Materials up-scaling: Bringing Materials characterisation and materials simulation together:

FormPlanet & i-TRIBOMAT showcases

September 28 th
(10:00h - 11:30 CET)

FORM PLANET

i-TRIBOMAT
Intelligent Open Test Bed for Materials Tribological Characterisation Services

EMMC

This event has been organised under the framework of FormPlanet (GA num. 814517) and i-TRIBOMAT (GA num. 814494) projects, under the European Union's Horizon 2020 research and innovation programme

1. **10.00 – 10.05 – Welcome and introduction**
   Eduard Piqueras, *FormPlanet project coordinator,* **Eurecat**

2. **10.00 – 10.15 – i-TRIBOMAT, the European Tribology Centre**
   Franz Pirker, *Business Development Manager,* **AC2T**

   10.15 – 10.25– FormPlanet, the Sheet Metal Forming Testing Hub
   Begoña Casas, *FormPlanet Technical Coordinator,* **Eurecat**

3. **10.25 – 10.45 – Services for upscaling of self-lubricating sealing materials**
   Ulrike Cihak-Bayr, *Senior Researcher,* Marin Herr, *Junior Researcher,* **AC2T**

4. **10.45 – 11.15– Services and data workflow on modelling methods for Edge Cracking and crashworthiness prediction**
   Jörgen Kajberg, Assoc. *Professor,* **Luleå University of Technology**, Ricardo Hernández, *Researcher,* **Eurecat**, Muntasir Hashim, *Project Manager,* **ANSYS GRANTA**

5. **11.15 – 11.30 – Questions & Answers**

Speakers

Franz Pirker
Business Development Manager
AC2T

Begoña Casas
FormPlanet Technical Coordinator
Eurecat

Ulrike Cihak-Bayr
Senior Researcher
AC2T

Marin Herr
Junior Researcher
AC2T

Jörgen Kajberg
Assoc. Professor
Luleå University of Technology

Ricardo Hernandez
Researcher
Eurecat

Muntasir Hashim
Project Manager
ANSYS GRANTA

Eduard Piqueras
FormPlanet Coordinator
Eurecat

i-TRIBOMAT
Intelligent Open Test Bed for Materials
Tribological Characterisation Services

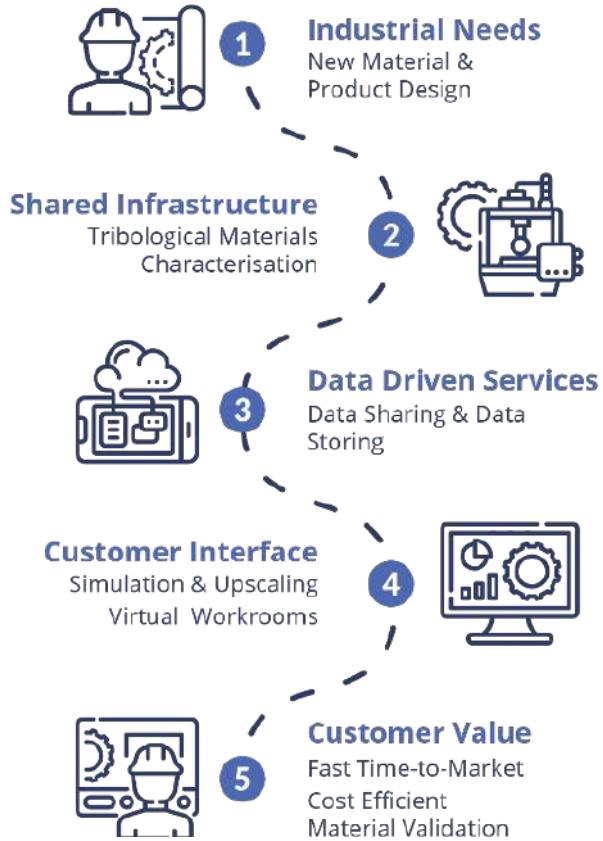
i-Tribomat

Overview

Franz Pirker
Business Development Manager, **AC2T**

i-TRIBOMAT
Intelligent Open Test Bed for Materials Tribological Characterisation Services

Digital services and digital business models in tribology



THE EUROPEAN TRIBOLOGY CENTER

Franz Pirker
AC2T research GmbH

This project has received funding from the European Union's **Horizon 2020** research and innovation programme (innovation action) under grant agreement No. 814494 (Call: H2020-NMBP-TO-IND-2018)

Key Figures

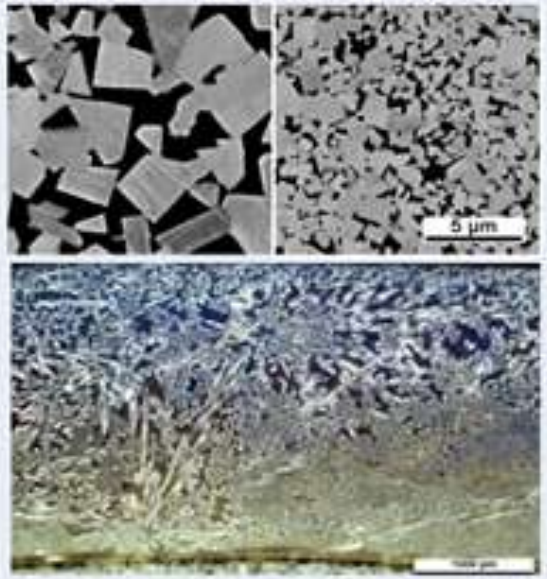
- Project Title: i-TRIBOMAT Intelligent Open Test Bed for Materials Tribological Characterisation Services
- GA No.: 814494 (Call: H2020-NMBP-TO-IND-2018)
- Duration: 48 months
- Grant: € 7.113.313,88
- Resources: 790 PMs

Please note!

i-TRIBOMAT is not an ordinary research project

i-TRIBOMAT builds up sustainable digital business

Motivation



new materials
steel, alloys, polymers, coatings, lubricants

i-TRIBOMAT
Intelligent Open Test Bed for Materials Tribological Characterisation Services

Materials Characterisation

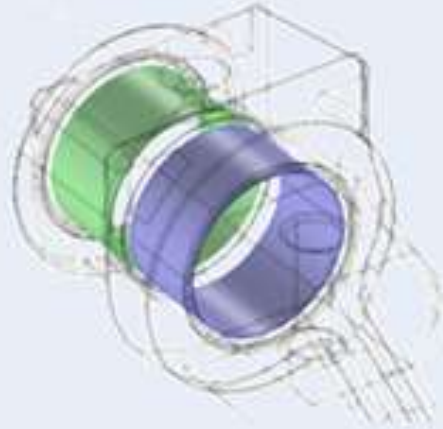
Tribological

Functionality → Reliability → Maintainability → Recyclability

Performance

Innovative Industrial Applications

can a material be applied in a industrial system?

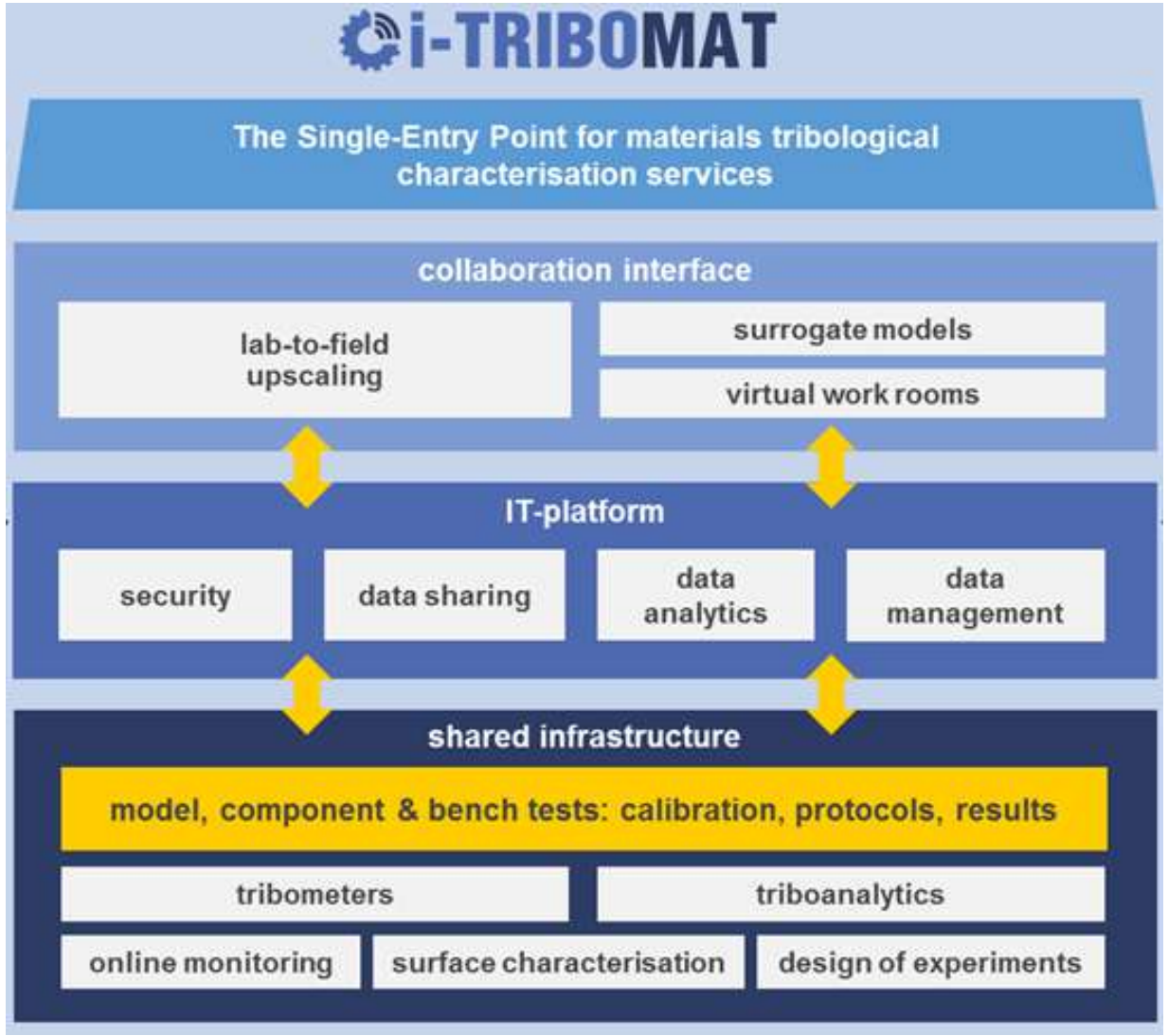


product design
sectors: energy, transport, manufacturing...

Industrial Motivation → Materials up-scaling
Reduction of time to market & reduction of costs

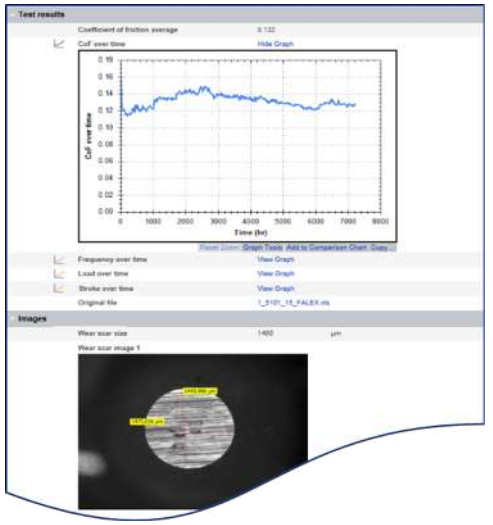
Main Concept - Implementation

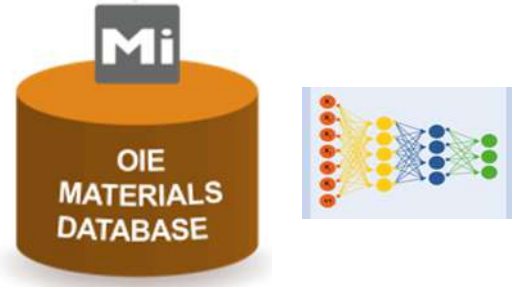
- **4 Interacting Units**
  - **Shared infrastructure**
    - Enabling standardised tribological materials characterisation services
  - **IT-platform**
    - Data driven services
  - **Collaboration interface**
    - Virtual work rooms and lab-to-field upscaling tools
  - **Single-Entry Point ETC**
    - Service Provider

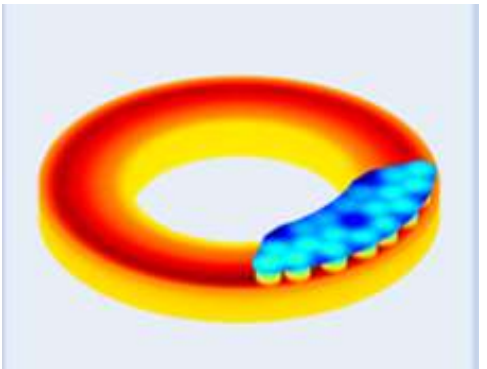


i-TRIBOMAT *"digital"* services

- **3 categories of services**
  - Standardised tribological characterisation services
  - Data driven services
  - Virtual workrooms and up-scaling

