predictions



crash of high-strength steel



sheet metal forming

Damage concept: multi step evaluation of crashworthiness

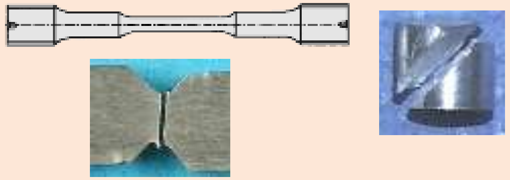
Process

- Casting
- Injection moulding
- Deep drawing
- Extrusion

Manufacturing

- Process Simulation
- Material models
- Mapping

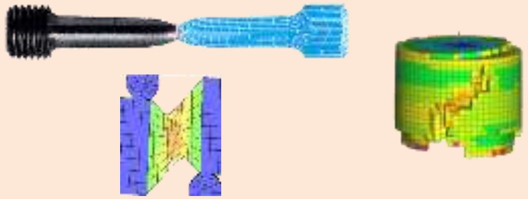
Material



Tension-, compression-, shear-tests static, dynamic

Material models

Simulation of specimen tests

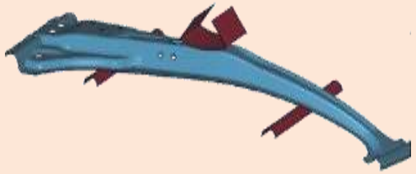


Component

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

Structural modeling

Simulation of component tests



Vehicle

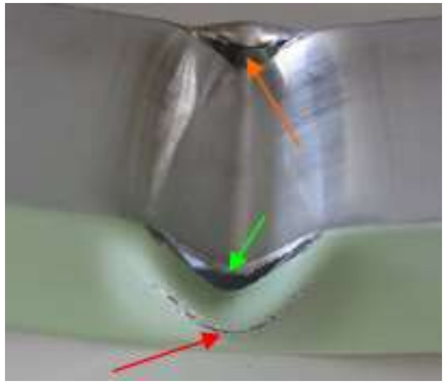
Full scale test

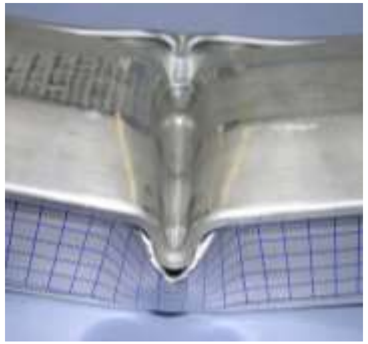
Crashworthiness prediction

Simulation of Full-Scale Tests

Investigated Aluminum profiles from different alloys
Material properties in three orientations

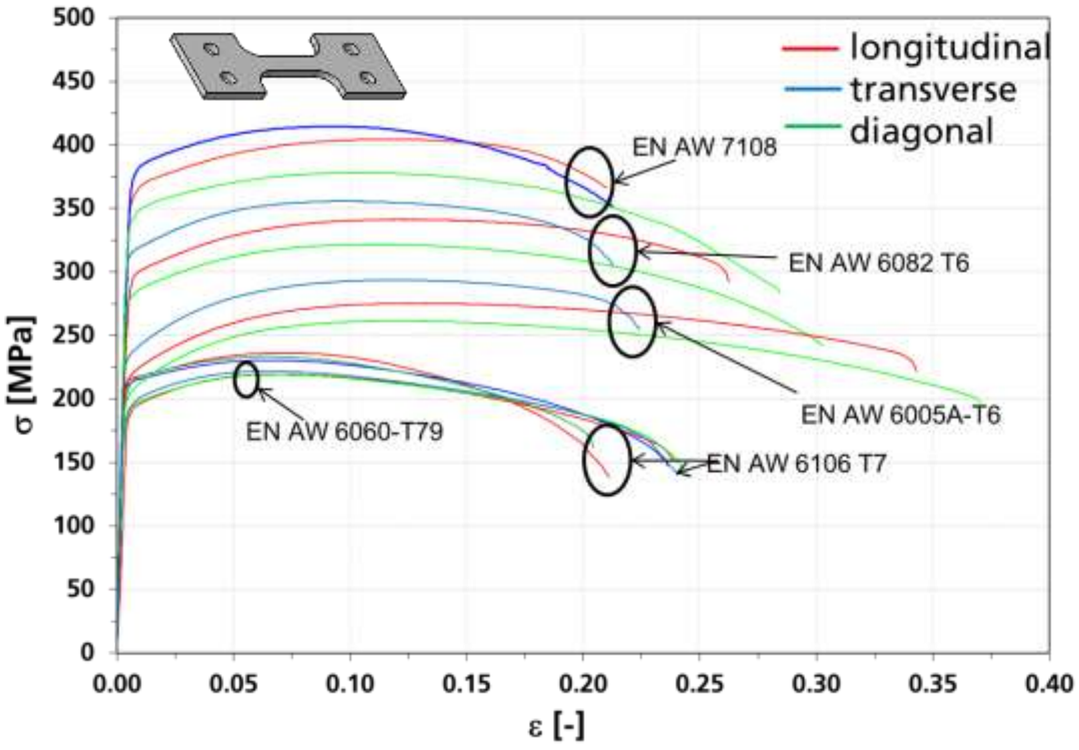

EN AW-6005A
(AlMgSi0.7)


EN AW-6082 T6
(AlMgSi1)


EN AW-7108
(AlZn5Mg1Zr)

EN AW-6060-T79
(AlMgSi0.5)


EN AW-6106 T7
(AlMgSiMn)



D.-Z. Sun, F. Andrieux, C. Fehrenbach, LightMAT Bremen, 8.-10.11. 2017

Different specimen tests for EN AW-6060-T79

Two chamber profile, 3.5mm wall thickness

Smooth tension


long. trans. diag.

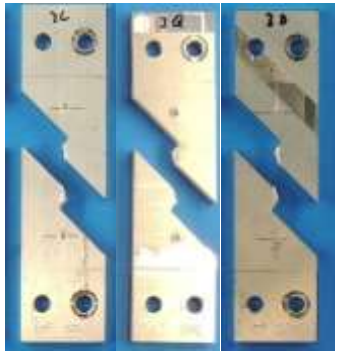
Notch tension

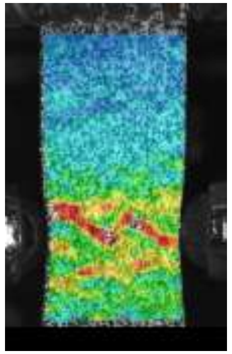

long. trans. diag.

Hole tension

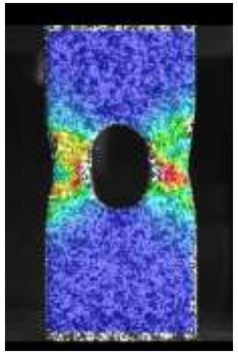

long. trans.

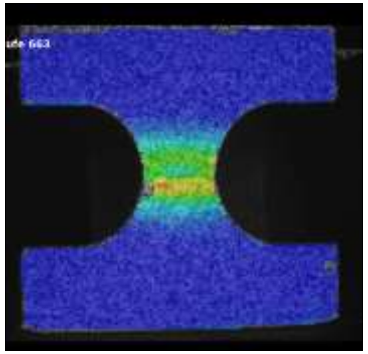
Shear tension θ=0°


long. trans. diag.

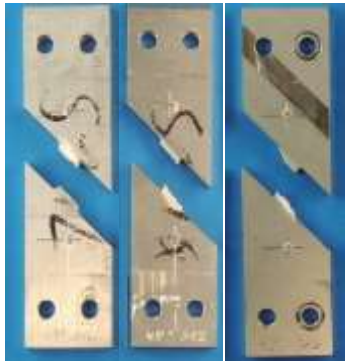

Smooth tension

Hole tension

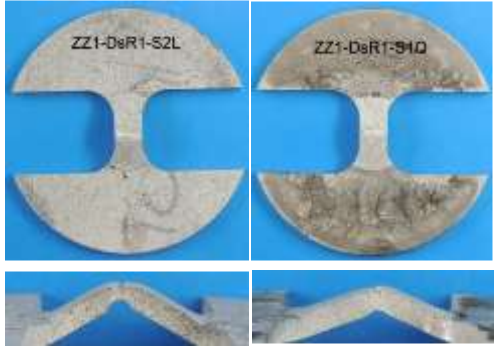



Notch tension

Shear tension θ=45°

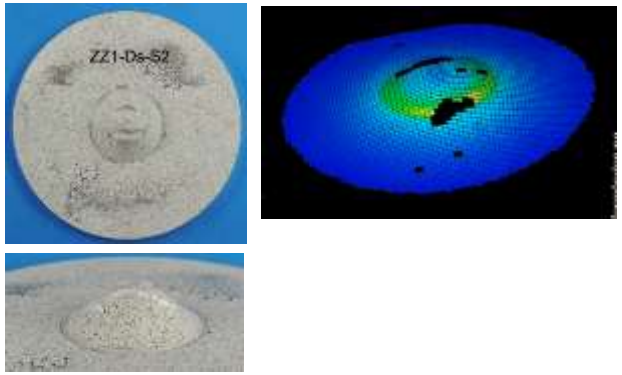

long. trans. diag.

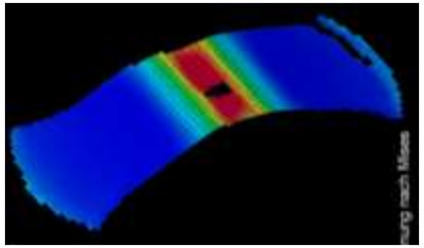
Bending with superimposed tension

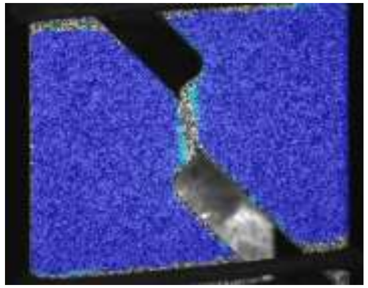


longitudinal transverse

Biaxial tension (punch)




Bending

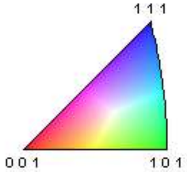

Shear tension θ=0

D.-Z. Sun, M. Krawiec, T. Reichert, H. Hooputra, ALUMINIUM TWO THOUSAND, 10th Int. Congress & ICEB Verona, June 2017

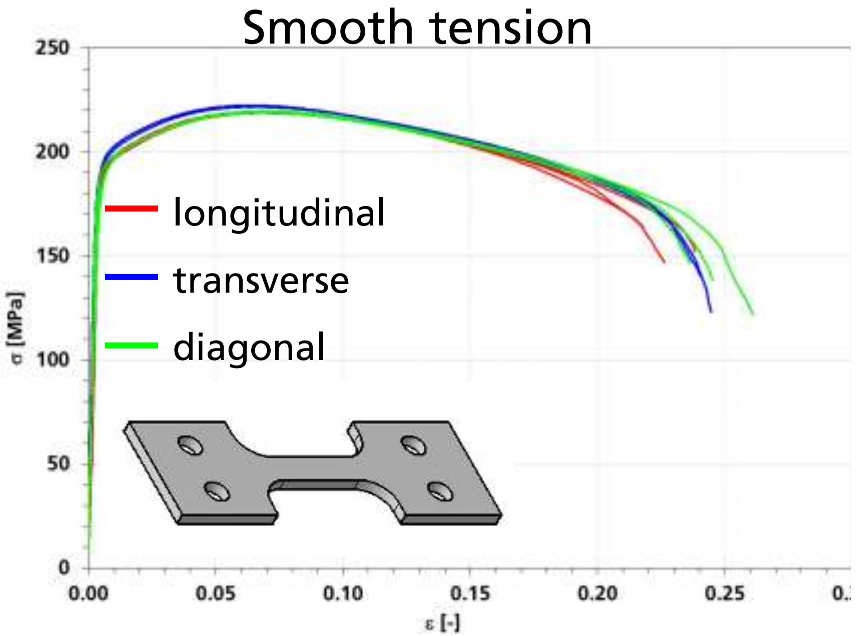
Anisotropic effects in smooth and notched tension tests of EN AW-6060-T79

