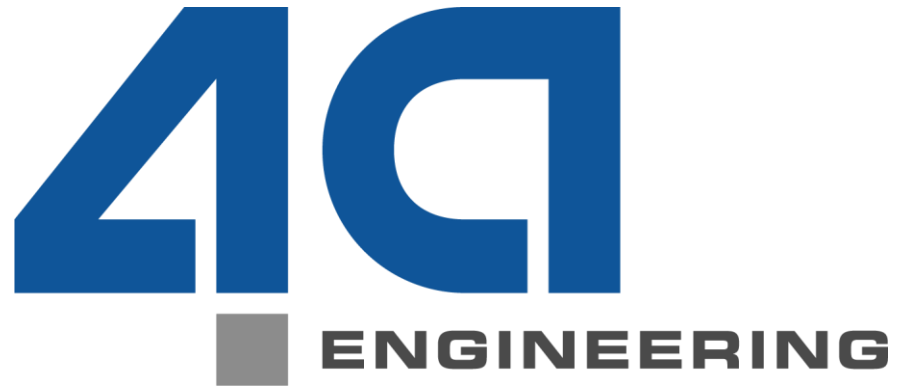




excellence in ...
material modelling
testing equipment
lightweight products



Automated Evaluation of Forming Limit Curves Using 3D-DIC and LINOVIS for Sheet Metal Forming Simulations

M. Schwab, S. Riemelmoser

International LS-DYNA Conference 2025, Munich, Germany
28.-30.10.2025



4a engineering GmbH
Industriepark 1
A – 8772 Traboch

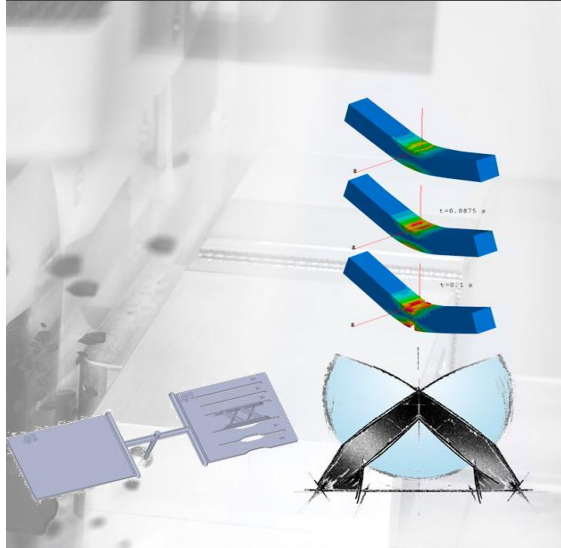
4a engineering - Business Units

Testing hard- and software



Seamless testing and simulation solution for automated material characterization

Material characterization



Static and dynamic material characterization from specimen to component validation – all under one roof

Validated material cards



Optimized packages for common material models for LS-Dyna, PamCrash and Abaqus.

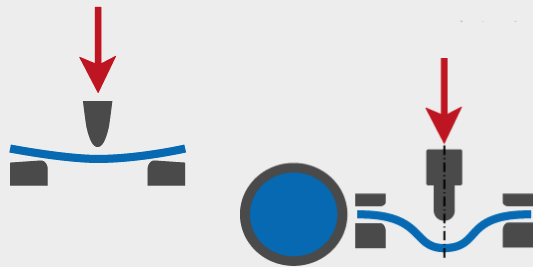
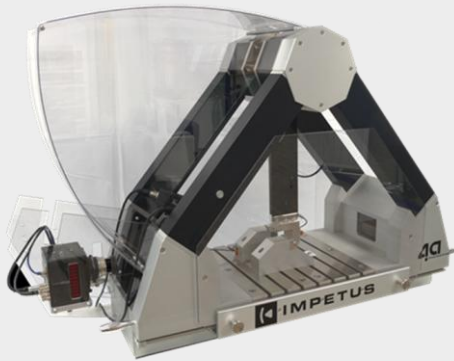
Battery Testing and Simulation



Testing and multiphysics modelling of battery cells, cell stacks and modules.

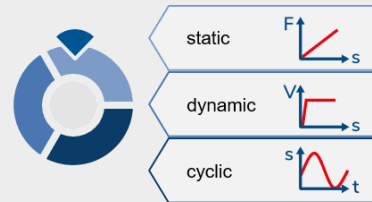
intelligent reliable solutions for plastics, composites, metals, foams, ...