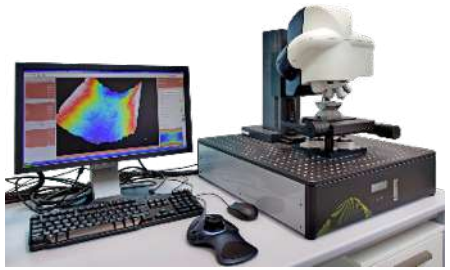


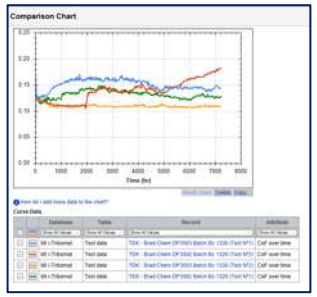


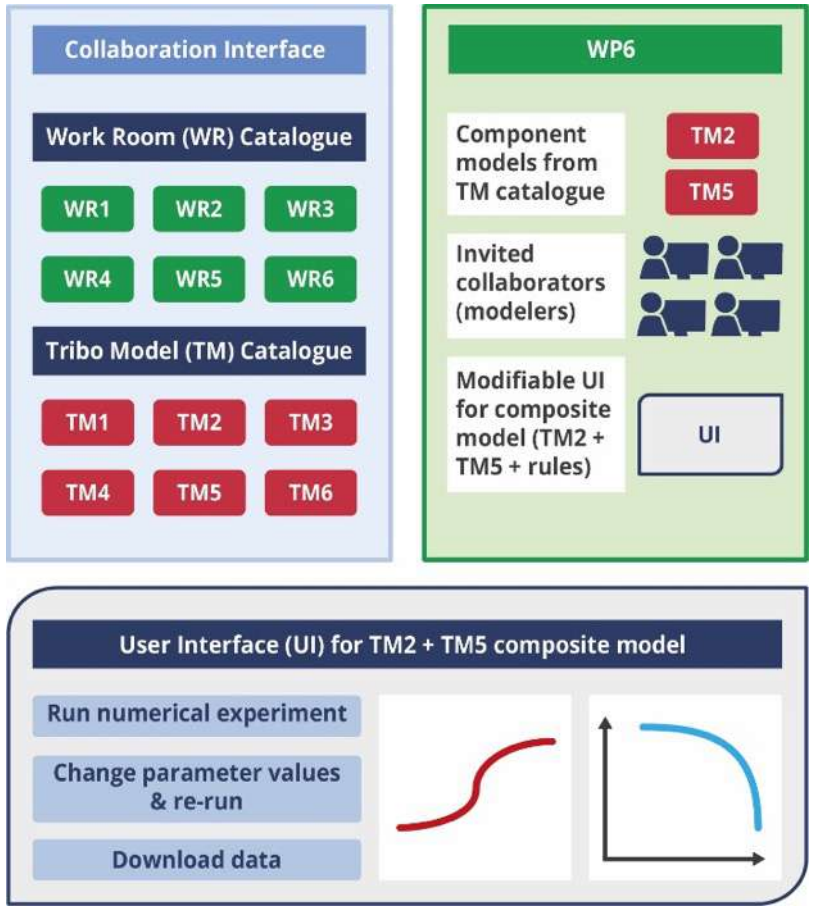


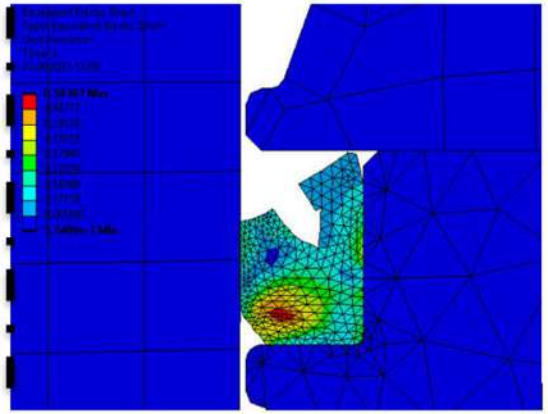
Digital - Services

- **Up-scaling materials via a seamless simulation workflow**









Service 1 **Service 2** **Service 3**

i-TRIBOMAT – THE EUROPEAN TRIBOLOGY CENTER

i-TRIBOMAT
Intelligent Open Test Bed for Materials Tribological Characterisation Services

- **We are the world's largest provider of tribological material characterization and materials up-scaling services**
  - More than 100 tribometers and additional advanced characterization methods
  - More then 250 experts
- **Trusted characterisation and qualification of materials by reliable standardised testing procedures**
  - We guarantee highest accuracy, repeatability and interoperability
- **Database with over 10.000 tribological material characterization datasets**
  - Coefficient of friction, wear etc.
  - Daily growing
- **Prediction of product performance via Virtual Workrooms**
  - Easy to use Lab-to-field materials up-scaling and simulation tools
  - Customized solution for your use case

FormPlanet

Overview

Begoña Casas
FormPlanet Technical Coordinator, **Eurecat**

FormPlanet project

Sheet Metal Forming Testing Hub

Facts and figures

AIM: boost the sheet metal forming industry by developing and validating an **integrated ecosystem** offering **novel sheet metal characterisation and modelling methodologies**

17 participants from **8 different countries**

3 years duration, from January 2019 to December 2021

Funded by the Horizon 2020 programme
Grant agreement ID: 814517

FormPlanet project

Consortium

FormPlanet consortium is composed of **17 partners** from **8 European countries**: 5 leading technological sites, 4 service providers and 8 industrial companies.

eurecat
Fraunhofer IWU
COMTES FHT Complete Technological Service - Forming, Heat Treatment
Luleå University of Technology
Università di Pisa
ANSYS GRANTA
UNE Normalización Española
Applus laboratories
LETOMEC
ArcelorMittal
arania
aludium premium aluminium
AP&T Automation · Presses · Tooling
Arçelik
Lamera
estamp
CRF Centro Ricerche Fiat

FormPlanet Test Bed

Open Innovation Test Bed (OITB) on metal characterisation and modelling

FormPlanet ecosystem is conceived as an Open Innovation Test Bed (OITB), a single entry point for accessing the services of leading characterisation organisations and service providers. The new entity is to be created by the end of 2021 as part of FormPlanet project.

Access to valuable technological developments

Single entry point

Equality of access and conditions

Service modularity

Integral service provision

FormPlanet

Competitive Advantage

Limitation

Productivity losses due to crack defects, limited formability and inaccurate quality assessment.

Need

NEED for accurate **MATERIALS CHARACTERISATION** and new **MODELLING APPROACHES** to assess **SHEET FORMABILITY** (predict & solve sheet cracking) and **PART PERFORMANCE**.

Offer

User-driven driven **INTEGRATED TEST BED ECOSYSTEM** offering **advanced Testing Methodologies** to assure zero-defects production and optimise sheet material development, production and performance.

Novel characterisation services

Advanced testing methodologies for more accurate **sheet metals characterisation, non-destructive in-process measurements** and **modelling**, addressing processability and quality parts problems in the sheet manufacturing sector

Sheet material development and production

Part and forming process design

Components production

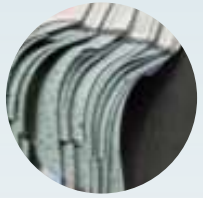
Service benefits

The new experimental and modelling methodologies can help the sheet metal sector:

1. **Assure zero-defects production** (reduction of rejected parts).
2. Develop new **high-performance sheet materials at reduced costs** by the optimisation of the design, production and performance of the sheet material.
3. **Reduce time-to-market** and develop **new high-performance sheet parts** at reduced cost by the optimisation of the design and manufacture processes.
4. Increase **productivity** in the manufacture of sheet metal parts.
5. Improve **quality parts** using non-destructive techniques to in-line assess part integrity in high quality products.
6. Build **robust processes** to prevent unexpected failures due to deviations from batch to batch of the sheet metal coil or plates, using tests to control raw material properties.

Novel characterisation services

Sheet material development and production



Edge cracking and stretch-flangeability

- Optimised Hole Expansion Test (HET)
- Half Specimen Dome Test (HSDT)
- Local damage evaluation of shear edges

Delayed fracture and H embrittlement

- H diffusion testing
- Slow Strain Rate Test (SSRT)
- Four Point Bending Test (FPBT)
- Small Punch Test (SPT) of thin sheets

Fatigue resistance

- Fatigue resistance test

Fracture toughness

- Fracture toughness evaluation of thin and thick sheets
- Quasi-static as well as dynamic conditions

Micro-mechanical characterisation

- Micro-tensile tests
- X-Ray microtomography

Crashworthiness

- Dynamic component testing
- Stereo high-speed imaging
- 3D deformation field measurement

Novel characterisation services

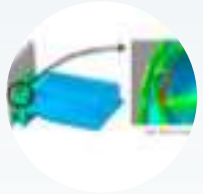
Part forming and process design

Forming limits evaluation at room and high temperature

- High temperature FLC characterisation
- Biaxal tensile test at room temperature
- Deep drawing test

Edge cracking

- Edge tracking modelling and prediction

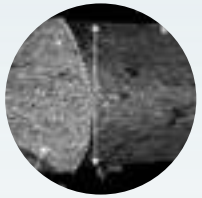


Modelling of part performance

- Modelling of crash boxes

H embrittlement

- Modelling of H embrittlement

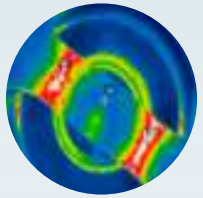


Material data for modelling

- Smart material data characterisation – Calibration of proper models
- Stepwise Modelling Method (SMM)
  - Hardening behaviour from initial yielding beyond necking to final fracture
  - Testing at various stress states
  - Isotropic and anisotropic materials

Novel characterisation services

Components production



In-process check systems

- Wear prediction in tooling
- Laser tracking
- Advanced thermography for part integrity

In-line part quality assessment

- 3MA system for quality inspection of components
- Industrial on-line diffusible H measurement

Complementary services

Components production

1

Incremental Sheet Forming (ISF)
Process to obtain 3D sheet metal parts without the need of dedicated tools.

2

Materials information services
Materials information management platform.

3

Material traceability for product certification and quality label
Product certification without the participation of a certification engineer.

4

Other material characterisation services
Heat treatment, tribometry, fatigue testing, forming or vaccum melting.

5

Consulting services
Market studies and cost-benefic analyses, financing plans for SMEs, identification of competitive advantage solutions.

6

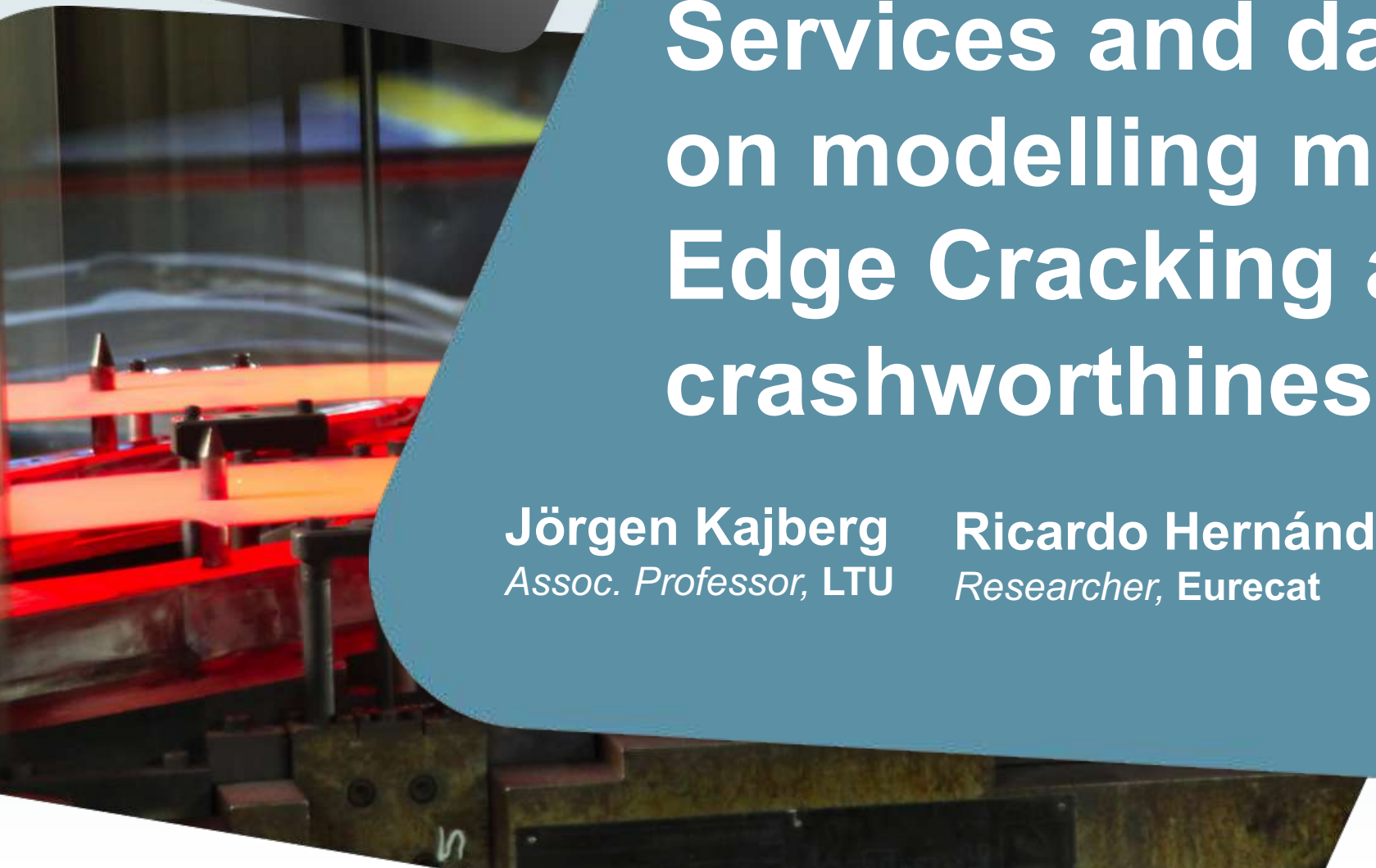
Training and knowledge
Tailor-made training programmes.