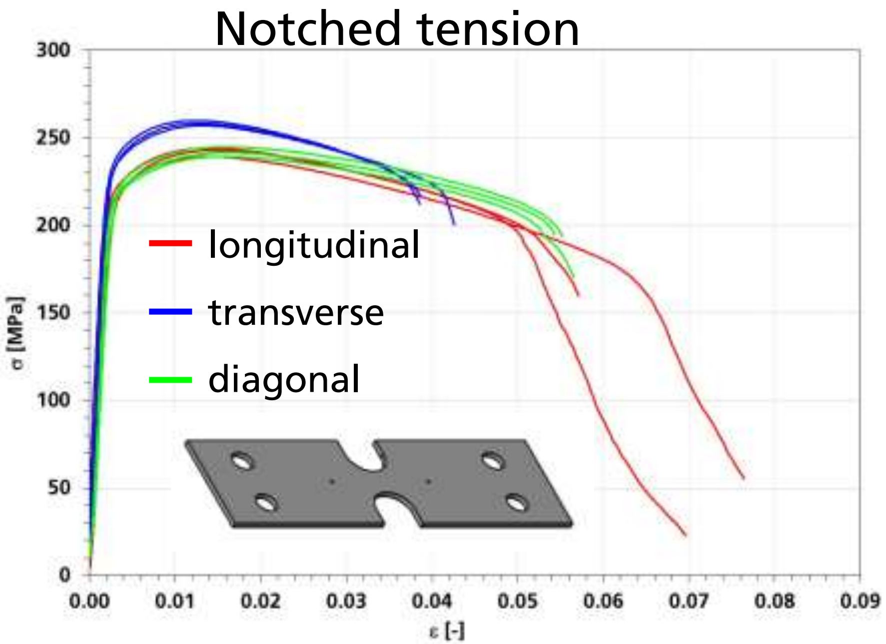
Wall thickness 3.5 mm

Inverse pole figure [001]



Distributions of grain size and orientation





- Negligible orientation dependence of flow curves
- Large orientation dependence of r-values: r_0=0.4, r_{90}=1, r_{45}=0.3

- Remarkable orientation dependence of deformation and damage behavior of notched tension specimens

D.-Z. Sun, M. Krawiec, T. Reichert, H. Hooputra, ALUMINIUM TWO THOUSAND, 10th Int. Congress & ICEB Verona, June 2017

Modeling

Anisotropic plasticity

- Barlat 3-parameter model (Yld89) with anisotropic hardening
- Barlat 1991 (Yld91) for solid elements
- Barlat 2000 (Yld2000) for shell elements

x = extrusion direction (longitudinal=0°)
y = transverse = 90°

Barlat 3-parameter

3 material parameters

$$\Phi = a\left|K_1 + K_2\right|^m + a\left|K_1 - K_2\right|^m + c\left|2K_2\right|^m = 2\sigma_0^m$$

Barlat Yld91

6 material parameters

$$\Phi = \left|S_1 - S_2\right|^m + \left|S_2 - S_3\right|^m + \left|S_3 - S_1\right|^m = 2\overline{\sigma}^m$$

Barlat Yld2000

8 material parameters

$$\Phi = \varphi' + \varphi'' == 2\overline{\sigma}^a$$

$$\varphi' = \left|X'_1 - X'_2\right|^a \quad \varphi'' = \left|2X''_1 + X''_2\right|^a + \left|X''_1 + 2X''_2\right|^a$$

K_i, resp. S_i, X'_I and X''_i are components of a transformed stress tensor

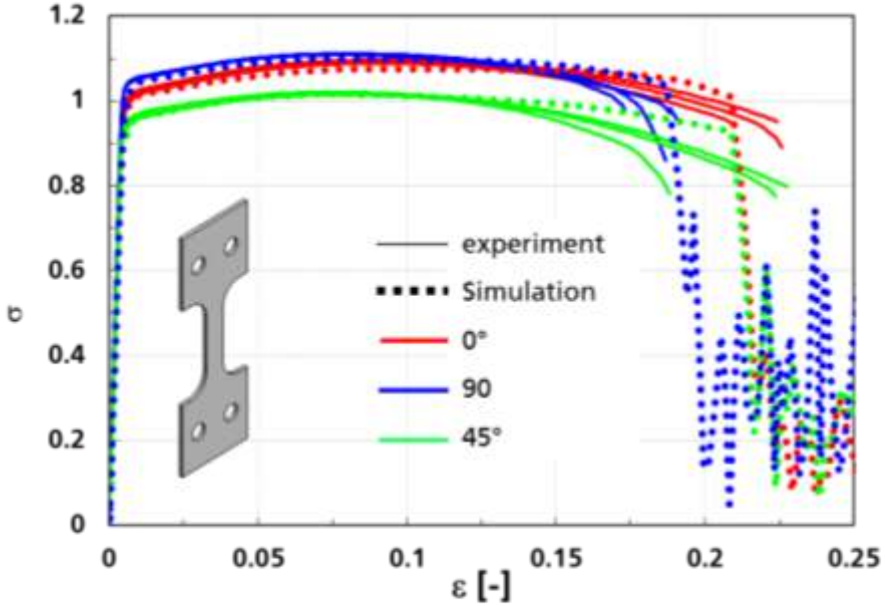
D.-Z. Sun, F. Andrieux, Modeling of anisotropic behavior of aluminum profile for damage prediction, ICAA16, Montreal, June 2018

Modeling of tensile and shear tests of EN AW 6082 T6

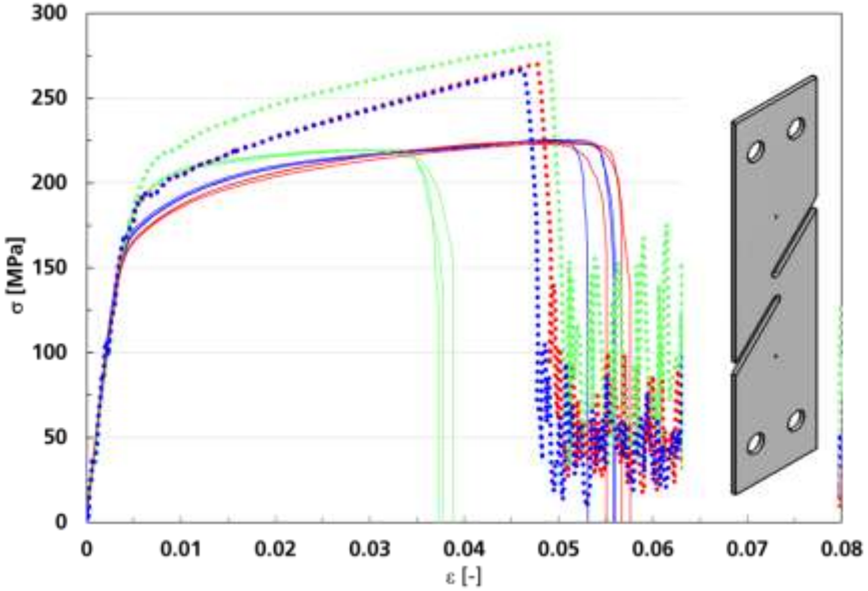
Barlat 3p with isotropic failure model GISSMO - shells

Measured and calculated stress vs. strain curves of tensile and shear tests in 0°, 45° and 90° directions

tensile test



shear test



- good prediction not only of the yielding but also of the hardening at larger strain level
- in combination with the isotropic failure model the orientation dependent failure is predicted in a good manner

- bad prediction of the yielding in shear tests

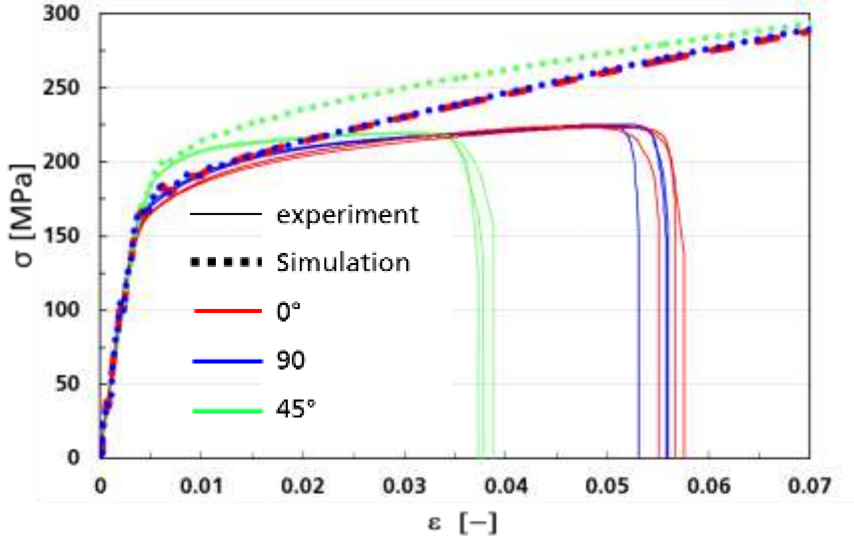
D.-Z. Sun, F. Andrieux, Modeling of anisotropic behavior of aluminum profile for damage prediction, ICAA16, Montreal, June 2018

Modeling of shear tests of EN AW 6082 T6

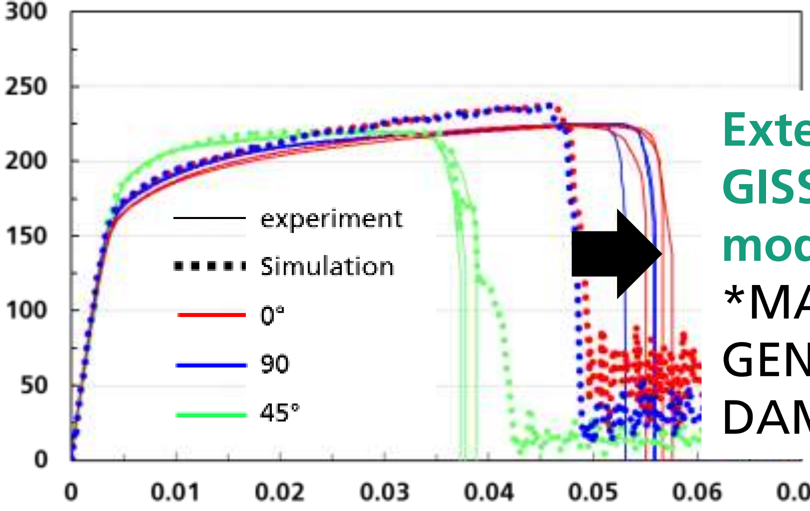
YLD2000 and YLD91

Measured and calculated stress vs. strain curves of shear tests in 0°, 45° and 90° directions.
Simulations with YLD2000 and with Barlat 1991 in combination with GISSMO