IMPETUS



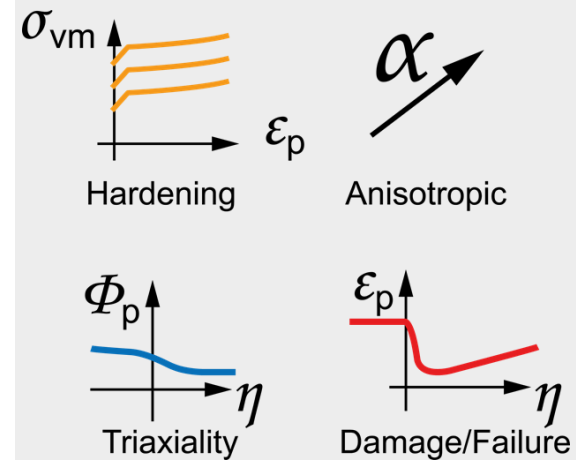
efficient
dynamic testing

LINOVIS



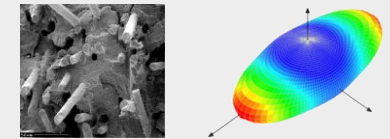
high performance
modular testing

VALIMAT



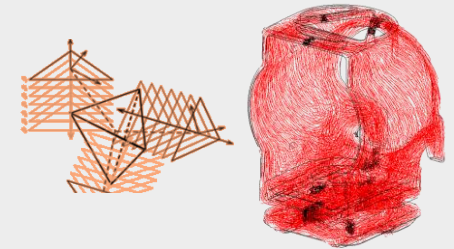
from test to validated
material cards

MICROMECH



3D anisotropic
material cards

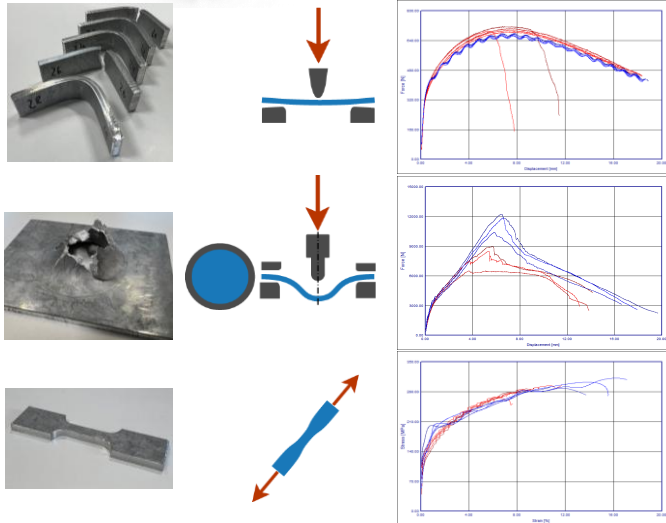
FIBERMAP



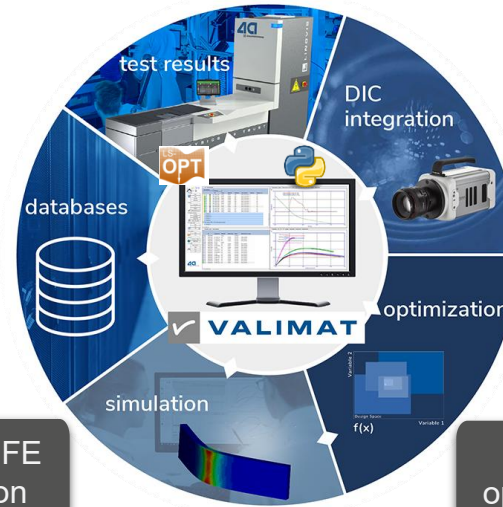
individual mapping
process information

Creation of a „digital twin“ of a material

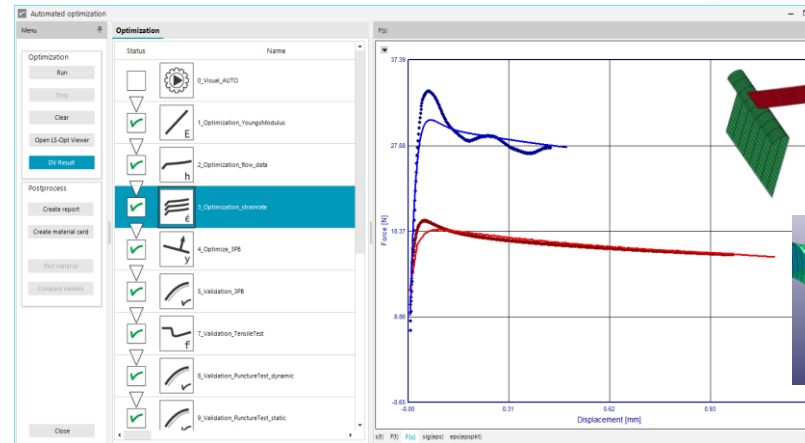
Static and dynamic mechanical characterization



Modelling and parameter identification

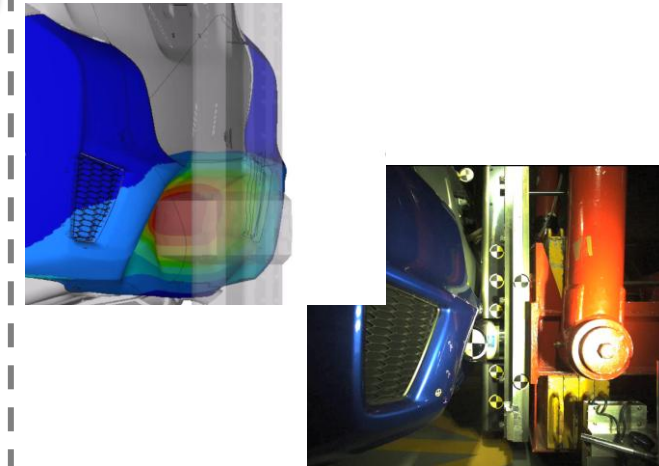
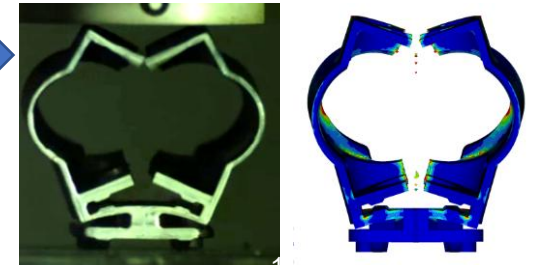