i-TRIBOMAT
Intelligent Open Test Bed for Materials Tribological Characterisation Services

Services for upscaling of self-lubricating sealing materials

Ulrike Cihak-Bayr
Senior Researcher, **AC2T**

Marin Herr
Junior Researcher, **AC2T**



Services and data workflow on modelling methods for Edge Cracking and crashworthiness prediction

Jörgen Kajberg
Assoc. Professor, **LTU**

Ricardo Hernández
Researcher, **Eurecat**

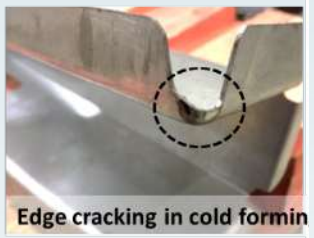
Muntasir Hashim
Project Manager, **ANSYS GRANTA**

Modelling

addressed problems

1

Edge Cracking



The use of new high strength sheet materials still represents unpredictable occurrence of edge cracking.

Traditionally, sheet formability has been addressed through tensile tests and forming limit curves (FLC), with good enough results.

However, such tests do not allow understanding crack-related problems, which remain as still unsolved issues in the sector and hamper the use of new materials and the development of high-performance parts at reduced costs.

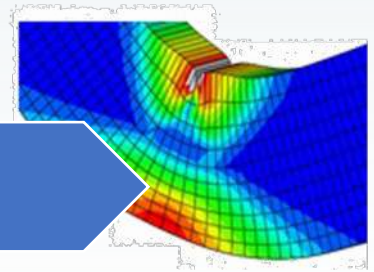
2

Crashworthiness

New AHSS:s are of great interest when designing energy absorbing safety parts.

To investigate the crashworthiness and to predict potential crack formation, calibrated material relations covering large deformations, high strain rates and failure are needed.

Furthermore, well instrumented crash tests are beneficial when studying new grades and validating calibrated material relations



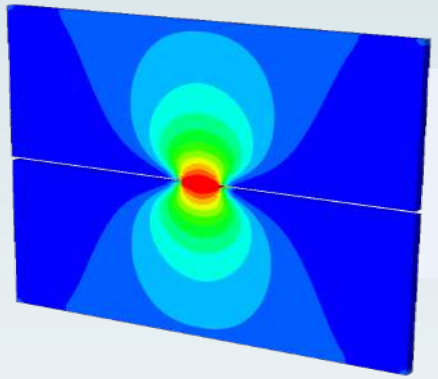
Test & Material Properties → Material Models → FEA

Data Base

Edge Cracking Modelling

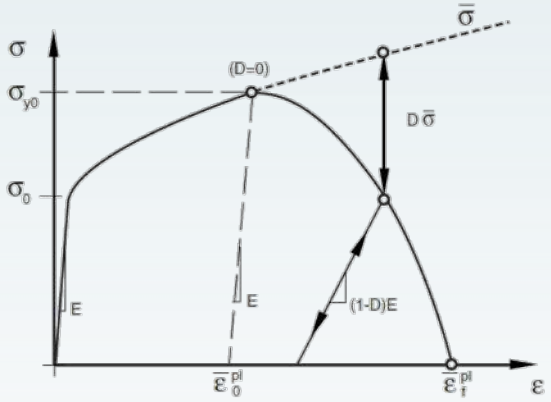
Damage model

DENT Simulation



Ductile Damage:
- Damage Initiation
- Damage Evolution

SIMULIA ABAQUS



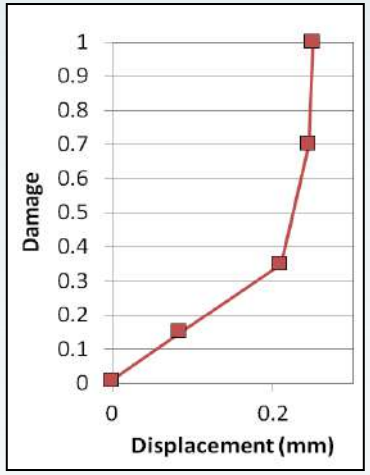
Criterion for damage initiation:

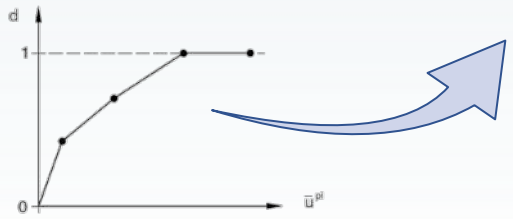
$$\omega_D = \int \frac{d\bar{\varepsilon}^{pl}}{\bar{\varepsilon}_D^{pl}} = 1$$

Criterion for damage evolution:

$$D = \frac{L \cdot \dot{\bar{\varepsilon}}^{pl}}{\bar{u}_f^{pl}} = \frac{\dot{\bar{u}}^{pl}}{\bar{u}_f^{pl}}$$

L Characteristic length



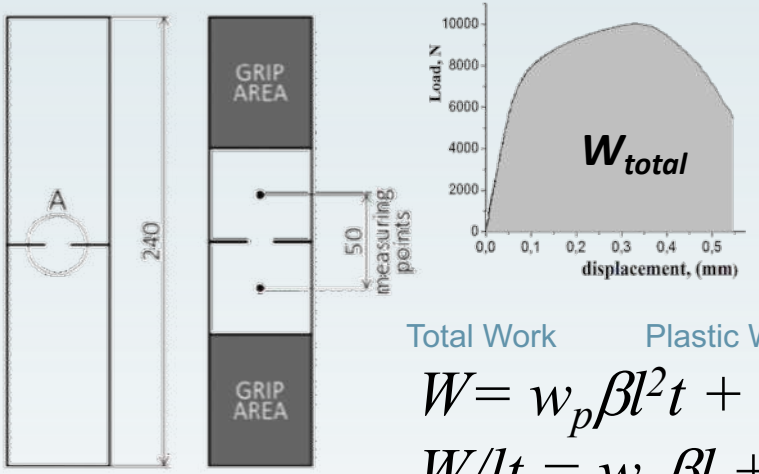


Damage Evolution

neither linear
nor exponential

The plastic-damage model in Abaqus is based on the models proposed by Lubliner et al. (1989) and by Lee and Fenves (1998).

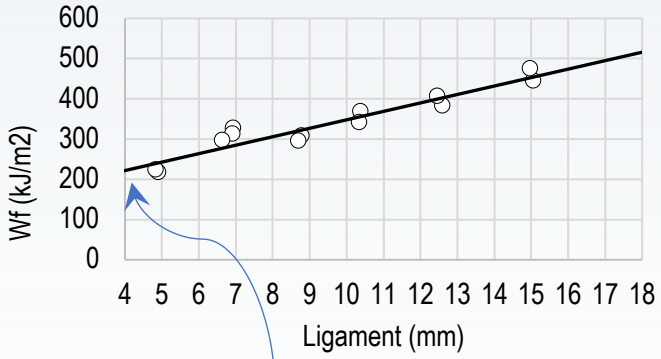
Toughness Measurements
Essential Work of Fracture (EWF)
Double Edge Notch Tensíon Test (DENT)