YLD2000 - shell elements



YLD91& GISSMO - solid elements



Extended GISSMO failure model (MAGD)
*MAT_ADD_
GENERALIZED_
DAMAGE

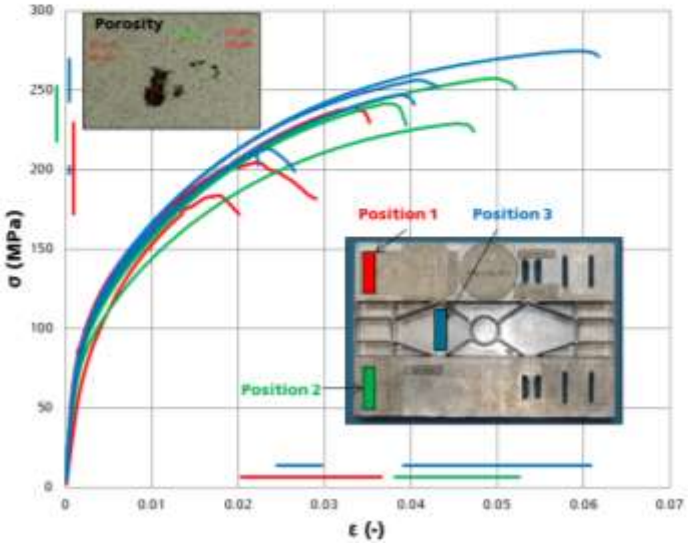
- good prediction of the yielding in shear tests with a good accuracy., but with increasing deformation the discrepancy increases
- discrepancy obtained also due to the element formulation (shell)

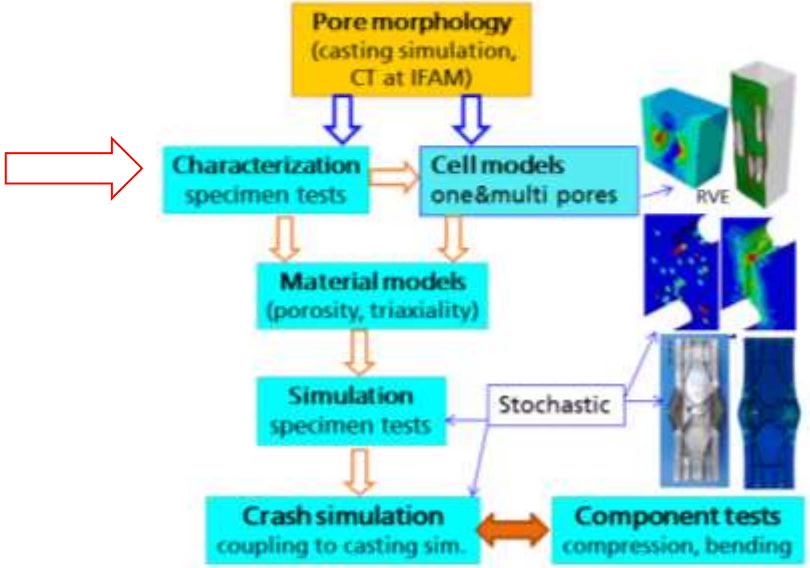
- good prediction not only of the yielding but also of the hardening at larger strain level
- in combination with the isotropic failure model the orientation dependent failure is predicted in an acceptable manner

D.-Z. Sun, F. Andrieux, Modeling of anisotropic behavior of aluminum profile for damage prediction, ICAA16, Montreal, June 2018

Integrated modeling of aluminum die casting alloys

- Inhomogeneous microstructure and porosity result in a large scatter of local properties in a casting component
- There are not reliable methods to predict damage behavior of cast components considering pore morphology and its stochastic character
- Coupling of casting simulation with crash simulation is a necessary step to solve the problem
- The approach used in this work:
  - characterization of influence of porosity and triaxiality
  - development of material models
  - modeling of influence of pore morphology on damage at different loadings




Pore morphology
(casting simulation, CT at IFAM)

Characterization
specimen tests

Cell models
one&multi pores

RVE

Material models
(porosity, triaxiality)

Simulation
specimen tests

Stochastic

Crash simulation
coupling to casting sim.

Component tests
compression, bending

D.-Z. Sun, F. Andrieux, Automotive CAE Grand Challenge 2018, April 17–18, 2018 Hanau

Constitutive equations about porosity effects

Deformation and damage

- Elastic properties

$$\begin{cases} E = E_0(1 - f^{E_a})^{E_b} \\ \nu = \nu_0(1 - f^{\nu_a})^{\nu_b} \end{cases}$$

E_0 and ν_0: Young's modulus and Poisson's ratio of matrix
f: porosity
E_a, E_b, ν_a, ν_b: parameters

- Yield and hardening

$$\sigma_y = \sigma_{y_0}(1 - f^{s_a})^{s_b}$$

$$\sigma_{y_0} = A + B(\bar{\varepsilon}_m^{pl})^n$$

σ_{y_0}: yield stress of matrix
$\bar{\varepsilon}_m^{pl}$: equivalent plastic strain of matrix
s_a, s_b, A, B, n: parameters

- Damage

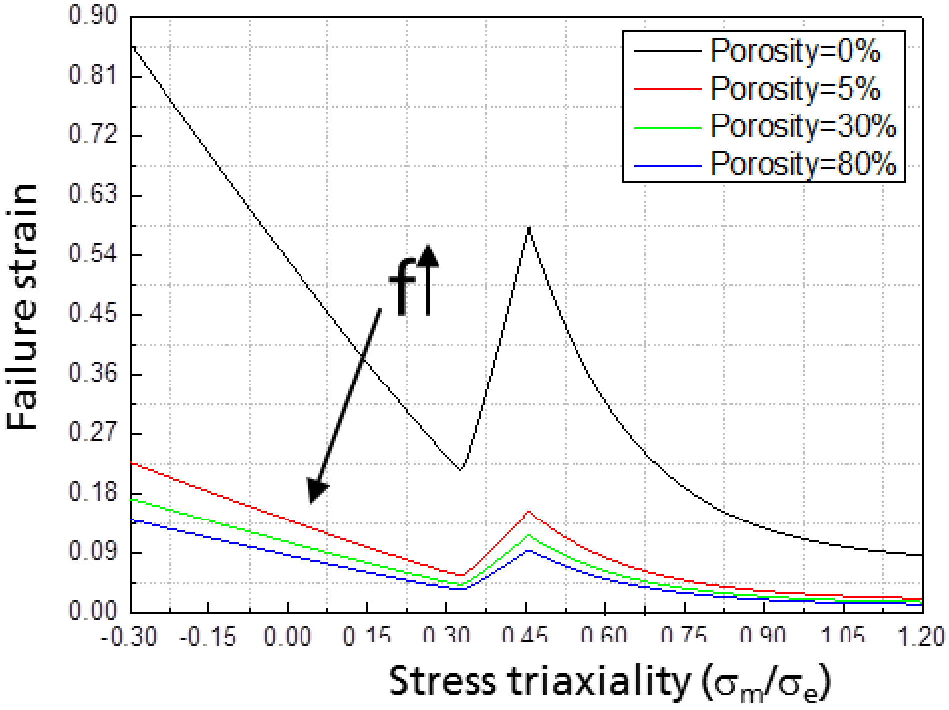
$$\bar{\varepsilon}_f^{pl} = (1 - F_a f^{F_b})^{F_c} \bar{\varepsilon}_{f\ 0}^{pl}$$

$\bar{\varepsilon}_{f\ 0}^{pl}$: failure strain of matrix
F_a, F_b, F_c: parameters

$$\bar{\varepsilon}_{f\ 0}^{pl} = d_{shear1} + d_{shear2}\left|\left(\frac{\sigma_m}{\sigma_e} - T_0\right)\right|^{m_2} + d_{shear3}\left\langle -\left(\frac{\sigma_m}{\sigma_e} - T_0\right)\right\rangle^{m_3}$$ for $1/3 \geq \sigma_m/\sigma_e - T_0 > -1/3$

$$\bar{\varepsilon}_{f\ 0}^{pl} = \left(d_1 + d_2 exp(-d_3 \frac{\sigma_m}{\sigma_e})\right)$$ for $\sigma_m/\sigma_e - T_0 \geq 1/3$

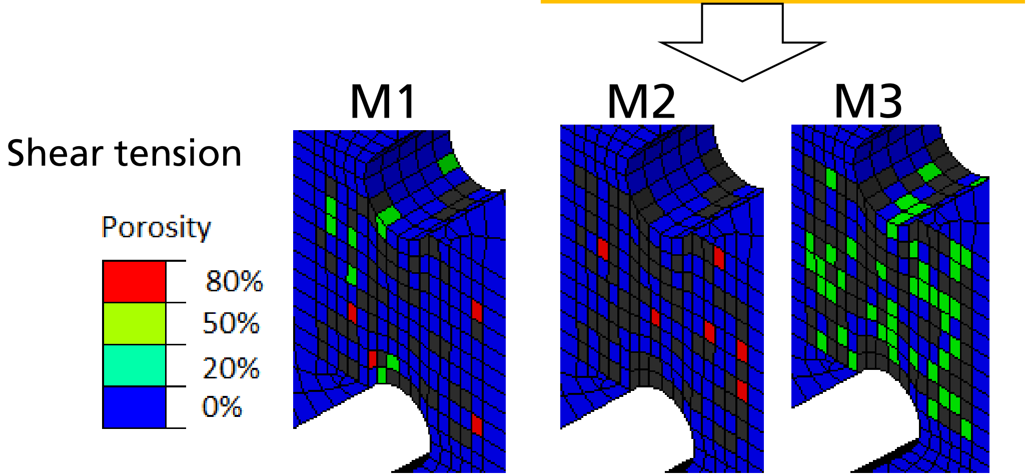
Damage curves: $\varepsilon_f^{pl}(\mathrm{f}, \sigma_m/\sigma_e)$