Fully automated FE model generation



Automated optimization workflows

Validation and implementation to bigger models





LINOVIS

high performance modular testing

 servo drive, electronics

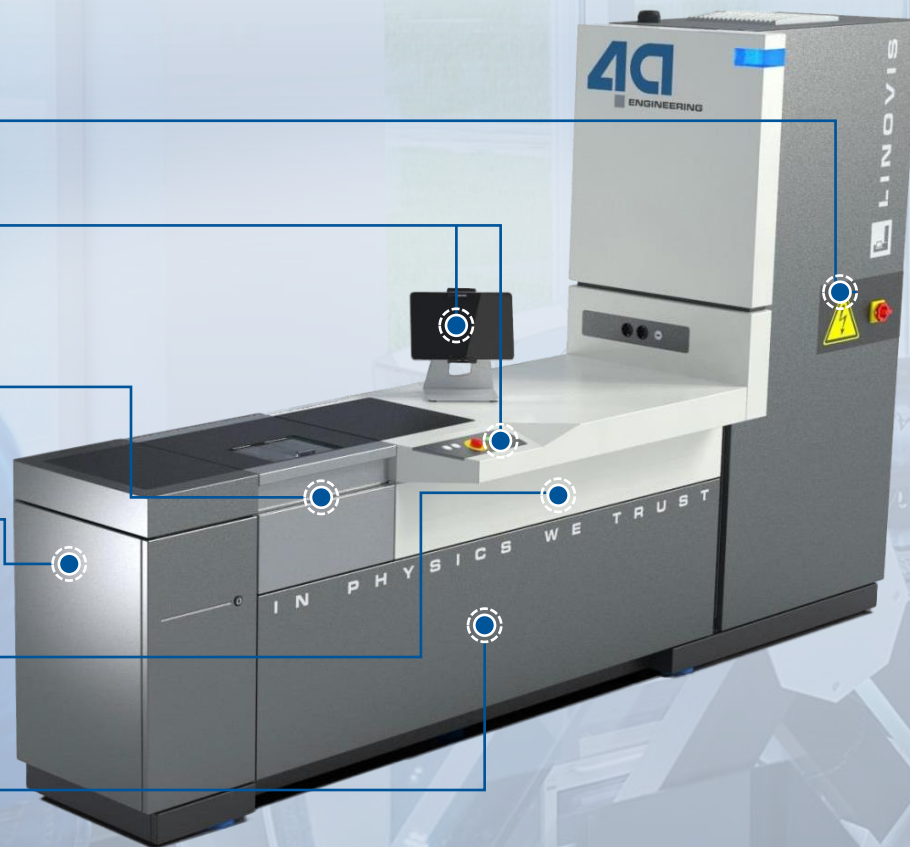
 user interface

 testing chamber

 high speed camera

 drive unit

 support structure



specifications