Total Work Plastic Work

$$W = w_p \beta l^2 t + w_e l t$$

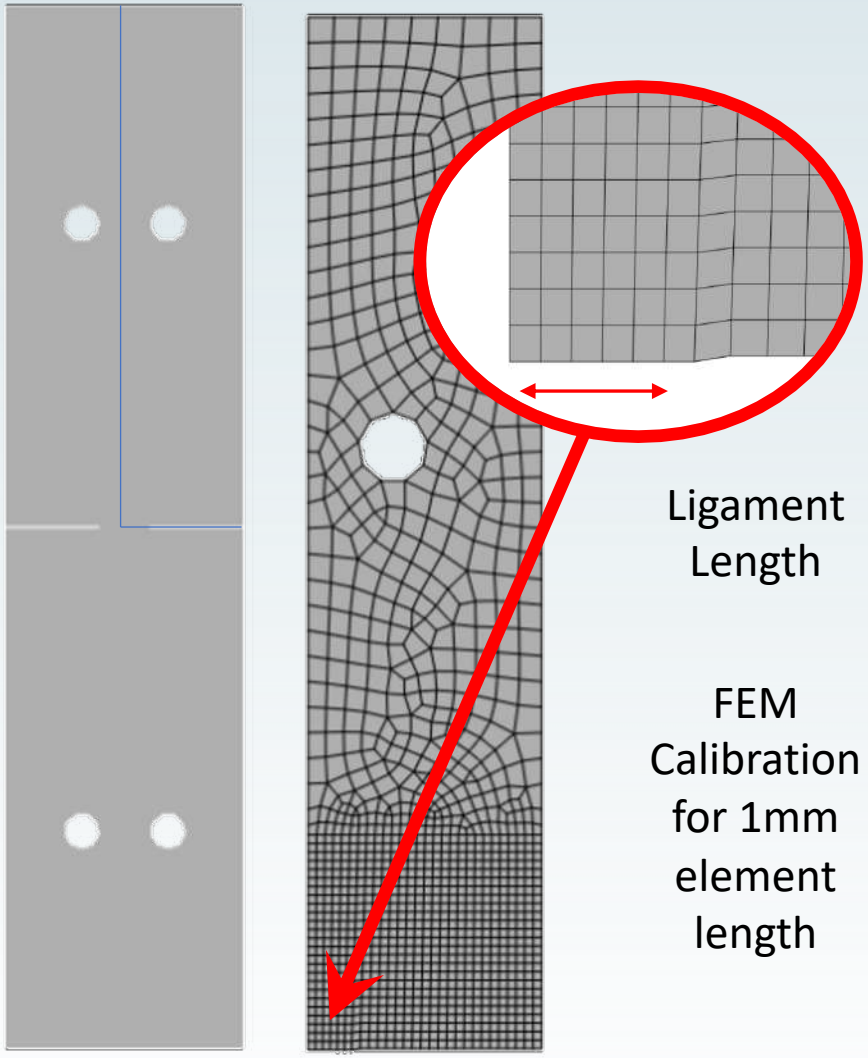
$$W/lt = w_p \beta l + w_e$$



Essential Work of Fracture

Edge Cracking Modelling

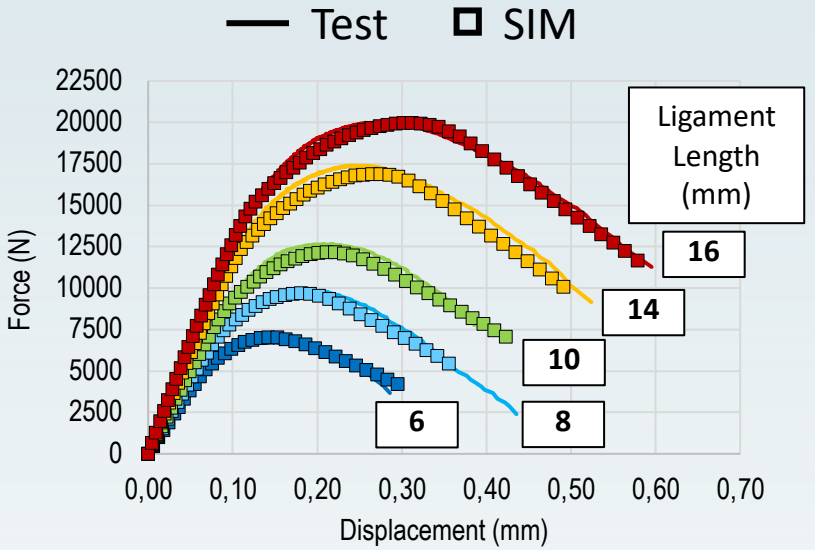
DENT Simulation

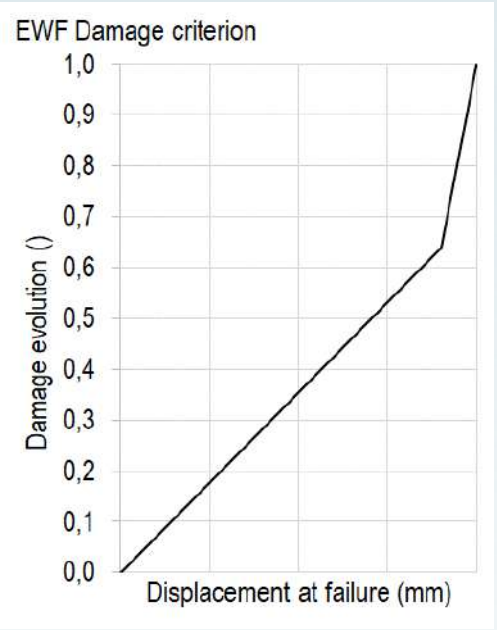


Ligament Length

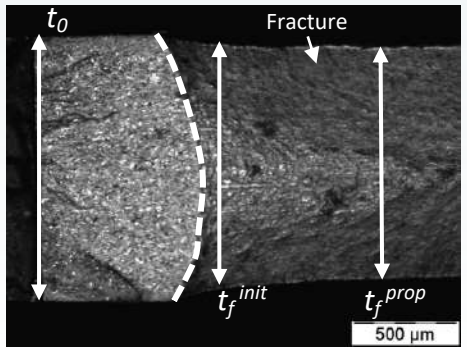
FEM Calibration for 1mm element length

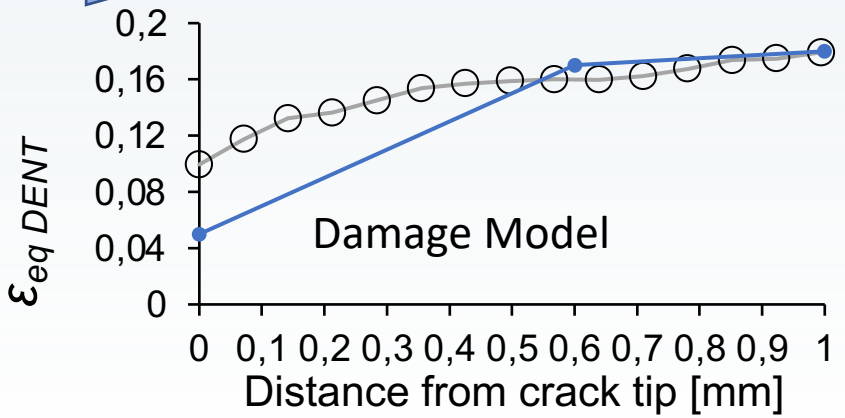
Symmetry → a quarter of model





Full Empirical Approach



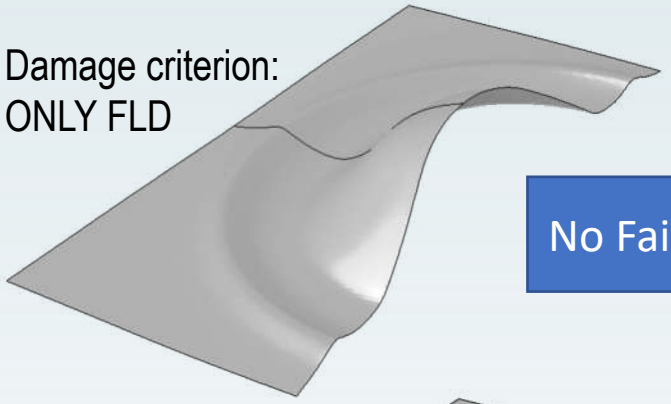


Edge Cracking Modelling

Validation

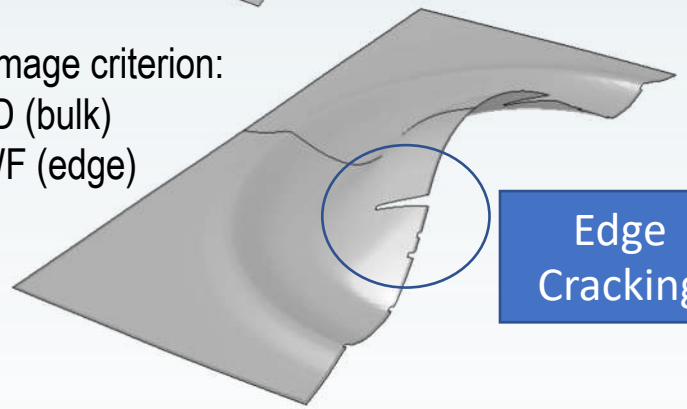
Half specimen dome test (HSDT)

Damage criterion:
ONLY FLD

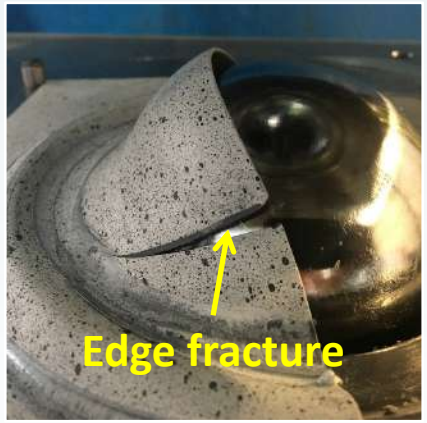


No Failure

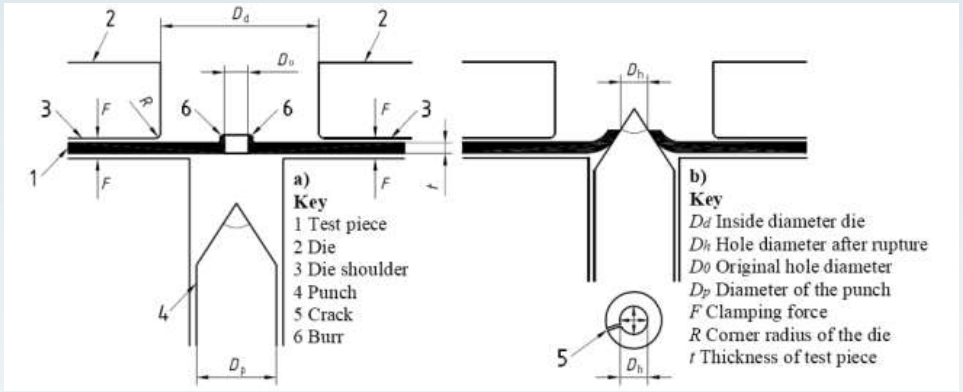
Damage criterion:
FLD (bulk)
EWF (edge)



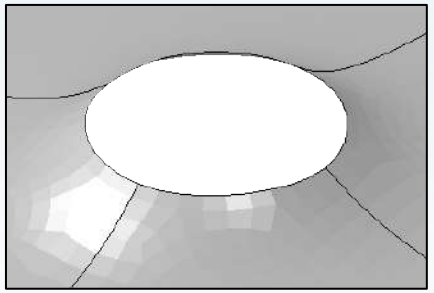
Edge Cracking



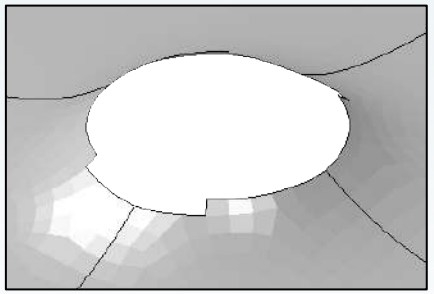
Hole Expantion Test (HET)