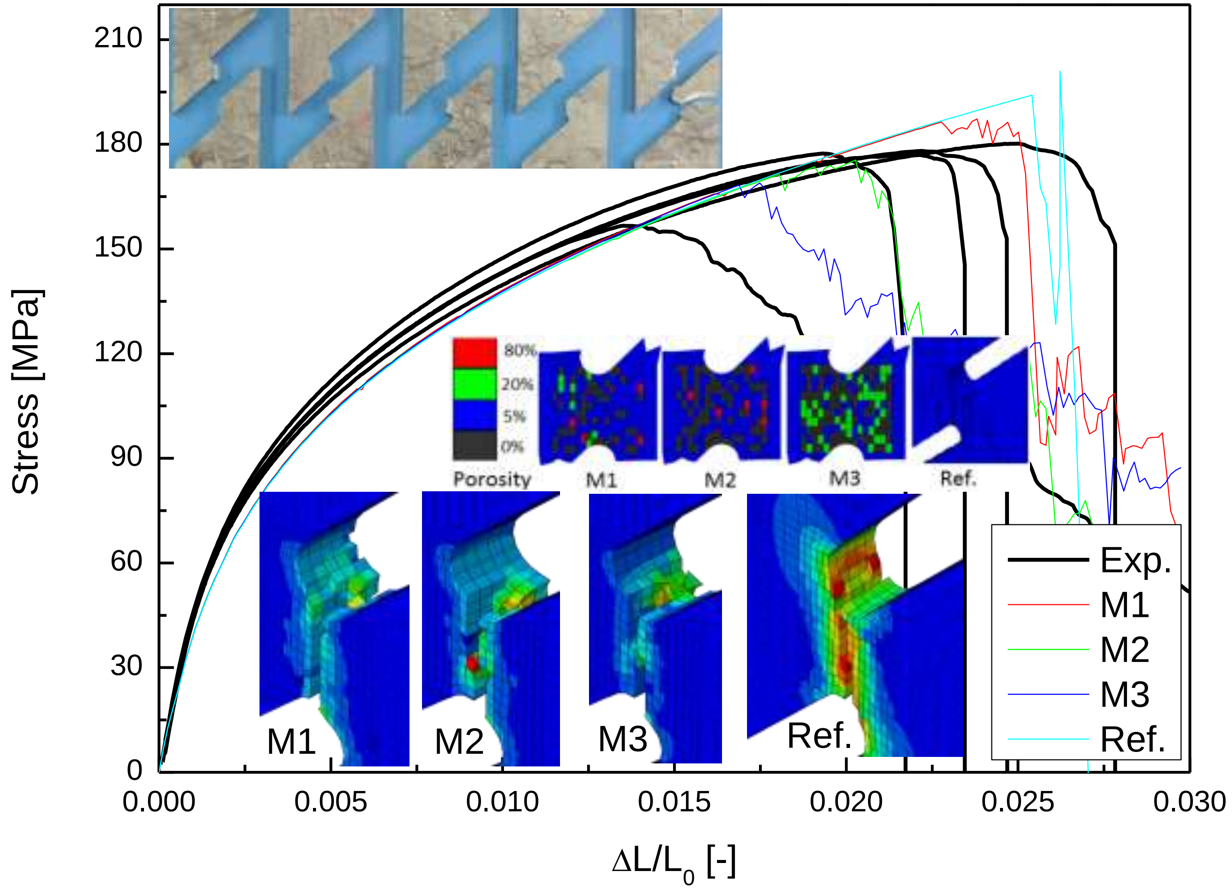


Modeling of different pore morphologies (f=5%)
under shear loading

- Three pore morphologies
  (840 elements in specimen center)
  - M1: 30*80%+30*20%+600*2%+180*0%
  - M2: 50*80%+100*2%+690*0%
  - M3: 200*20%+100*2%+540*0%
  - Ref: Homogeneous pore distribution
    840*5%
- User Material model

Casting simulation (stochastic)





→ Scatter in simulation is similar to that in experiment

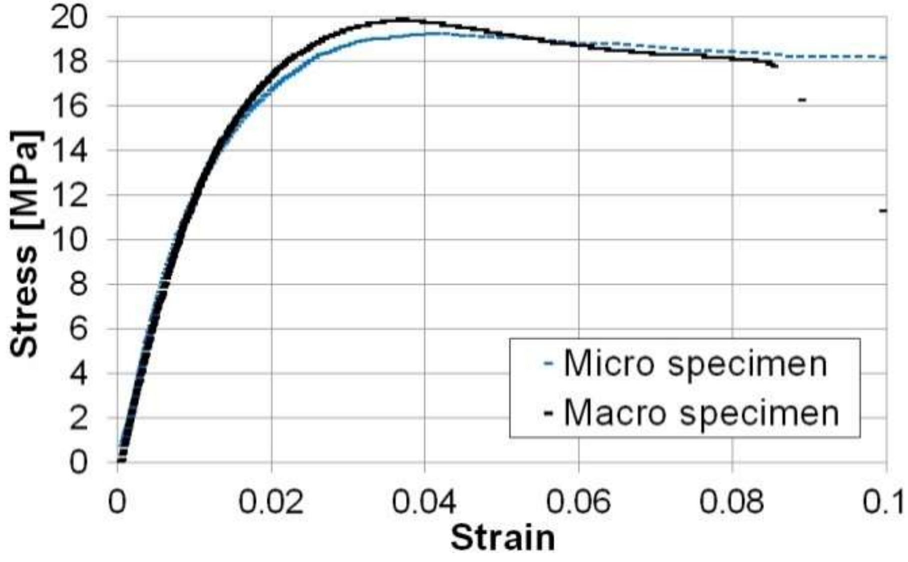
D.-Z. Sun, F. Andrieux, Automotive CAE Grand Challenge 2018, April 17–18, 2018 Hanau

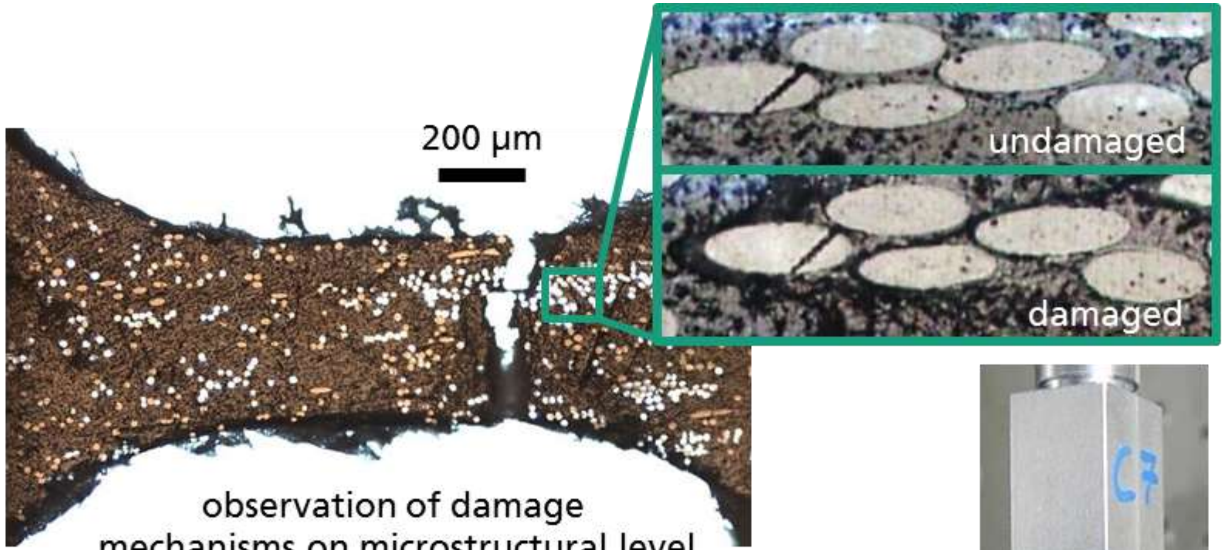
Characterization and modeling of the fiber / matrix / interface behavior of FRP

Micromechanical in-situ testing methods

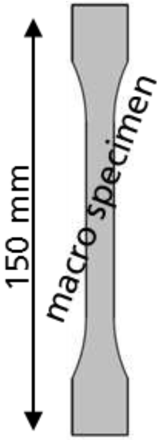
- local characterization of material properties
- specimen preparation from small components
- direct observation of damage mechanisms

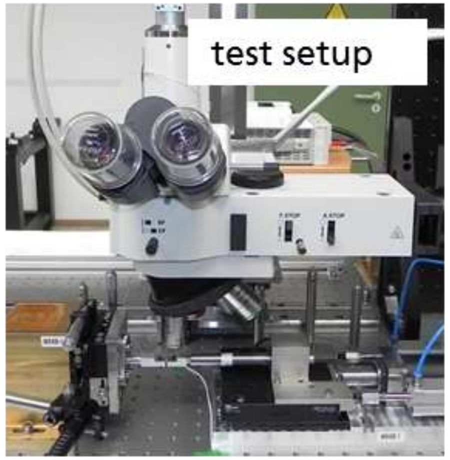
stress-strain curves: micro vs. macro





observation of damage mechanisms on microstructural level

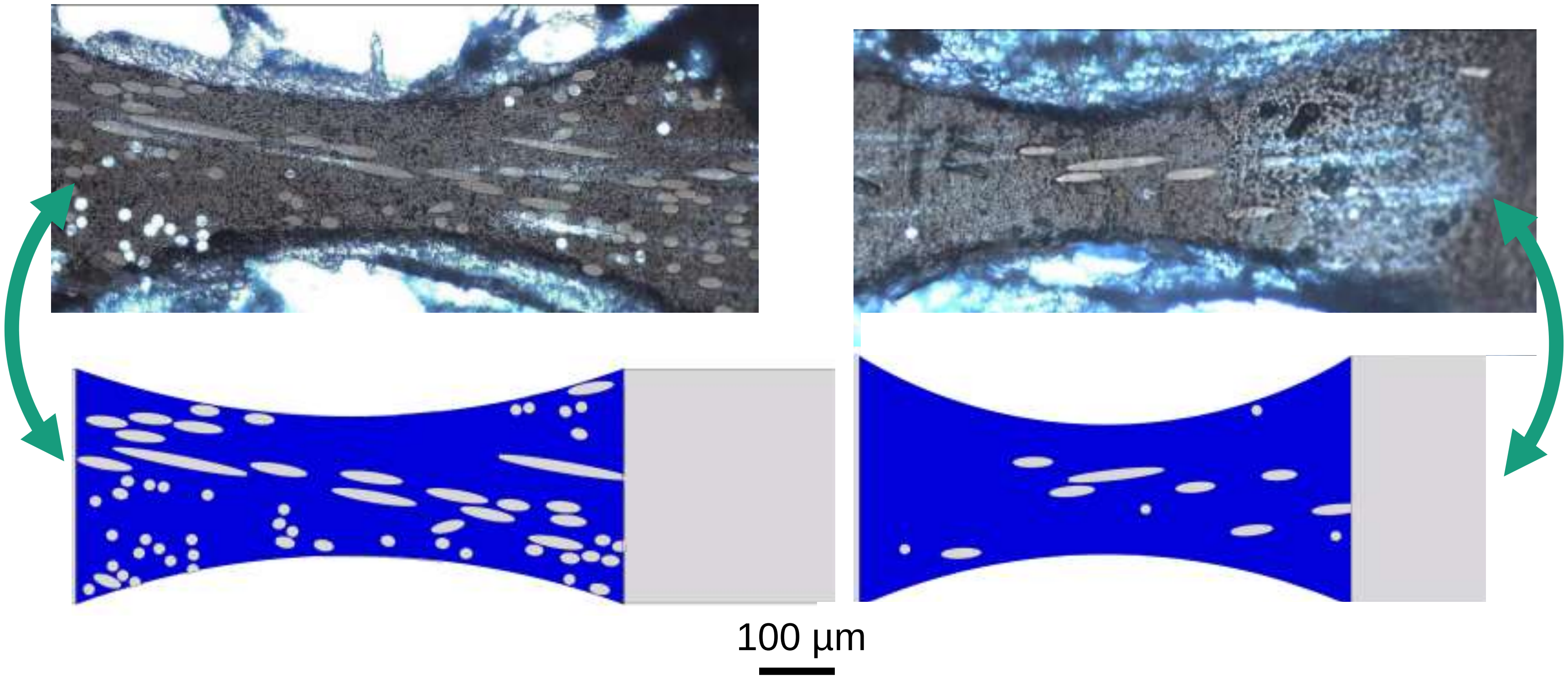




loading device

Characterization and modeling of the fiber / matrix / interface behavior of FRP

Identification of the constitutive properties (fiber/matrix/interface) using inverse simulation