max. force 25kN

max. speed 3.2m/s

max. stroke 200mm

energy 600J

frequency ~30Hz



modes of operation



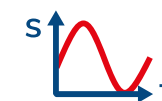
static



dynamic



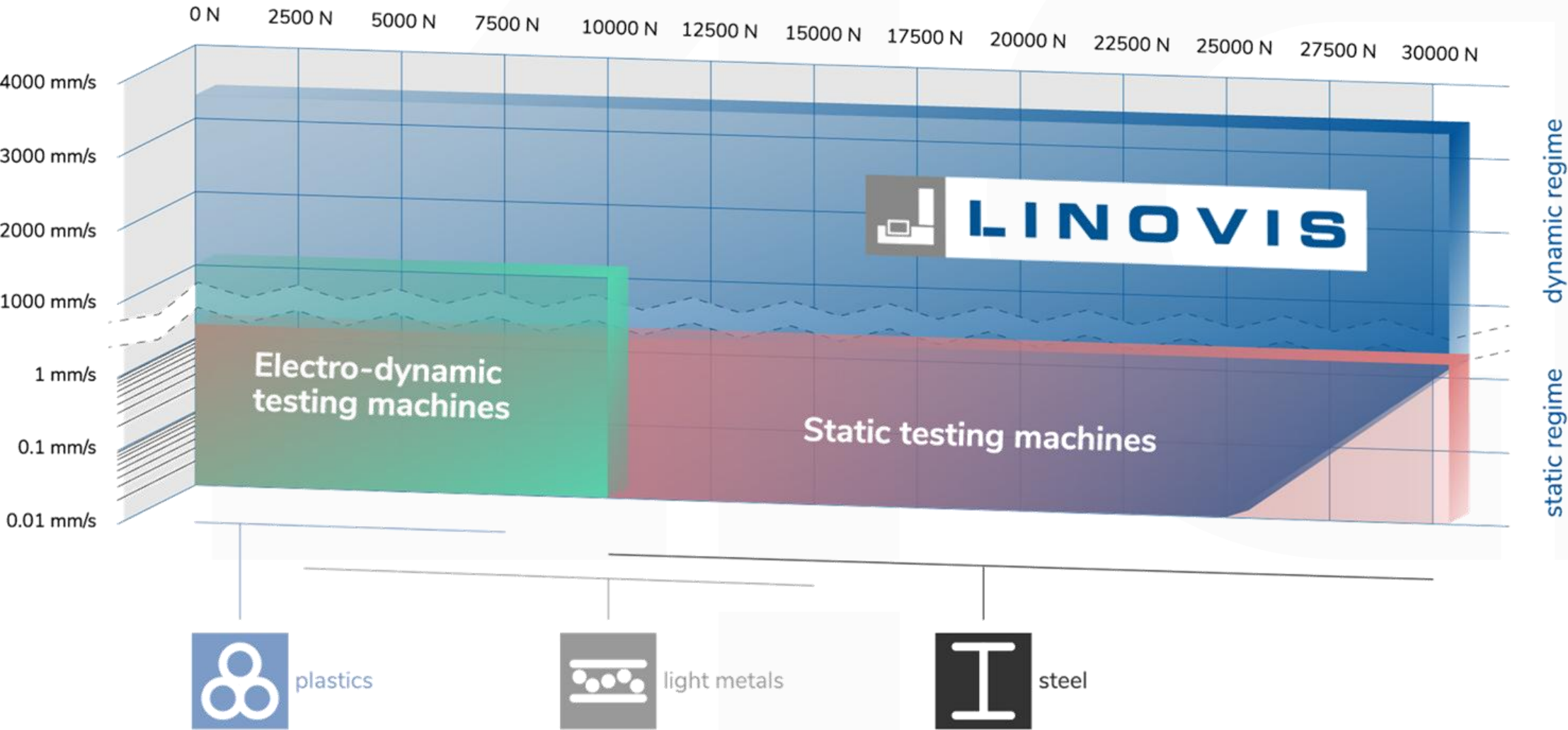
cyclic



I N P H Y S I C S W E T R U S T



Testing range





LINOVIS

high performance modular testing