Some preliminary result of HET simulations



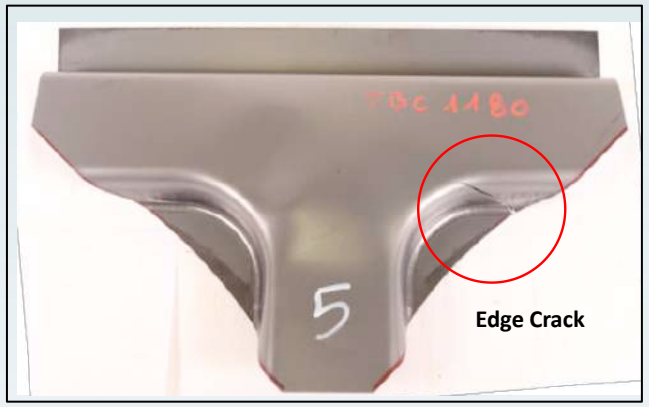
FLD No failure



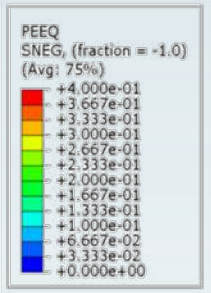
Edge cracking with EWF criterion

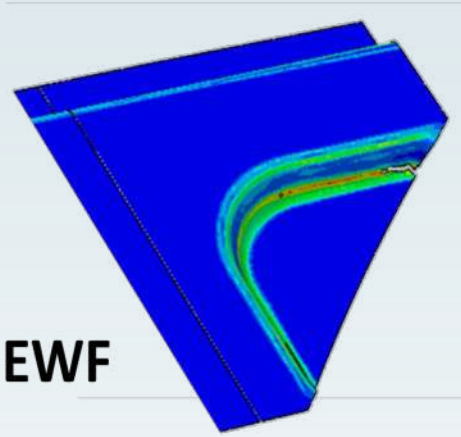
Edge Cracking Modelling

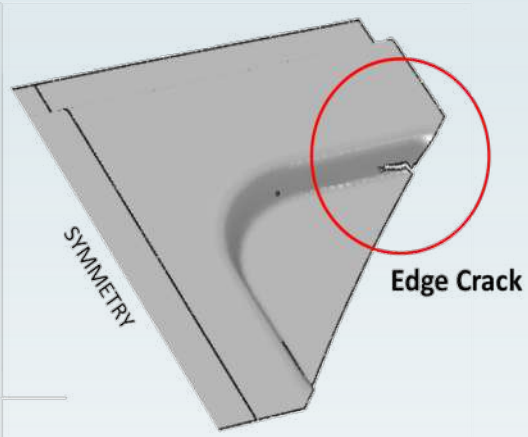
Validation

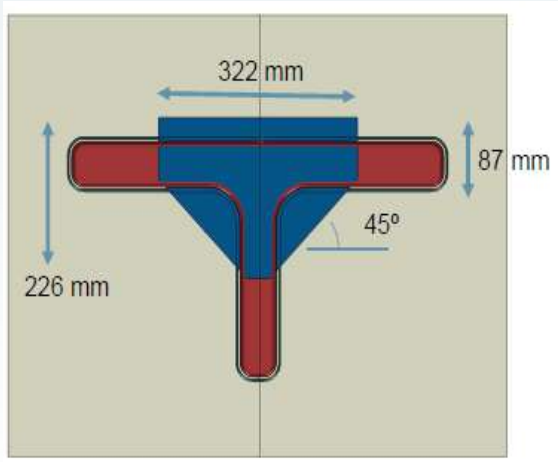


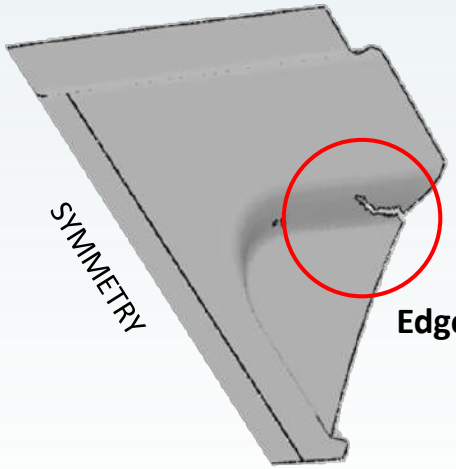
FIAT - T Node

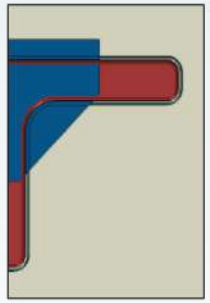


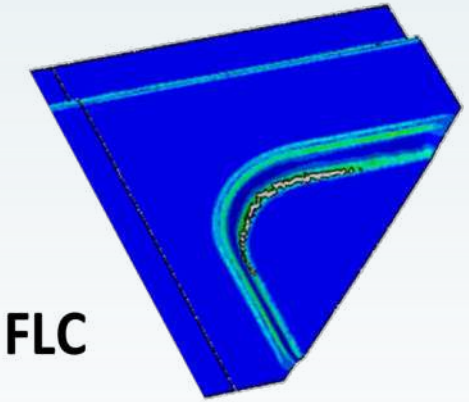


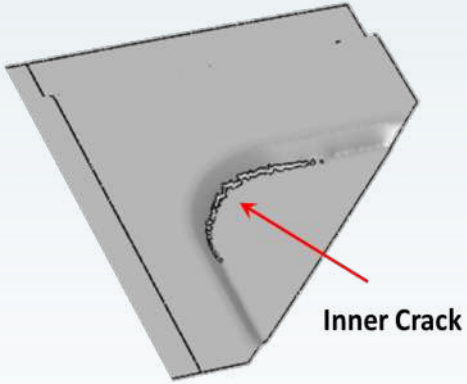












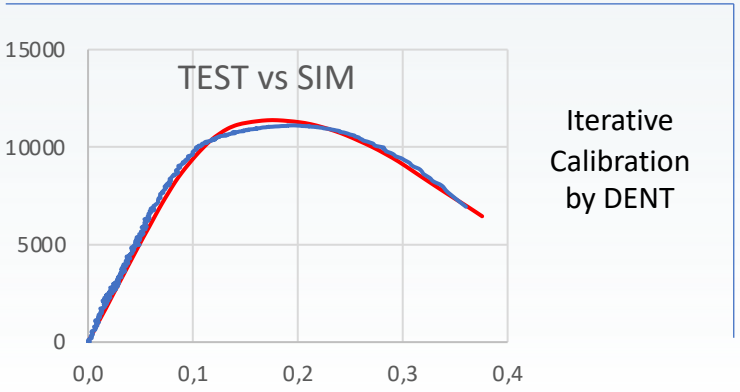
Edge Cracking Modeling

Data

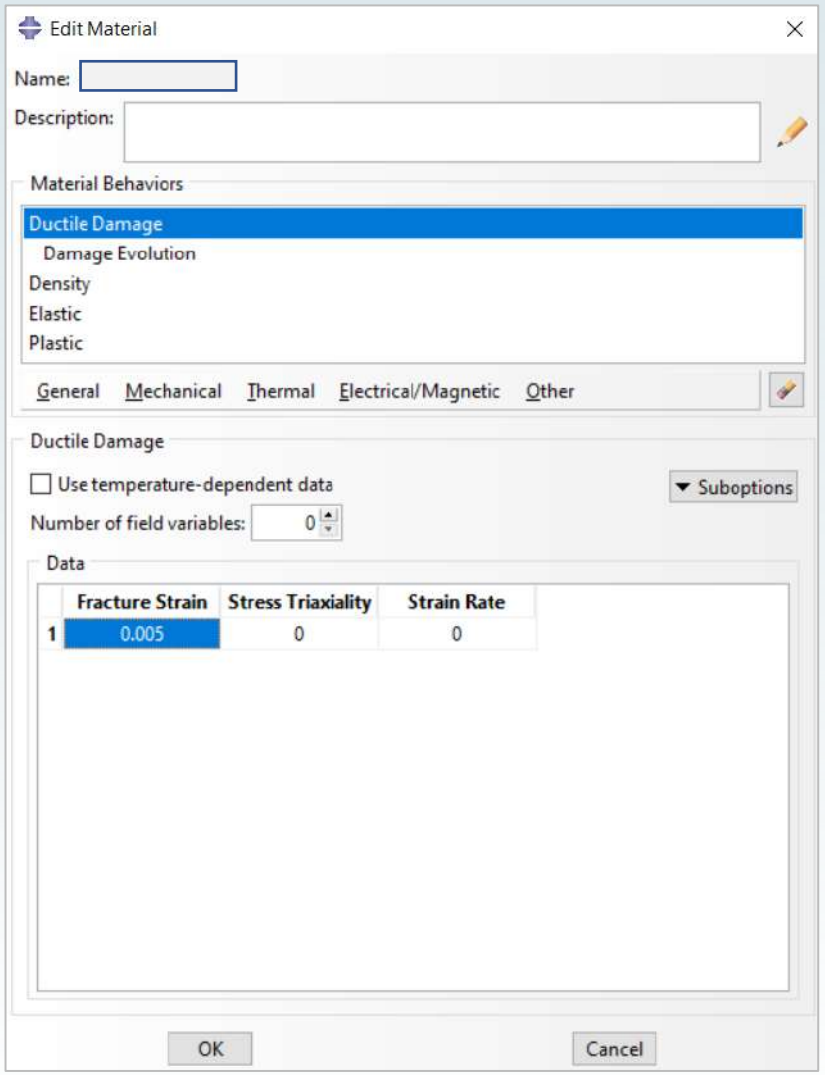
Damage Model Parameters	
Damage Initiation	
εp	0,005
Damage Evolution	
Upl (mm)	*D ()*
0,000	0,000
0,170	0,600
0,180	1,000

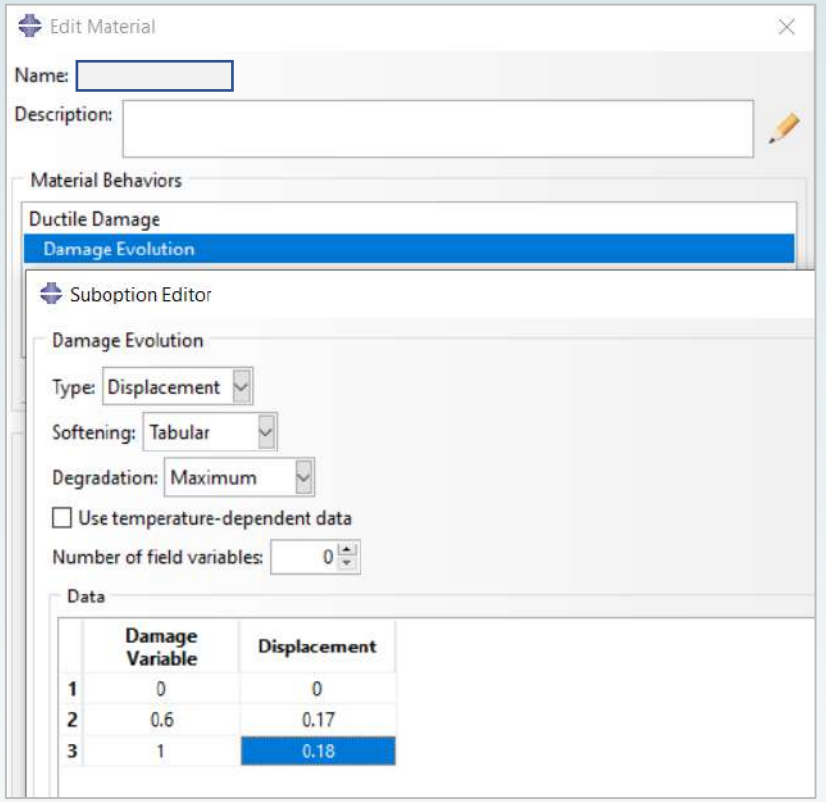
ABAQUS INPUT FILE FORMAT

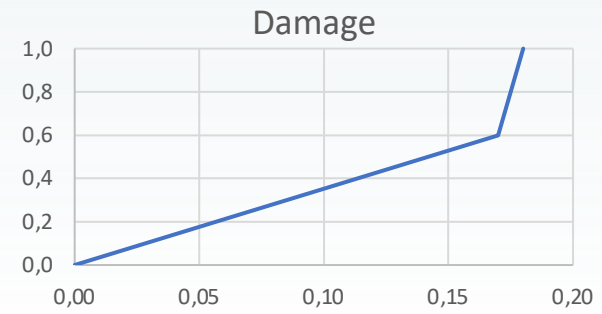
```
*Damage Initiation, criterion=DUCTILE
 0.005, 0.,    0.
*Damage Evolution, type=DISPLACEMENT, softening=TABULAR
  0.,   0.
 0.6, 0.17
  1., 0.18
```



Iterative Calibration by DENT







Crashworthiness prediction

Utilized services offered by FormPlanet

Experiments

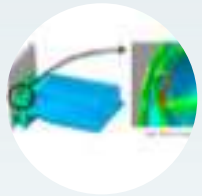
Material data for modelling

- Smart material data characterisation – Calibration of proper models
- Stepwise Modelling Method (SMM)
  - Hardening behaviour from initial yielding beyond necking to final fracture
  - Testing at various stress states
  - Isotropic and anisotropic materials

Crashworthiness

- Dynamic component testing
- Stereo high-speed imaging
- 3D deformation field measurement

Modelling



Modelling of part performance

- Modelling of crash boxes

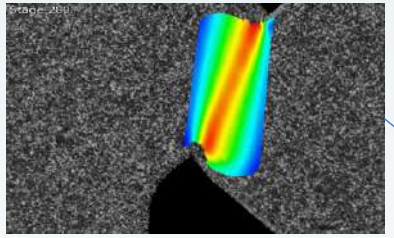
Crashworthiness prediction

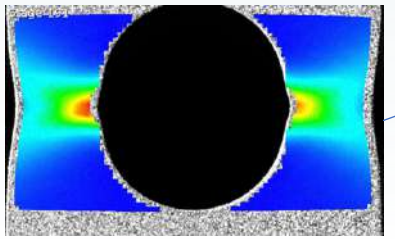
Utilized services

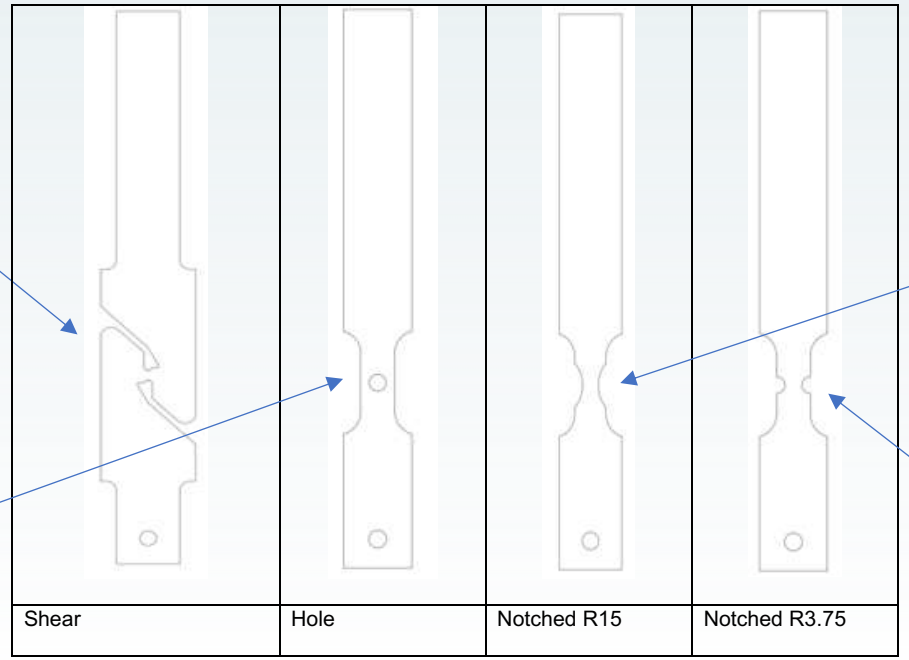
Experiments

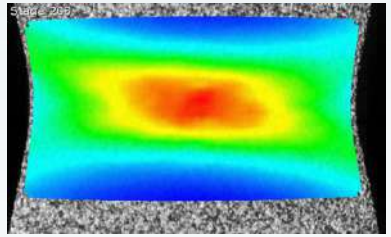
Material data for modelling

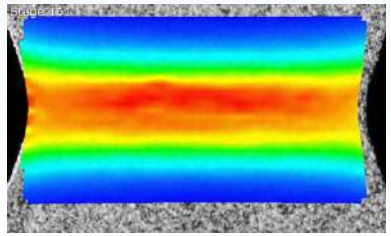
- Calibration of proper models
- **Stepwise Modelling Method (SMM)**
  - Hardening behaviour from initial yielding beyond necking to final fracture
  - Testing at various stress states
  - Isotropic and anisotropic materials