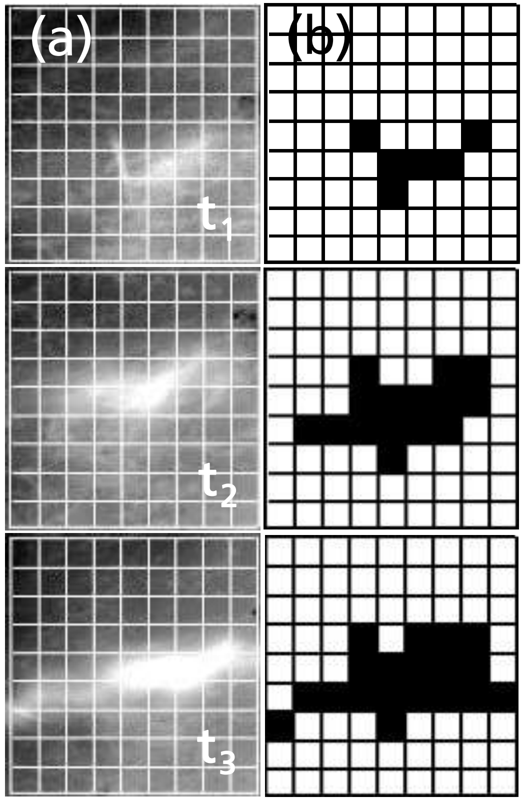
Strain rate dependent damage mechanisms

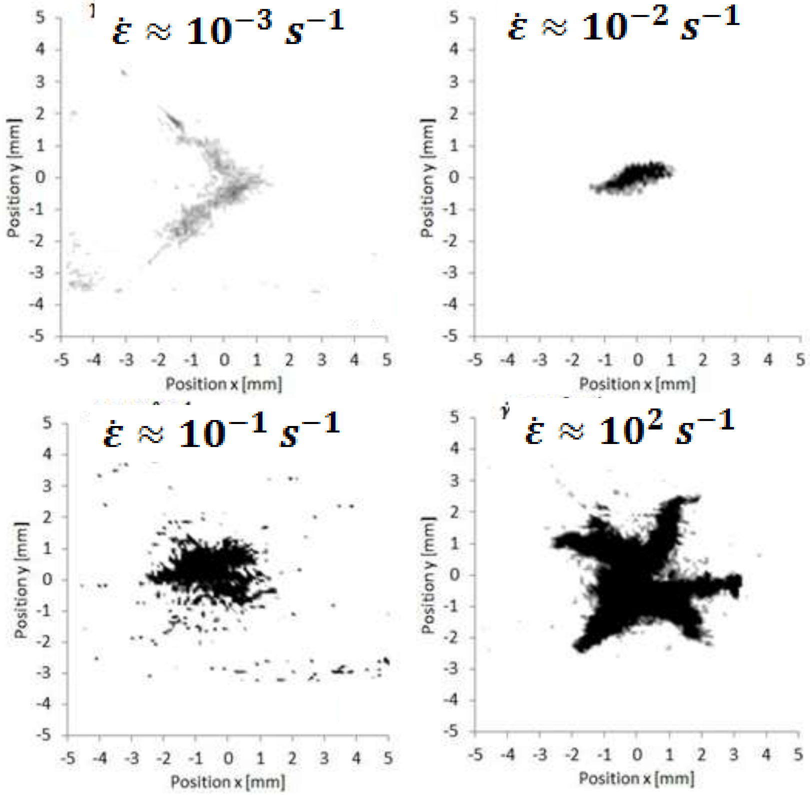
Hot-Spot-Detection

- Definition of a temperature window above reference temperature
- Reference temperature = ΔT_{int} (t)
- The temperature fields (t) are filtered for values within the defined window

Space and time summation

- Determined values within the temperature window are written with an **1** in an separate matrix
- Normalization on the number of time steps
- ➢ **Indication of the damage zone D(x_i,$\dot{\varepsilon}$)**





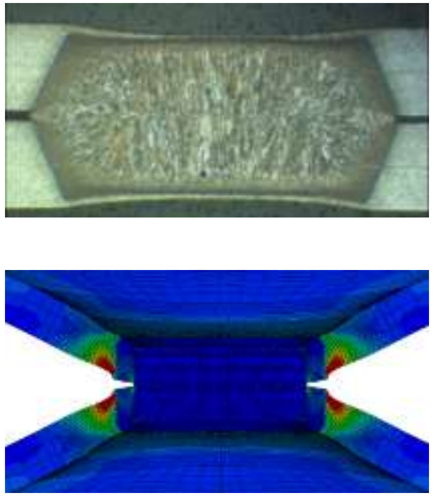
Lienhard J. *Dissertation, submitted to* Karlsruher Institut für Technologie (KIT), Aug.2018

Multi step evaluation of crashworthiness of Joints

Characterization of joints

TASKS

- Determination of material/joint data
- Simulation of specimen tests

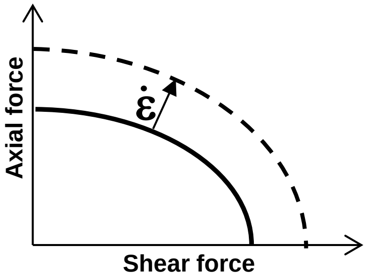


AIM

Validation of material and FE-models

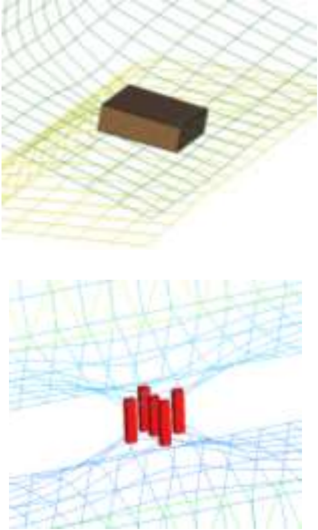
Transfer of Results

- Simulations of different loading situations
- Variation of sheet thickness, strainrate, material combinations



Failure criteria for simplified models

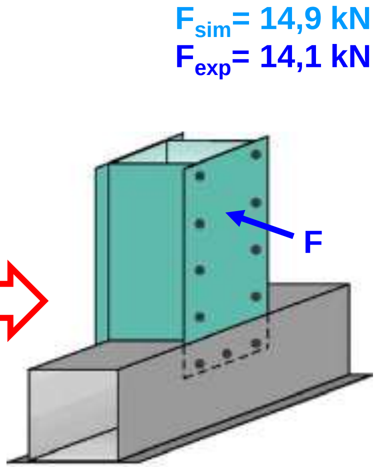
- Simulation of specimen tests with simplified models



Calibration of simplified models

Component behavior

- Simulation of component tests with simplified models

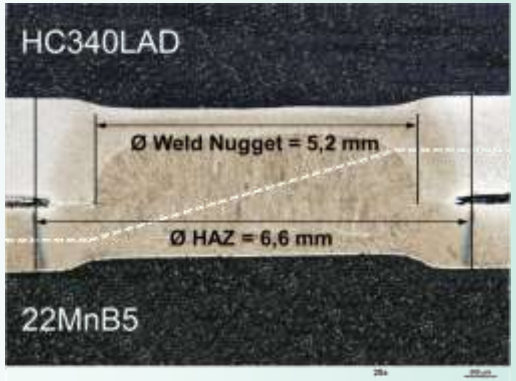


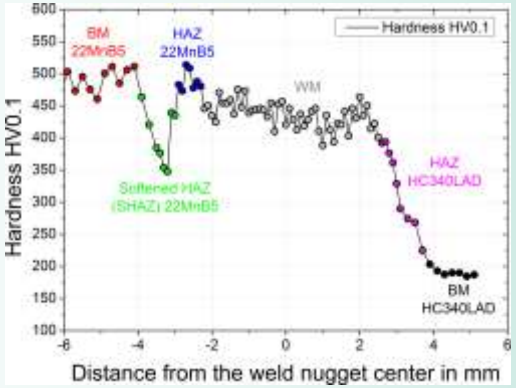
Validation with component tests

Experimental determination of material behavior

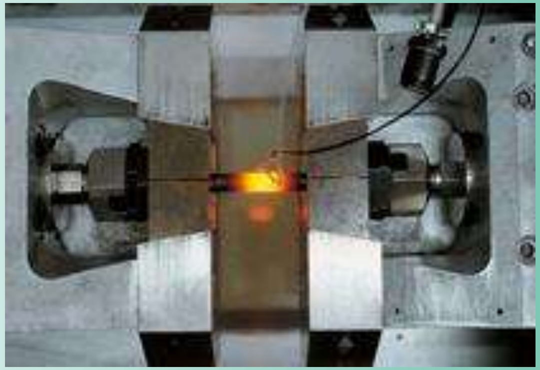
Deformation and failure behavior of the weld zone microstructures