seamless DIC integration



integrated mounts for full 3D DIC capability

fully time synchronized with DAQ system

closed environment to minimize external factors (e.g. reflexions)

glare free vision

automated processing of DIC

I N P H Y S I C S W E T R U S T



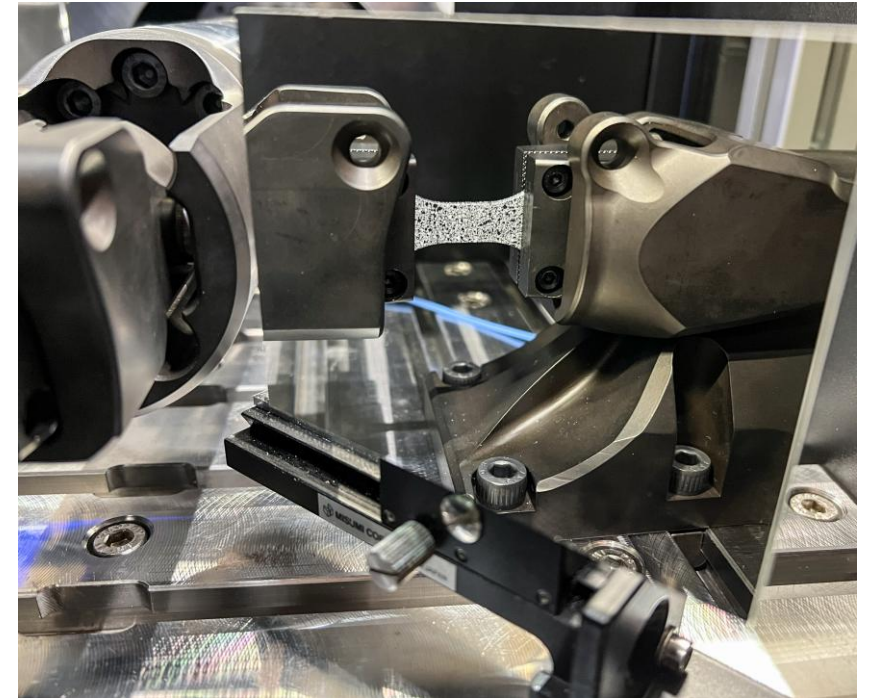
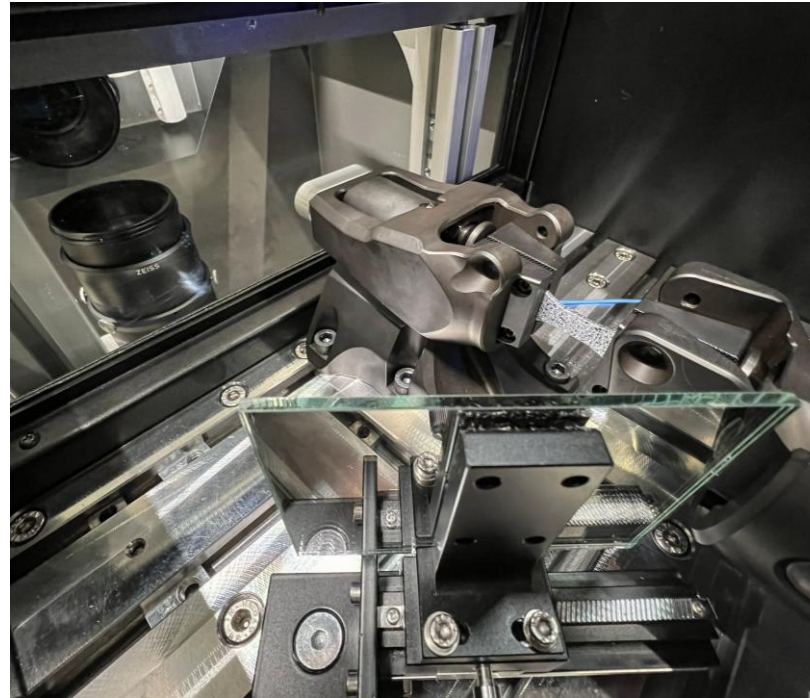