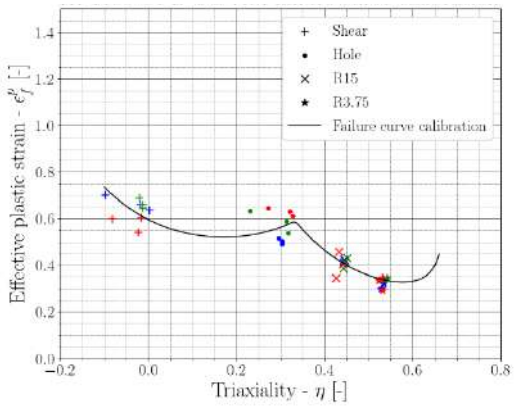




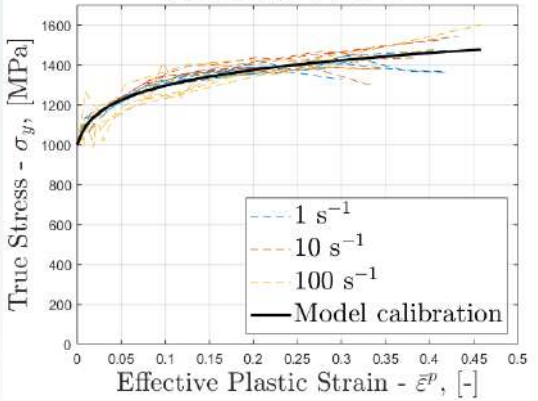




3rd gen AHSS



3rd gen AHSS



Stepwise Modelling Method (SMM)

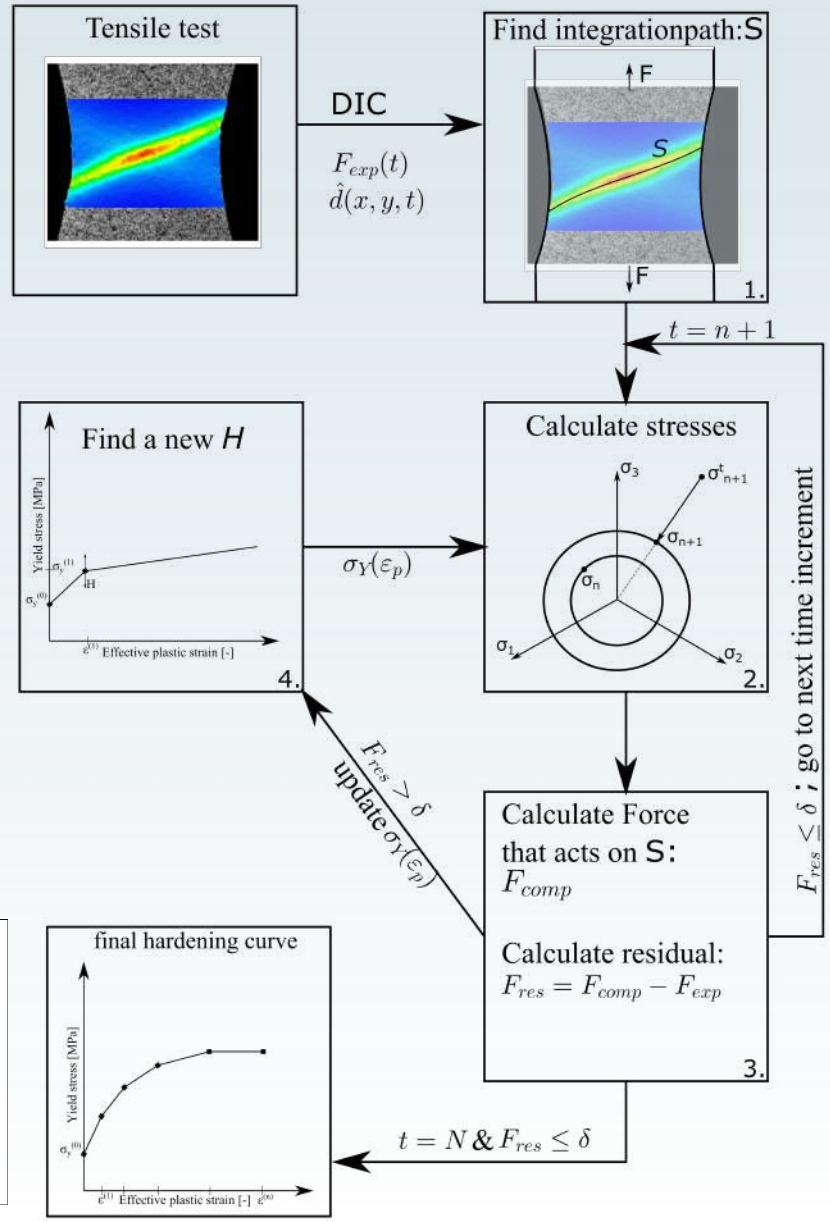
All material characteristics directly from experiments.

No FEA or inverse modelling needed

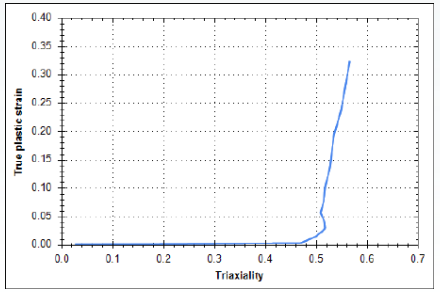
From low to high strain rates (10^{-3} – 10^{2} s^{-1})

From room temperatures to elevated temperatures (20 – 650°C)

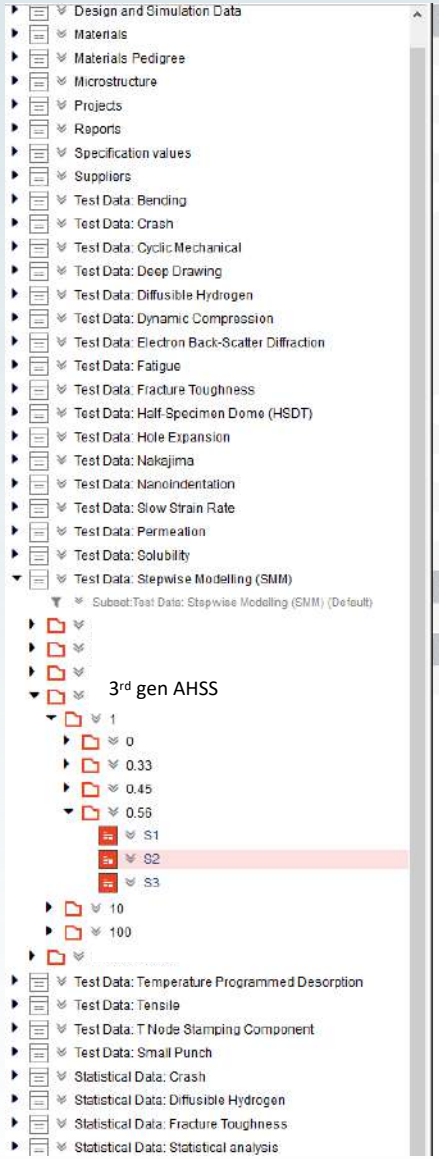
- Calculate the strain increments in the most strained region
- Compute the stress tensors with the radial return method. The current yield stress is described by a piecewise linear relation with a current hardening modulus H^i
- Compute resulting tensile force, F_{comp}
- Calculate residual force, i.e. $\delta = \left|F_{comp} - F_{exp}\right|$
- Update hardening modulus H^i
- Repeat until $\delta <$ tol
- **Final hardening curve to final fracture**
- **Fracture strain**
- **Triaxiality evolution**



Triaxiality evolution



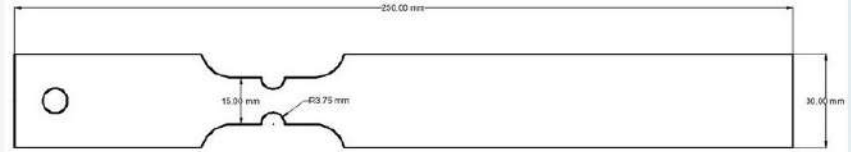
GRANTA – Data for designers



General information

3rd gen AHSS

Material name		
Material type	Advanced High Strength Steel	
Strain rate	1	/s
Stress state	0.56	
Specimen type	Notched R 3.75	
Specimen number	S2	
Specimen photo		



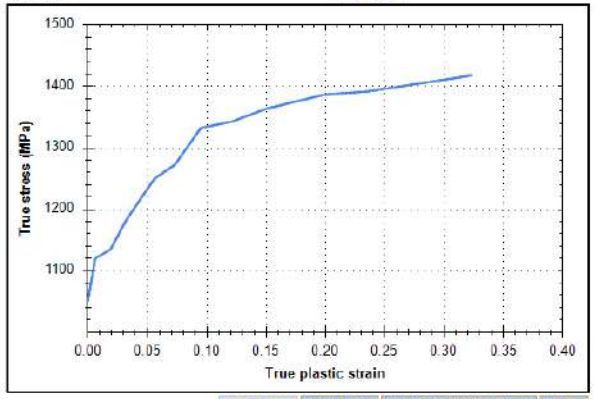
Test type	Stepwise Modelling	
Test temperature	23	°C
Sheet thickness	1.4	mm
Density	7850	kg/m^3
Provider		
Partner who can edit the record	LTU	

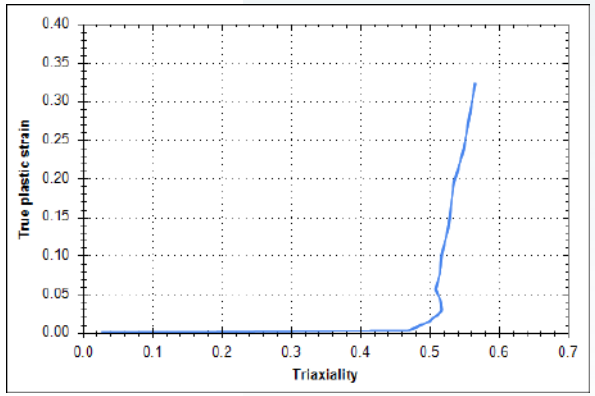
Test information

Test equipment	Instron VHS160/100-20	

Test results

Weighted triaxiality end-value	0.53	
Flow curve	Hide Graph	



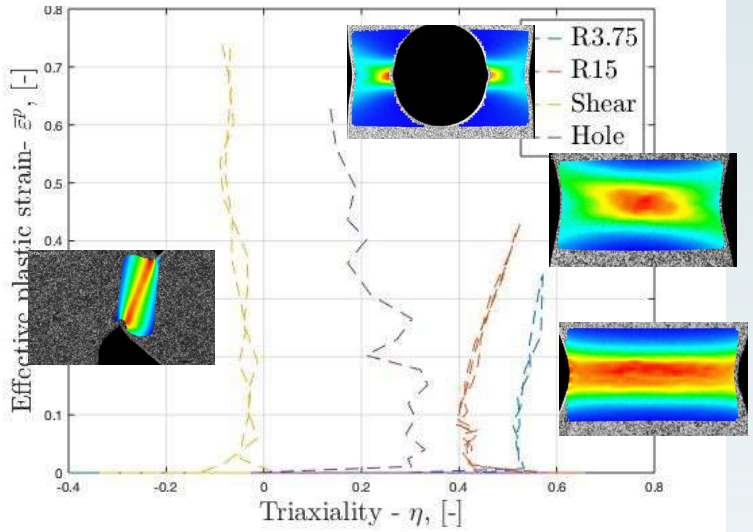


Reset Zoom | Graph Tools | Add to Comparison Chart | Copy...