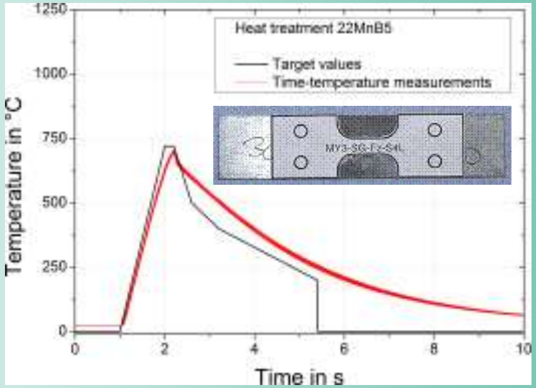
Identification of weld microstructures



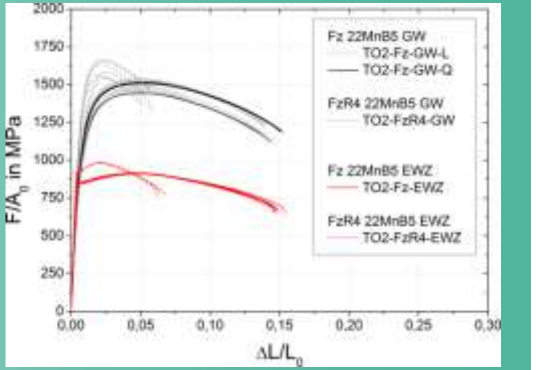


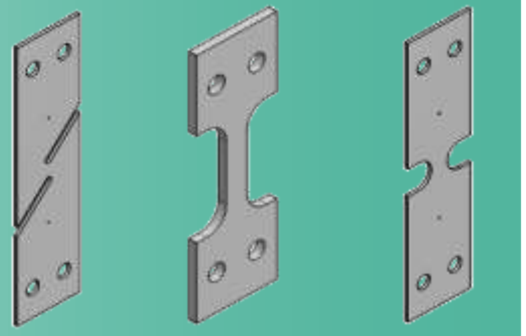
Manufacturing of weld microstructures





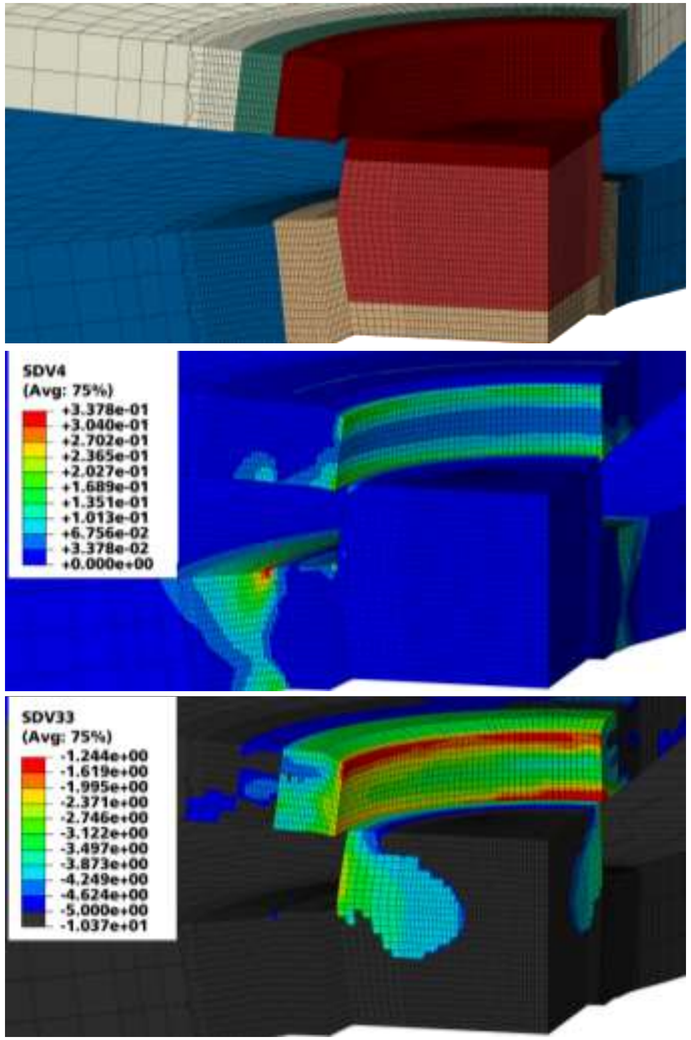
Characterization of weld microstructures

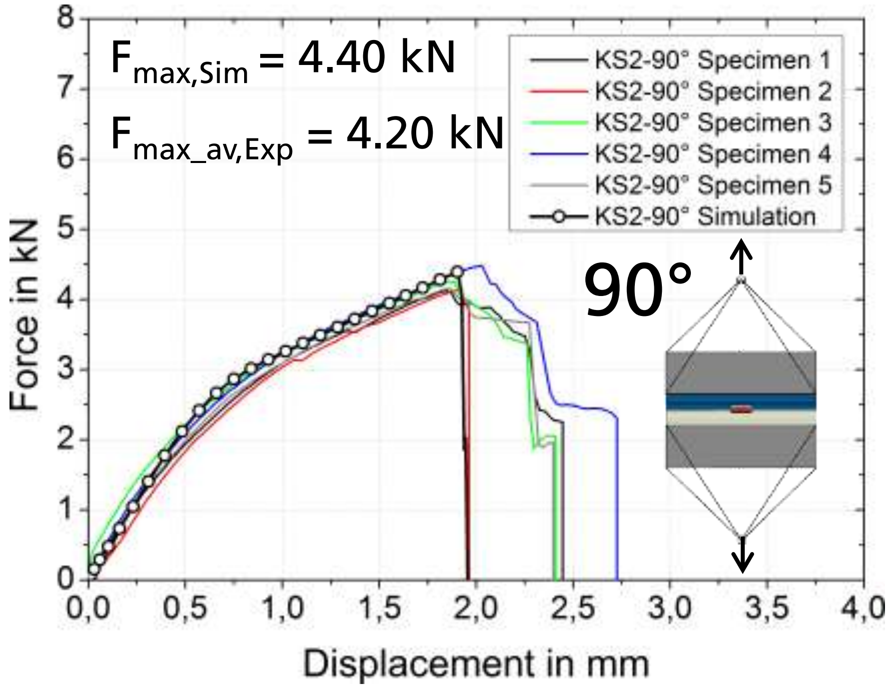




S. Burget, Modellierung des Verformungs- und Versagensverhaltens punktgeschweißter Mischverbindungen zwischen mikrolegierten und pressgehärteten Stählen, Dissertation, Karlsruher Institut für Technologie (KIT), 2016

Modeling of spot-welded joints

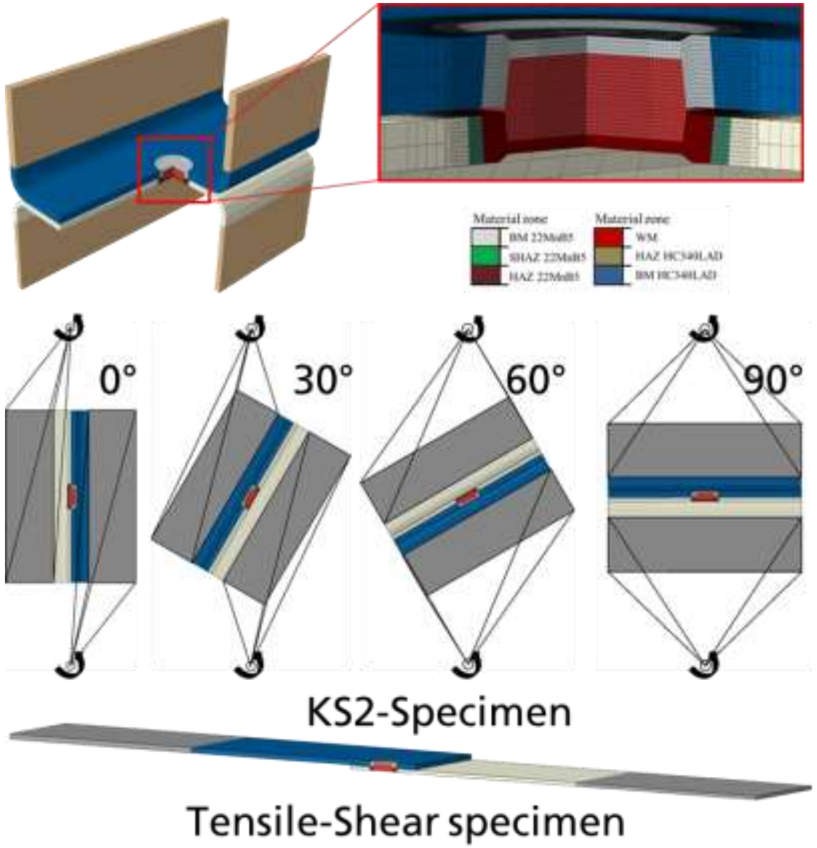


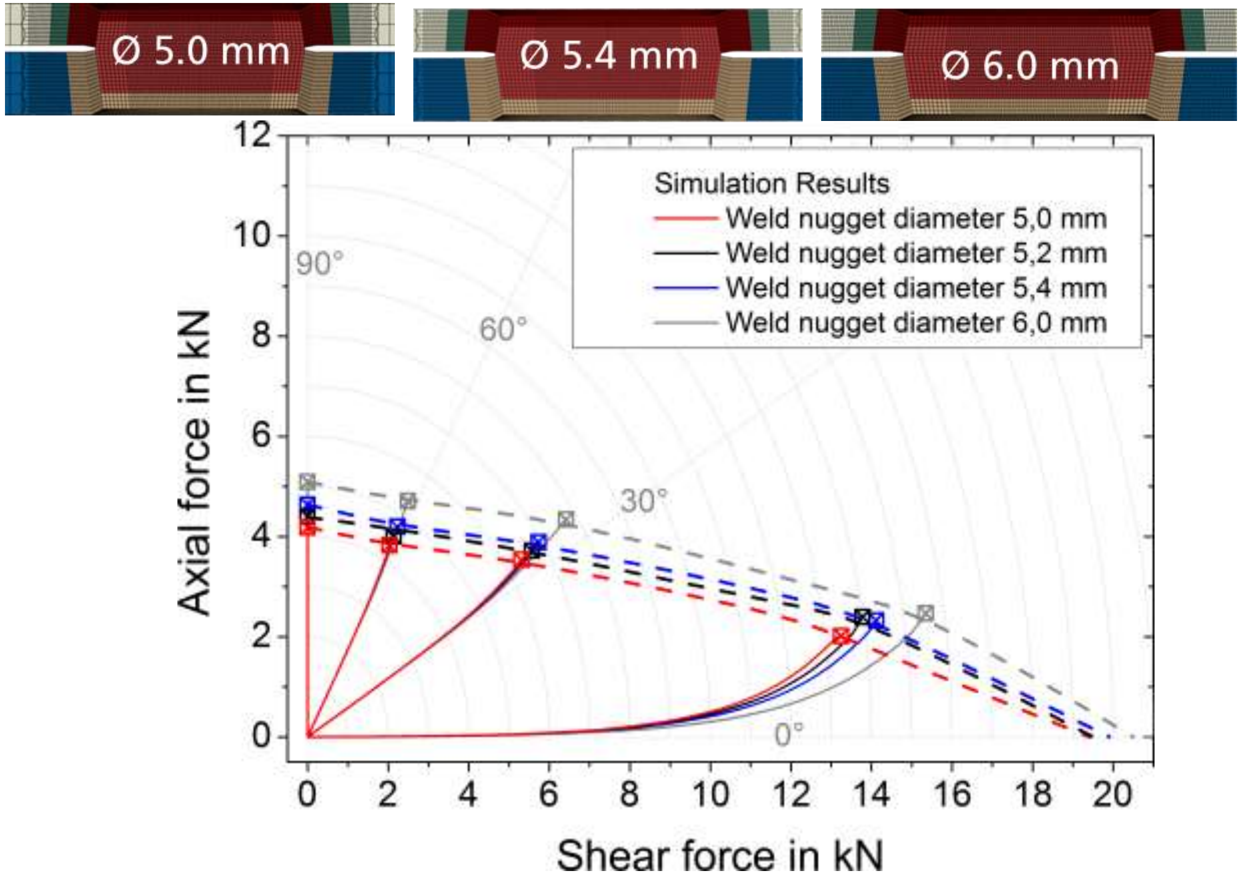


S. Burget, Modellierung des Verformungs- und Versagensverhaltens punktgeschweißter Mischverbindungen zwischen mikrolegierten und pressgehärteten Stählen, Dissertation, Karlsruher Institut für Technologie (KIT), 2016

Modeling of spot-welded joints

Numerical prediction of load bearing capacities using micromechanical damage models for the different weld zones