LINOVIS

high performance modular testing



seamless DIC integration – 2D case

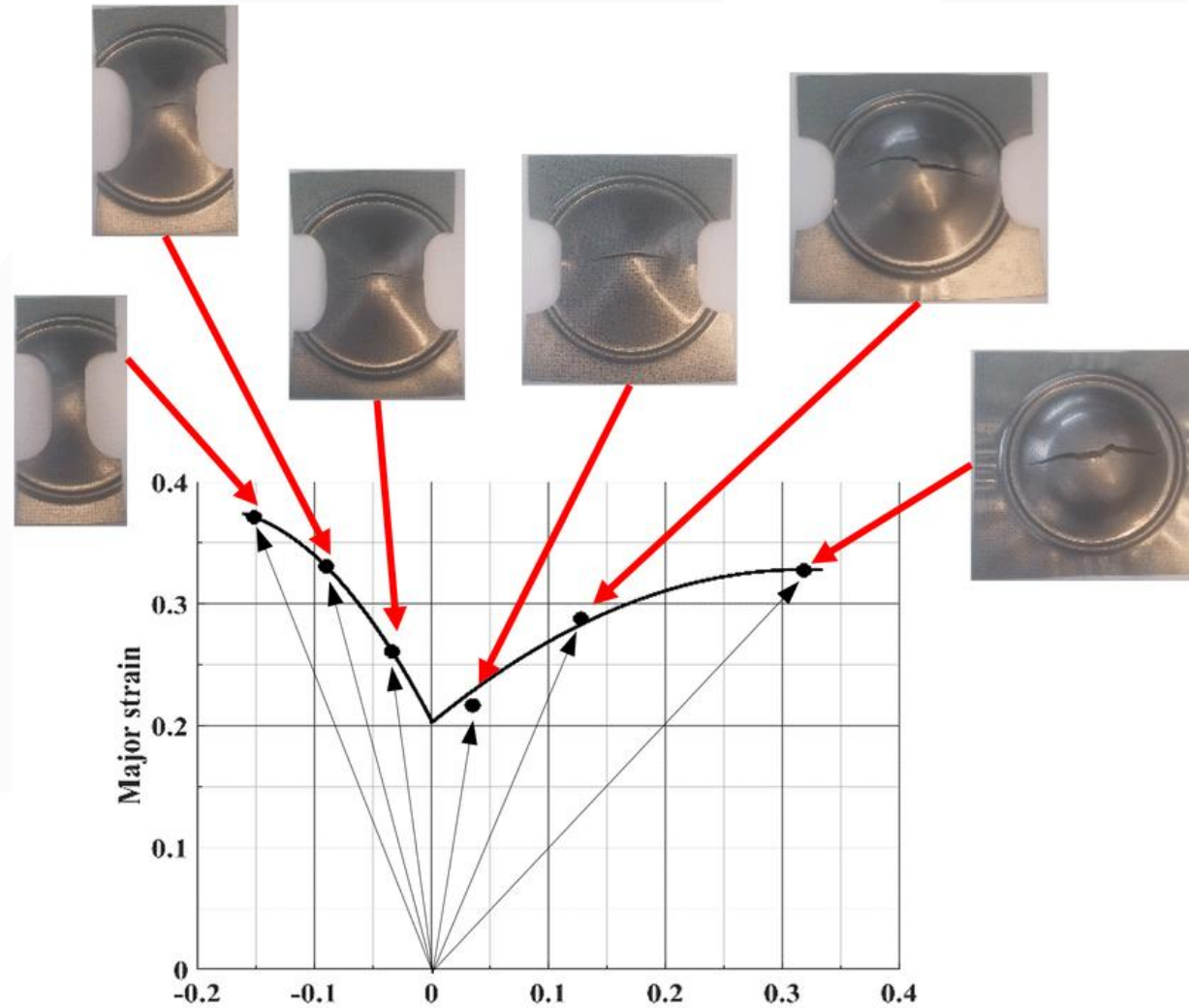


I N P H Y S I C S W E T R U S T



Characterization of forming limit with 3D DIC

Characterization of forming limit – punch and Nakazima tests