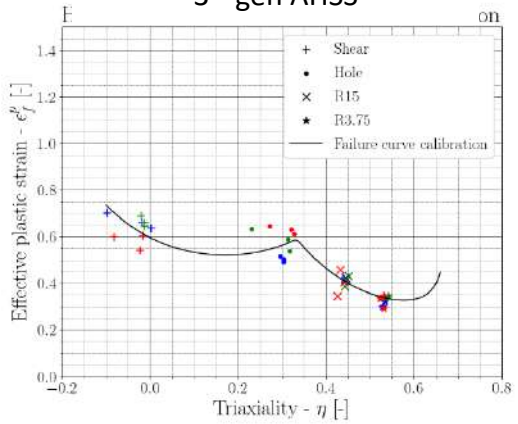
Notes

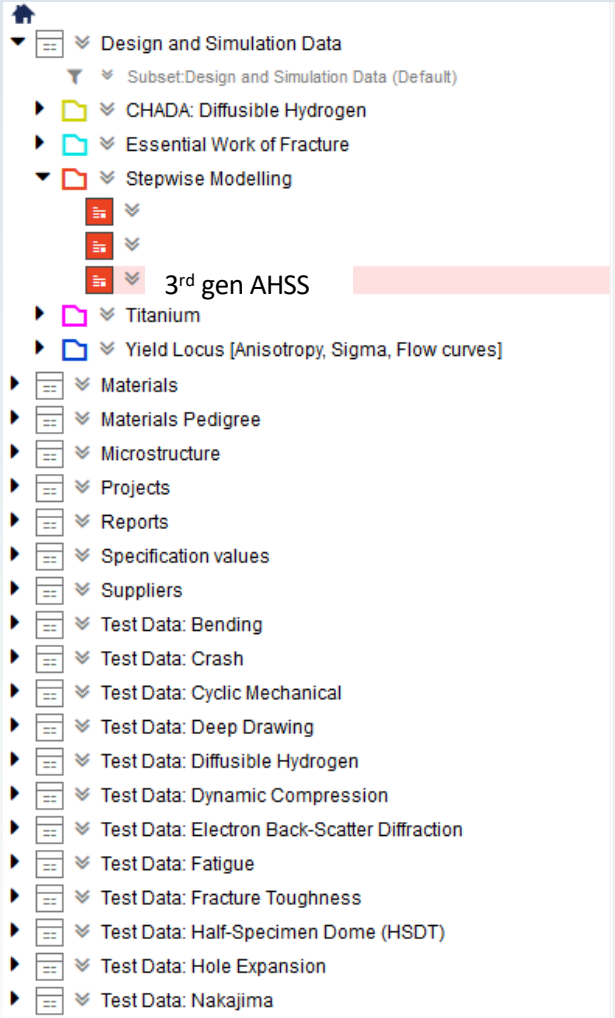
GRANTA – Data for designers

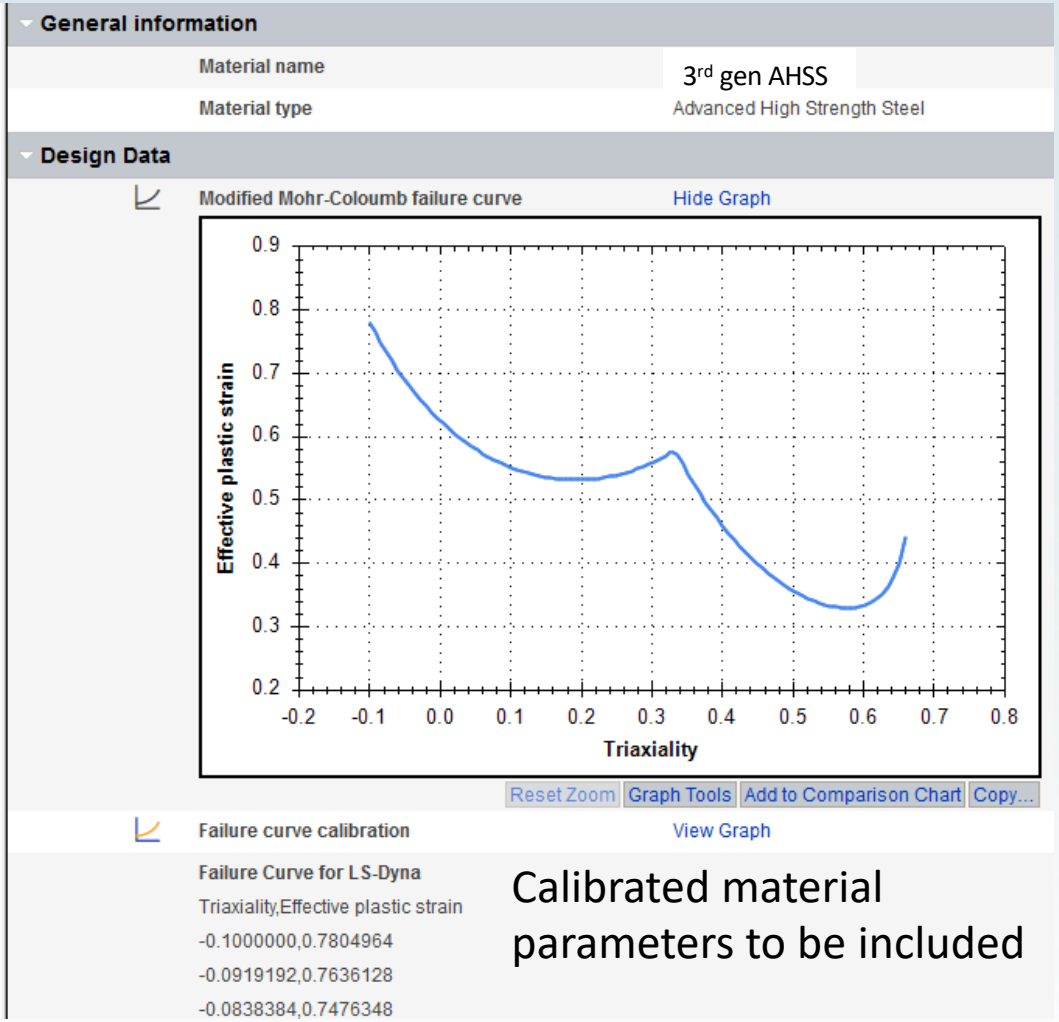
Triaxiality of 3rd gen AHSS



3rd gen AHSS







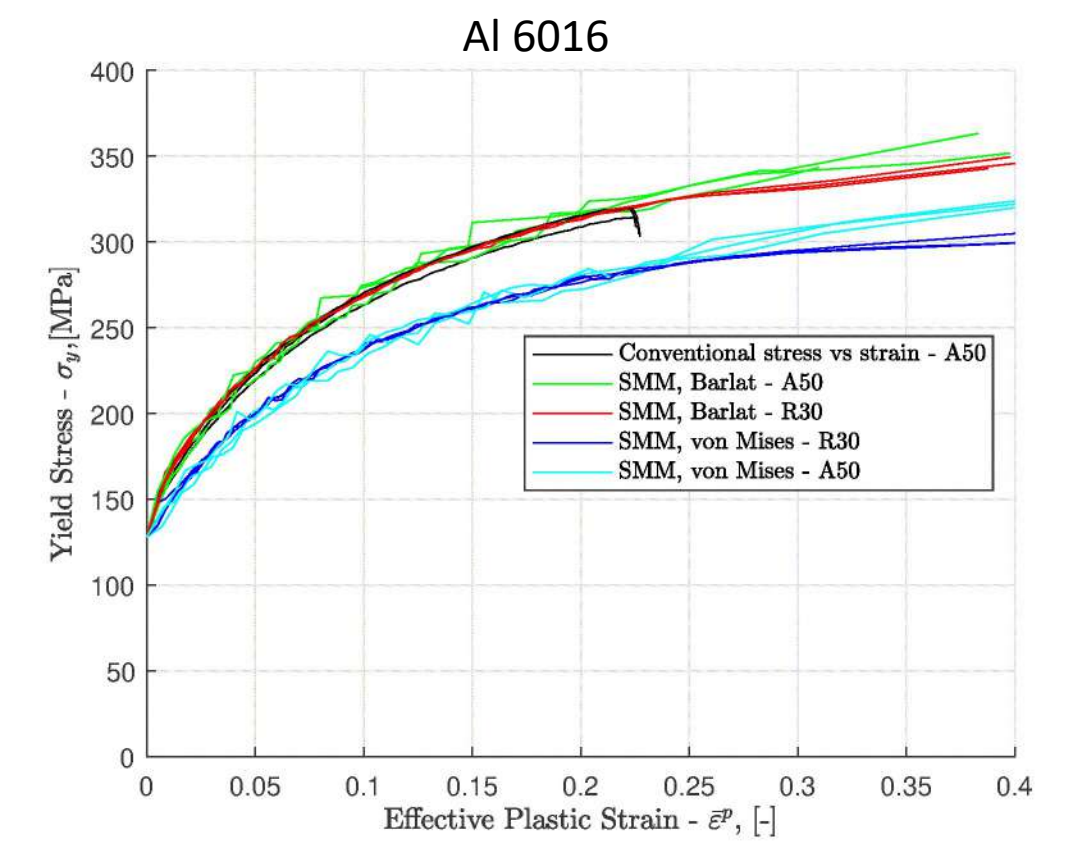
Calibrated material parameters to be included

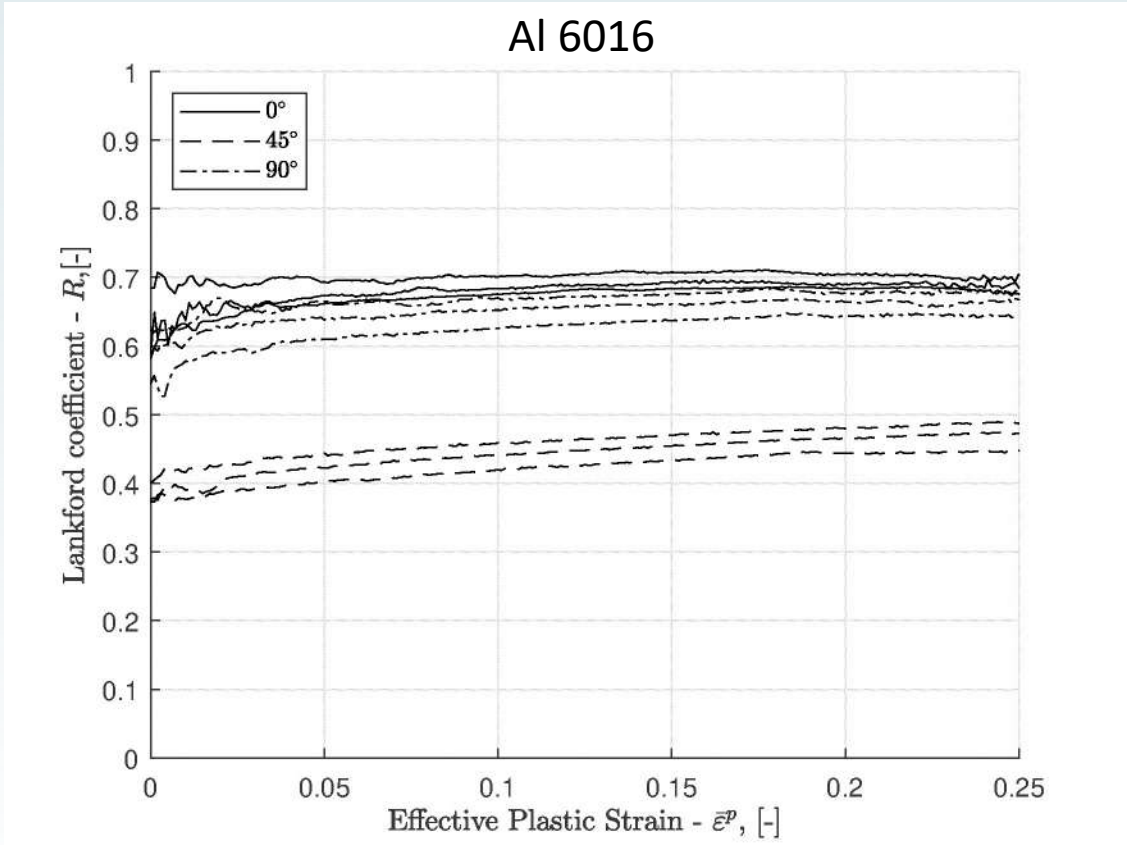
Marth, S., Häggblad, H.- Å., Oldenburg, M, Östlund, R. (2016) Post necking characterisation for sheet metal materials using full field measurement, *Journal of Materials Processing Technology* 238, 315–324.

Sjöberg, T., Marth, S., Kajberg, J., Oldenburg, M., (2017) Experimental characterization of triaxiality stress state evolution for sheet metal materials. *Eur. J. Mech. Solid.* 66, 279–286.