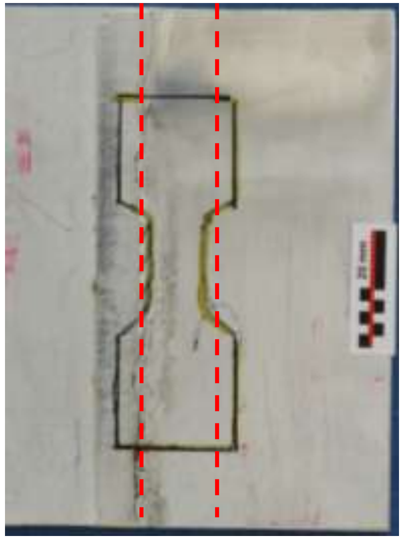


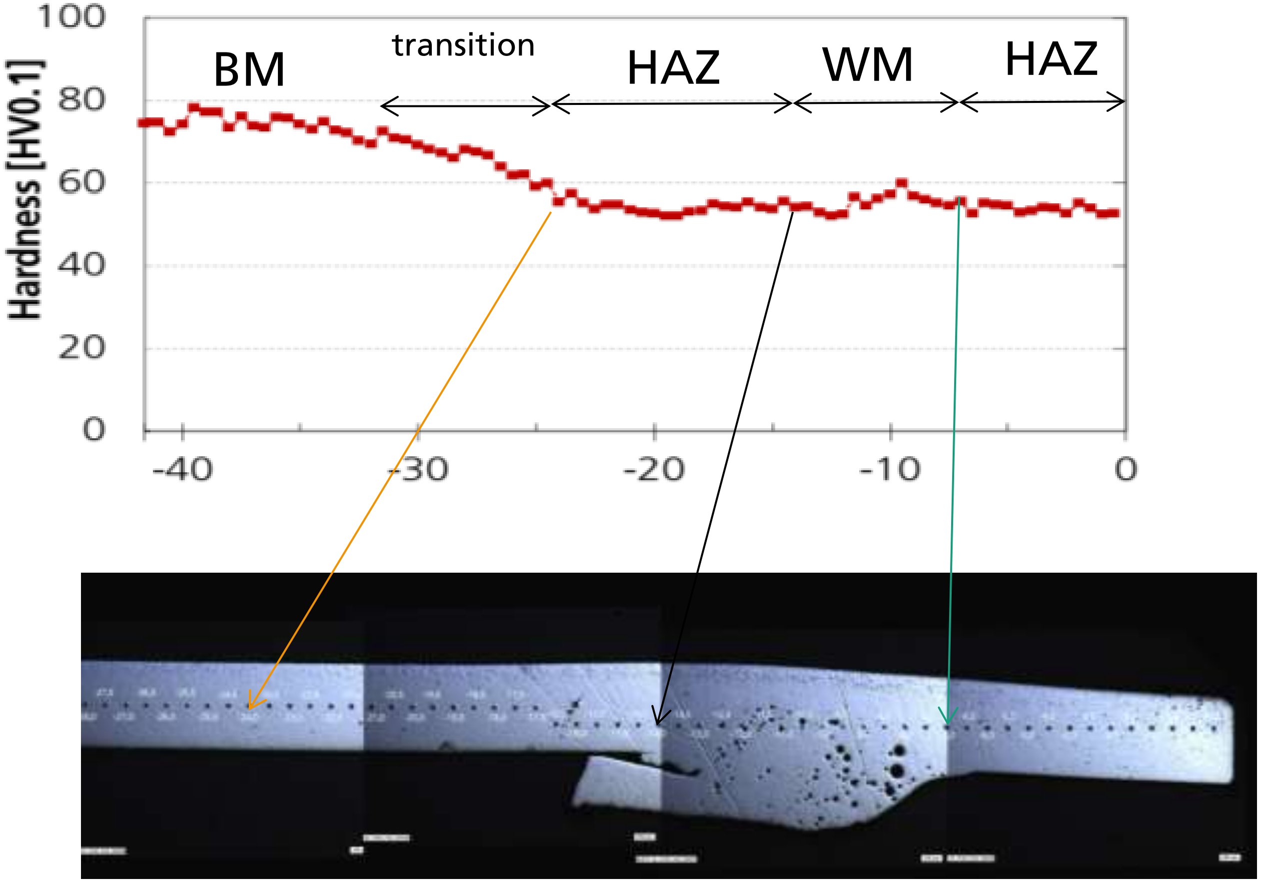
Calculated failure curves for different weld nugget diameters

S. Burget, Modellierung des Verformungs- und Versagensverhaltens punktgeschweißter Mischverbindungen zwischen mikrolegierten und pressgehärteten Stählen, Dissertation, Karlsruher Institut für Technologie (KIT), 2016

Characterization and modeling of weld zone specific material properties of GMAW weld seams

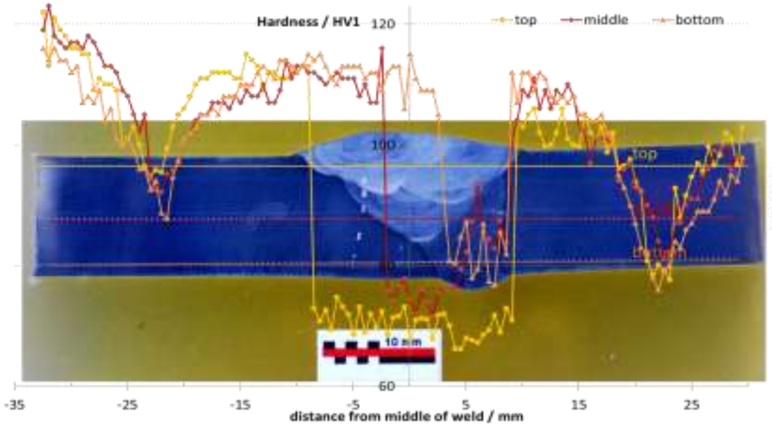
HAZ of Al 6000 series extrusion profil (MIG weld seam)

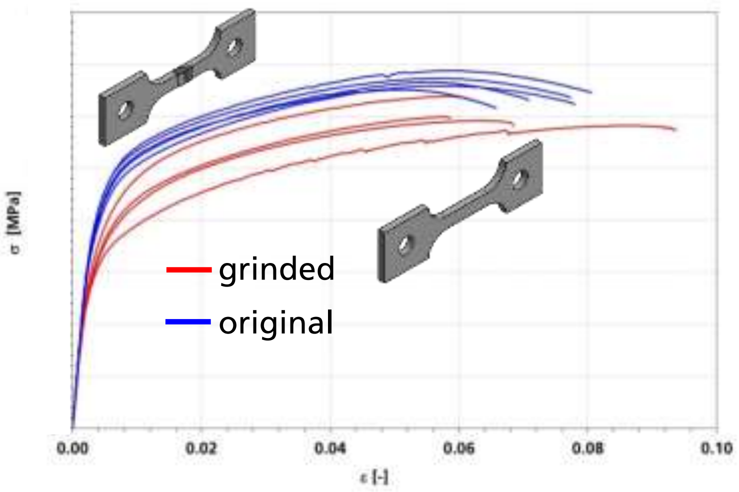




M. Feuerstein; F. Gensty; D.-Z. Sun, S. Sommer, Charakterisierung und Modellierung der Wärmeeinflusszone eines Aluminium-Strangpressprofiles, CrashMat, Freiburg, 2015

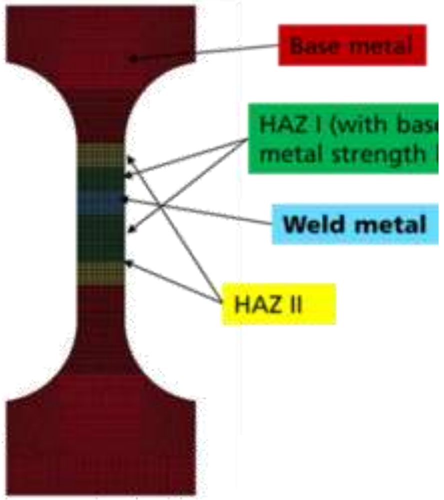
Layered butt weld of Al 7000 series alloy (MIG welded)
Tested smooth tensile specimens: as welded and grinded

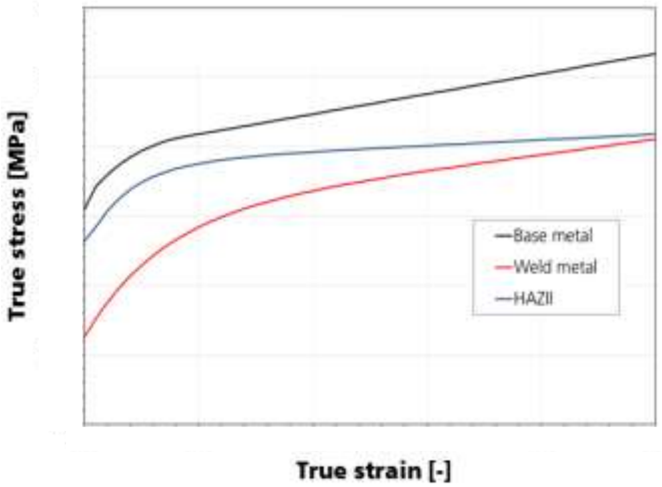


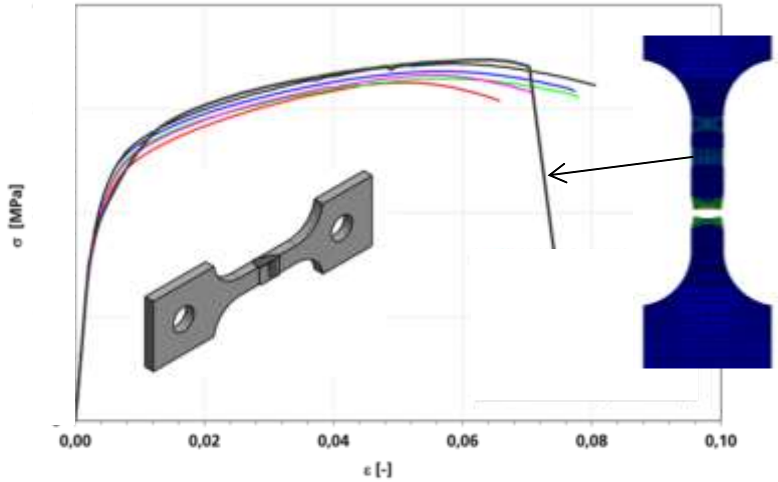


Specimens "as welded" fractured in softened HAZ

Specimens "grinded" fractured in weld metal



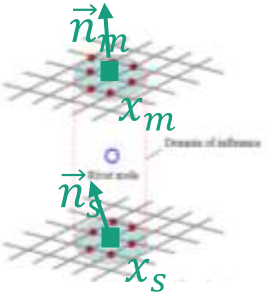




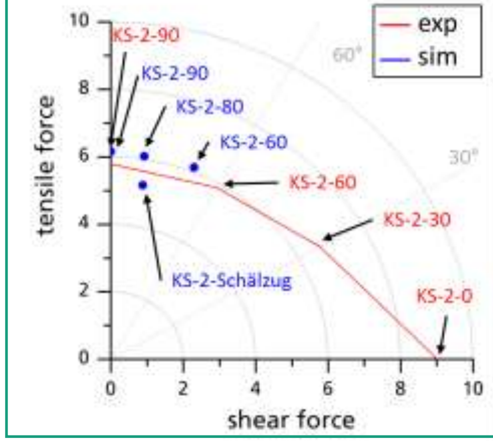
Modeling of self-piercing riveted joints