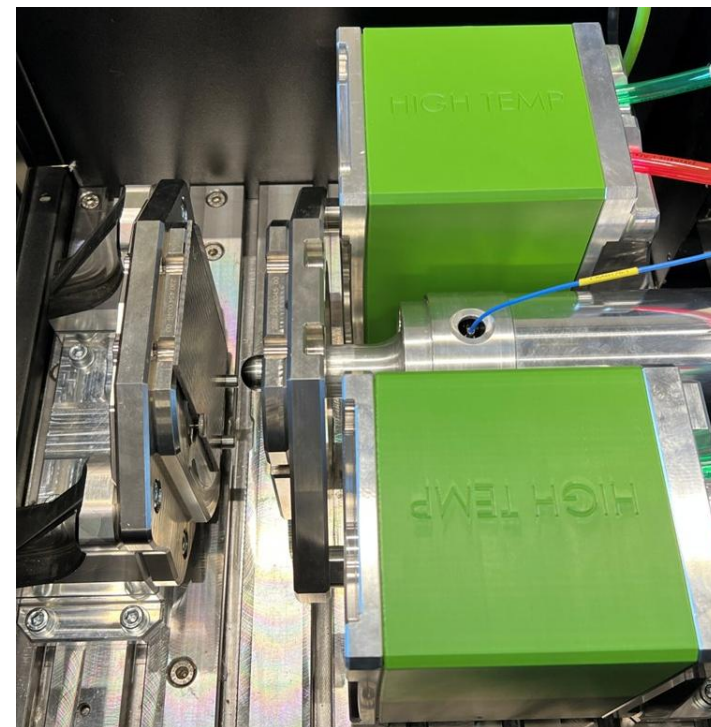
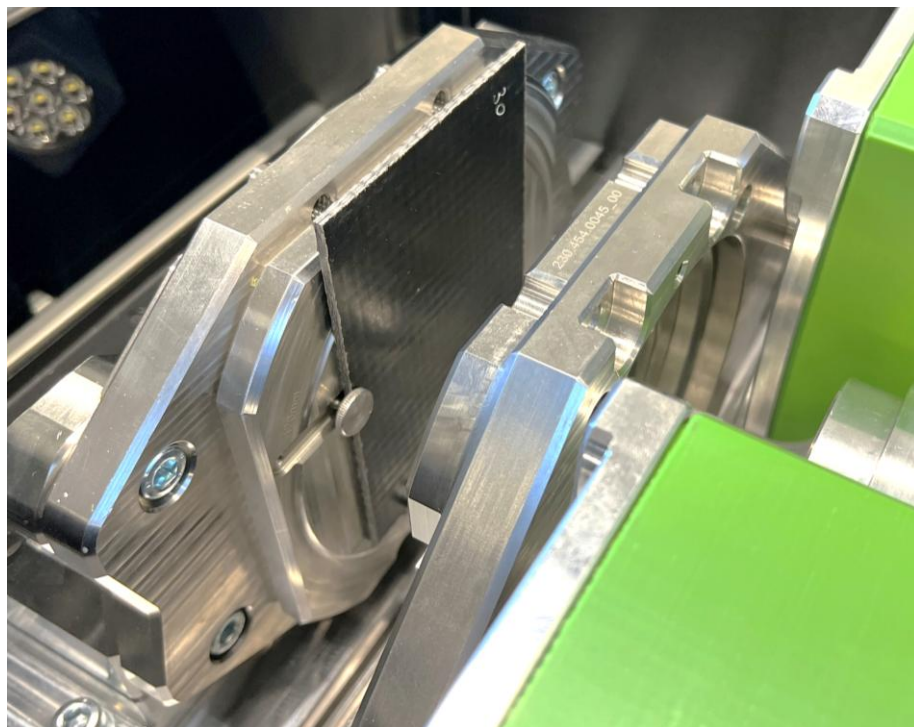
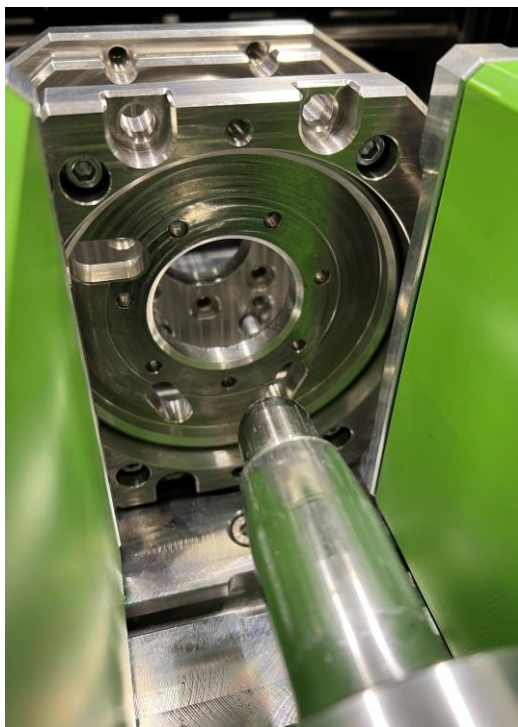
R. Amaral et. al., Formability prediction for AHSS materials using damage models, 6th International Conference on Fracture Fatigue and Wear, 2018