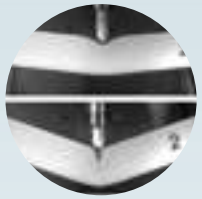
Stepwise Modelling Method (SMM)

Also works for anisotropic sheet materials





Marth S., Djebien S. , Kajberg J,. Häggblad H-.Å., (2021) Stepwise Modelling Method for Post Necking Characterisation of Anisotropic Sheet Metal, *Modelling, Simul. Mater. Sci. Eng. In press* https://doi.org/10.1088/1361- 651X/ac2797

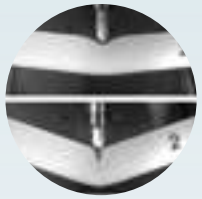


Crashworthiness

- Dynamic component testing
- Stereo high-speed imaging
- 3D deformation field measurement

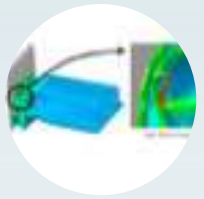
Instron VHS160/100-20, max ram speed 20 m/s

Two high-speed cameras - Vision Research Phantom v1610 and v2512
GOM – ARAMIS – DIC measurement system



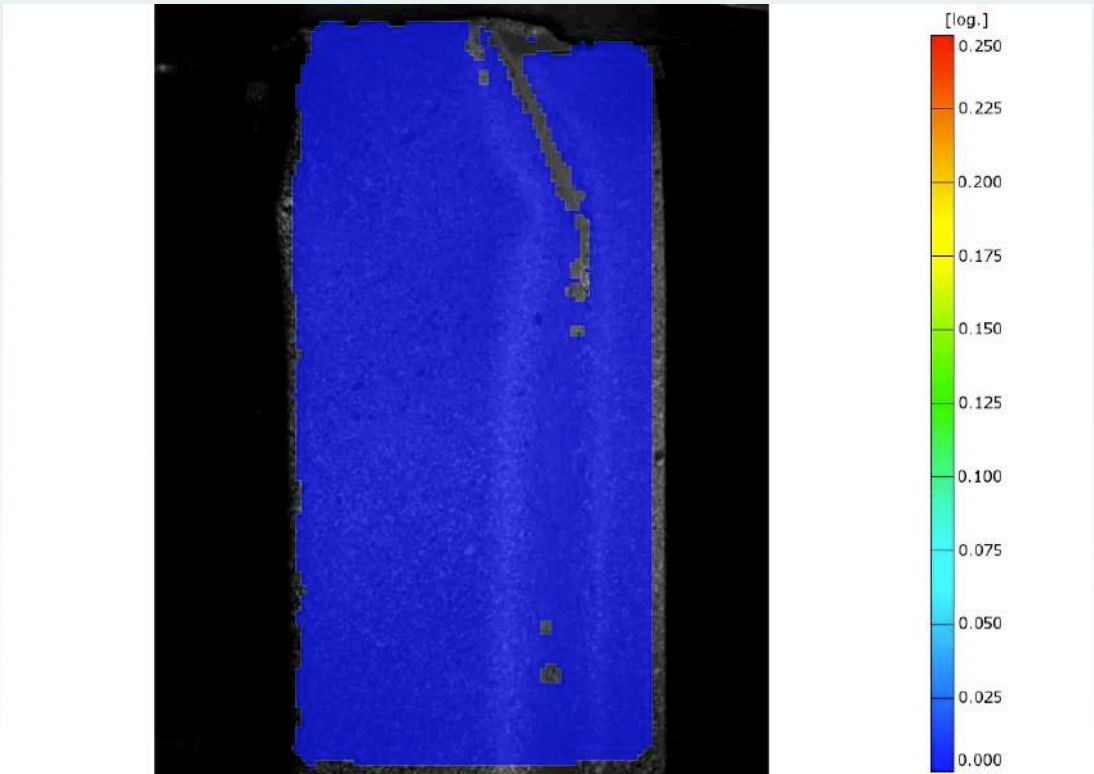
Crashworthiness

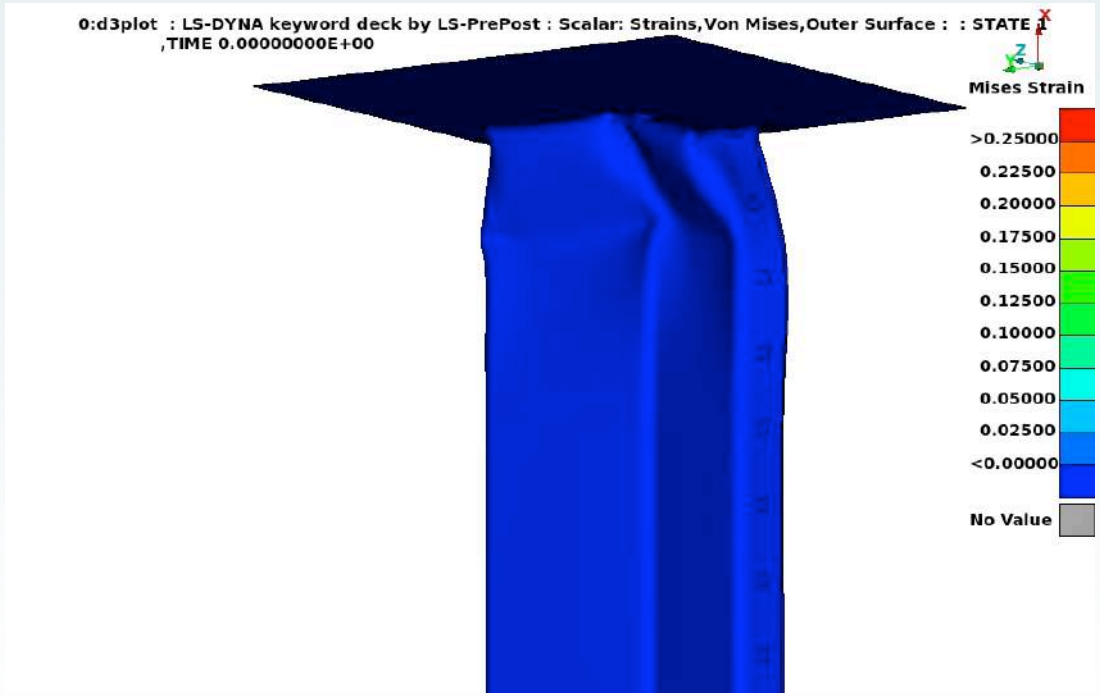
- Dynamic component testing
- Stereo high-speed imaging
- 3D deformation field measurement

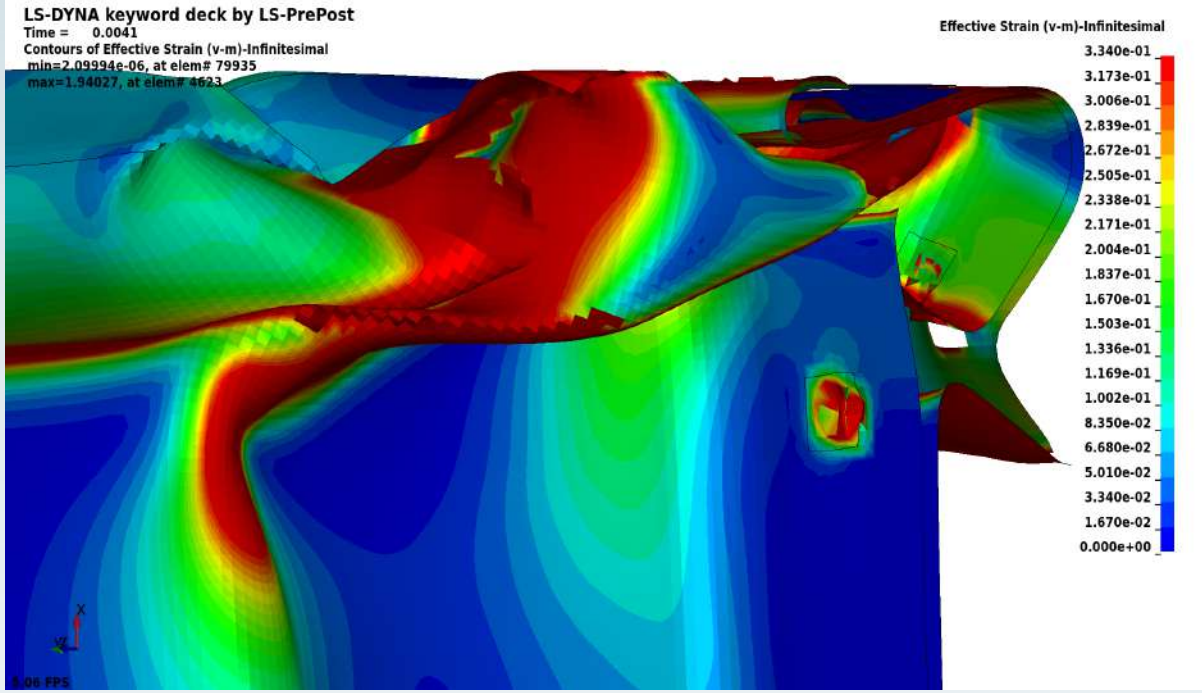


Modelling of part performance

- Modelling of crash boxes






LS-DYNA keyword deck by LS-PrePost
Time = 0.0041
Contours of Effective Strain (v-m)-Infinitesimal
min=2.09994e-06, at elem# 79935
max=1.94027, at elem# 4623
Effective Strain (v-m)-Infinitesimal
3.340e-01
3.173e-01
3.006e-01
2.839e-01
2.672e-01
2.505e-01
2.338e-01
2.171e-01
2.004e-01
1.837e-01
1.670e-01
1.503e-01
1.336e-01
1.169e-01
1.002e-01
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6.680e-02
5.010e-02
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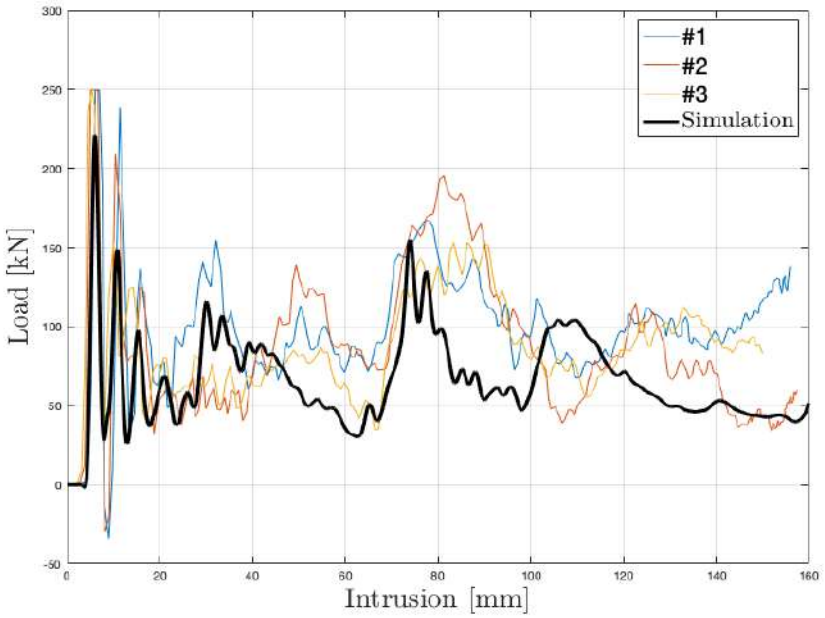
1.670e-02
0.000e+00

3rd gen AHSS

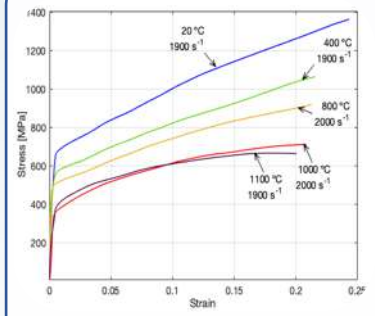

#1
#2
#3
Simulation
Load [kN]
Intrusion [mm]
300
250
200
150
100
50
0
-50
0
20
40
60
80
100
120
140
160

Future services within FormPlanet

- Up to the designer needs

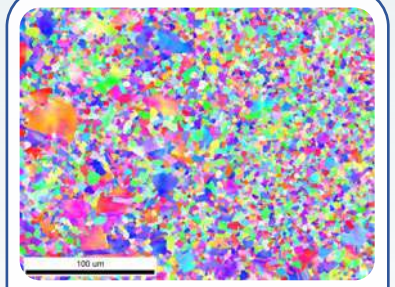
- Complete material cards for direct use in FE-models (LS-Dyna, Abaqus etc.)
- Physical-based material models

Mechanical tests



- Type: compression tests for different temperatures and strain rates
- Output: stress-strain curves

Microstructure analysis



- Method: OM and SEM
- Output: microstructural data (grain size, …) and information about the mechanisms taking place during and after deformation

Material model

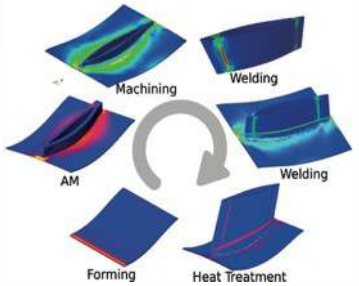
$$\sigma_y = \sigma_G + \sigma^* + \sigma_{HP} + \dots$$

$$\dot{\rho}_i = \dot{\rho}_i^{(+)} - \dot{\rho}_i^{(-)(dr)} - \dot{\rho}_i^{(-)(sr)}$$

$$H' = \frac{d\sigma_y}{d\varepsilon_p} = \frac{d\sigma_G}{d\rho_i}\frac{d\rho_i}{d\varepsilon_p} + \frac{d\sigma^*}{d\varepsilon_p} + \frac{d\sigma_{HP}}{d\varepsilon_p}$$

- Physics-based material model formulation (including the identified deformation mechanisms)
- Calibration of the model's parameters using experimental results

FEM simulation



Source: B. Babu Thesis, LTU

- FEM simulation of manufacturing processes using the established material model

OM: optical microscope

SEM: scanning electron microscope

Q&A session

Thank you!

This event has been organised under the framework of FormPlanet (GA num. 814517) and i-TRIBOMAT (GA num. 814494) projects, under the European Union's Horizon 2020 research and innovation programme

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