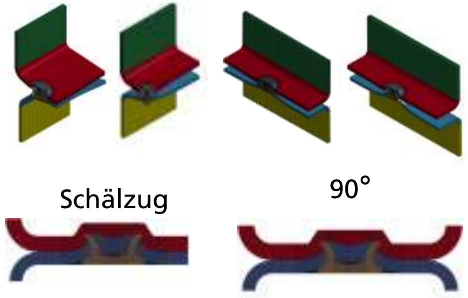
*CONSTRAINED_INTERPOLATION_SPOTWELD (Model 2) in LS-Dyna

*CONSTRAINED_SPR3 (Model 2)



Modell of SPRs
for crash simulation
based on
CONSTRAINED-
models





Deformation and

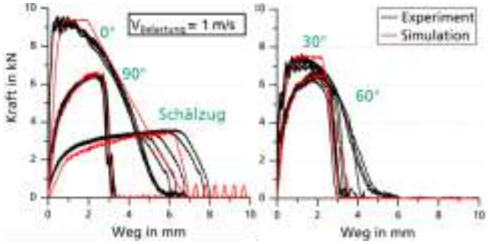
$sym = f\left(\measuredangle(\vec{n}_m, \vec{n}_s)\right)$

and damage behavior
up to failure

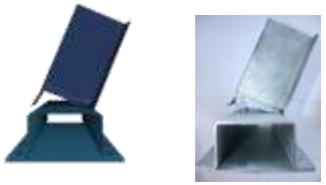
$$\left[\left(\frac{f_n}{R_n \cdot (1 - \alpha_1 \, * \, sym)}\right)^{\beta_1} + \left(\frac{f_s}{R_s}\right)^{\beta_1}\right]^{\frac{1}{\beta_1}} - F^0\left(\bar{u}^{pl}\right) = 0$$

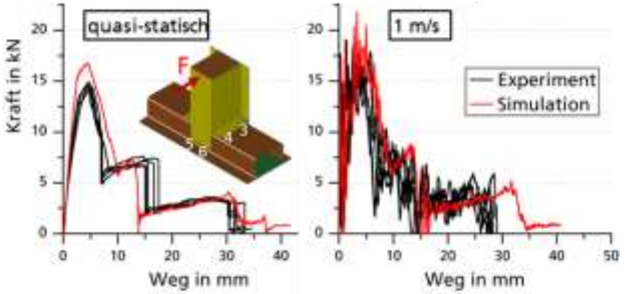
$$\left[\left(\frac{\bar{u}_f^{pl,n}}{\bar{u}_{f,ref}^{pl,n} \cdot (1 - \alpha_3 * sym\big)}\right)^{\beta_3} + \left(\frac{\bar{u}_f^{pl,s}}{\bar{u}_{f,ref}^{pl,s}}\right)^{\beta_3}\right]^{\frac{1}{\beta_3}} - 1 =$$

Determination of model parameters



Validation





M. Bier, S. Sommer: AIF IGF-Nr. 352ZBG / FOSTA P837 »Crash Mechanisches Fügen«

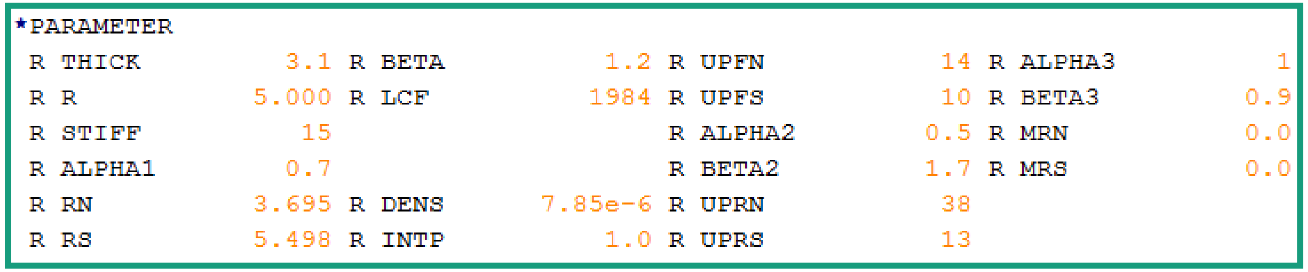
Automation of parameter identification and prediction of model parameters

*CONSTRAINED_INTERPOLATION _SPOTWELD (Model 2) in LS-Dyna

*CONSTRAINED_SPR3 (Model 2)

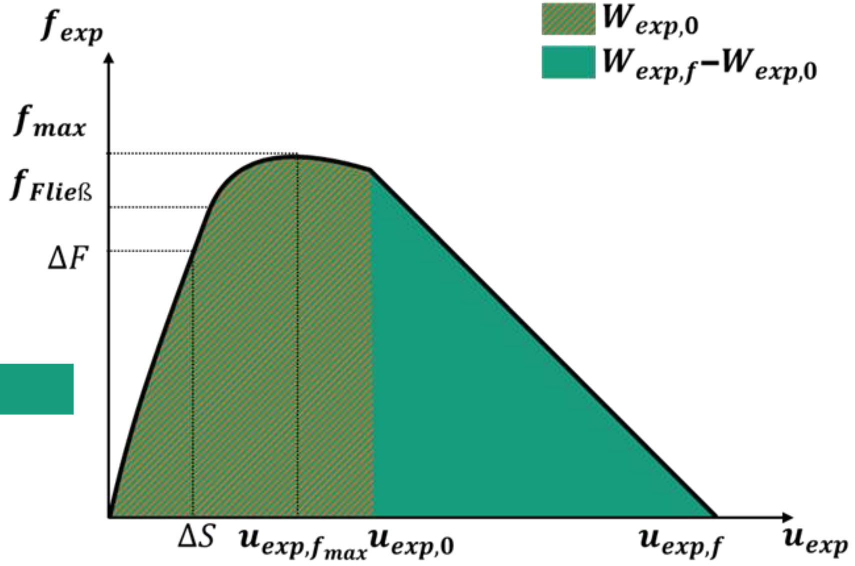
- Implementation of the calculation procedure in the software JoiningLab (GFaI)
- Model parameters are automatically determined from experimental test results
- <u>Prediction of properties and model parameters for untested connections, i.e. for unknown properties of a joint</u>
- Output of a material card file for LS-Dyna

Parameters / material card



```
*PARAMETER
 R THICK         3.1 R BETA          1.2 R UPFN           14 R ALPHA3          1
 R R           5.000 R LCF          1984 R UPFS           10 R BETA3         0.9
 R STIFF          15                     R ALPHA2        0.5 R MRN           0.0
 R ALPHA1        0.7                     R BETA2         1.7 R MRS           0.0
 R RN          3.695 R DENS      7.85e-6 R UPRN           38
 R RS          5.498 R INTP          1.0 R UPRS           13
```

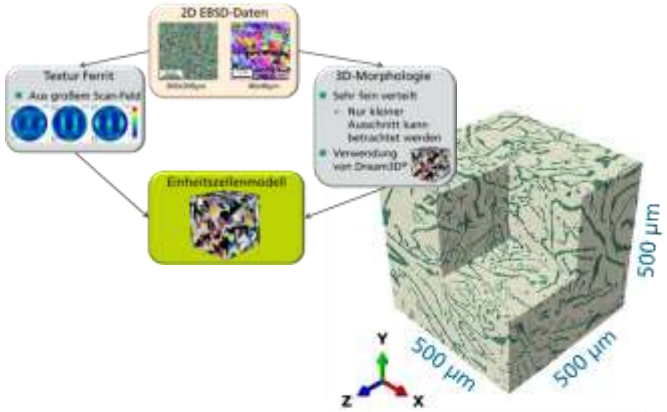
experiment or prediction



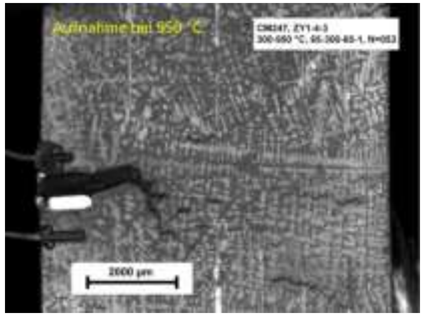
S. Sommer, P. Rochel, M. Guenther, D. Herfert, G. Meschut; P. Giese, Crash simulation of mechanical joints with automatically determined model parameters based on test results and prediction algorithms, 15th International LS-DYNA® Users Conference, Dearborn, 2018

Digitalization with Fraunhofer IWM: Integrated concept for reliability, lifetime, functionality of materials and components

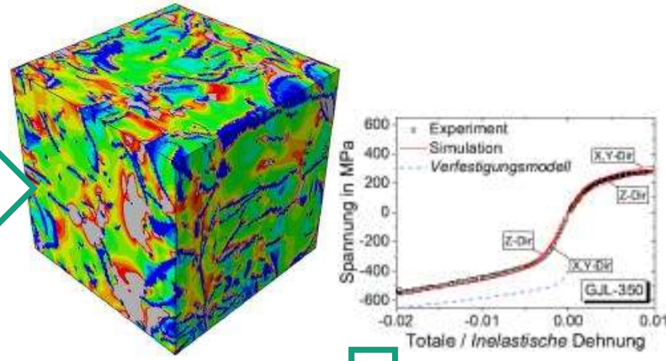
Systematic digitization of materials microstructure



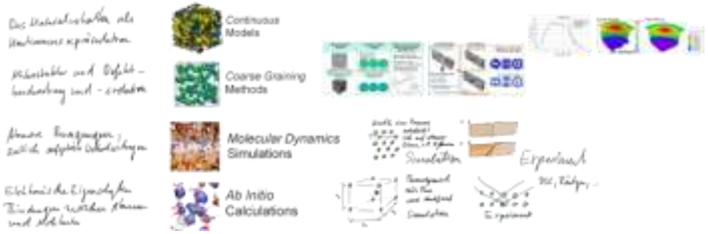
Microstructure evolution



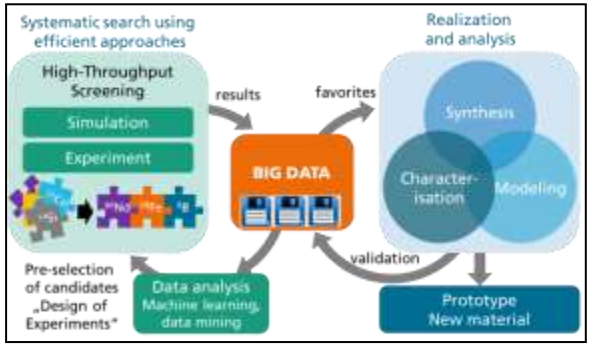
Integration across data and interfaces



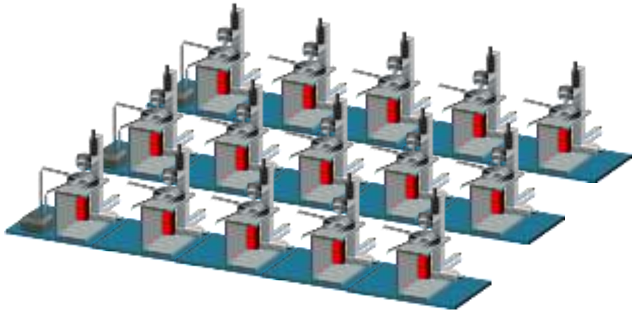
Problem oriented use of simulation and experiment



Multisclale high-throughput approach for experiments and simulations



Tribometer farm



Ch. Eberl, Workshop Material Digital, Fraunhofer IWM, 11.-12.04.2018

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