LINOVIS

high performance modular testing

punch test setup



I N P H Y S I C S W E T R U S T





LINOVIS

high performance modular testing

punch test setup



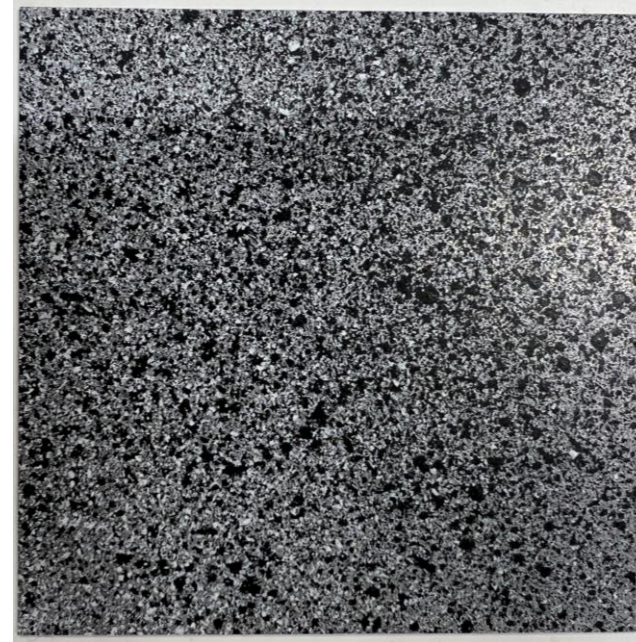
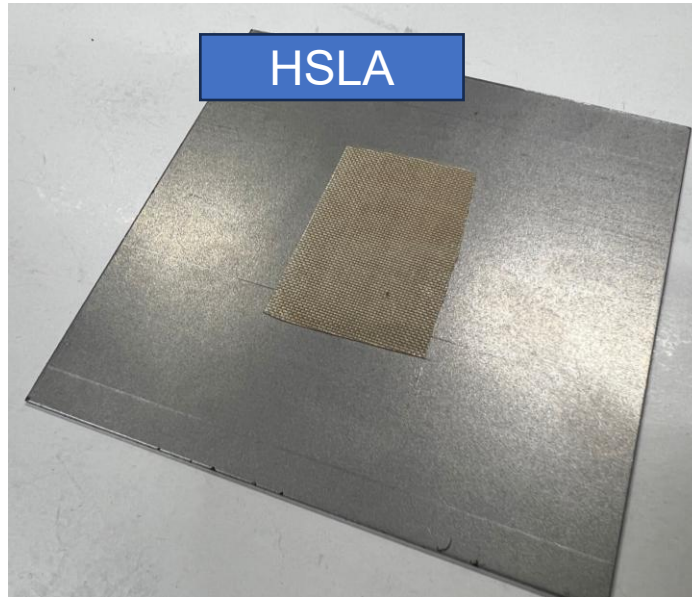
Pneumatically actuated clamping for automated high throughput testing

I N P H Y S I C S W E T R U S T



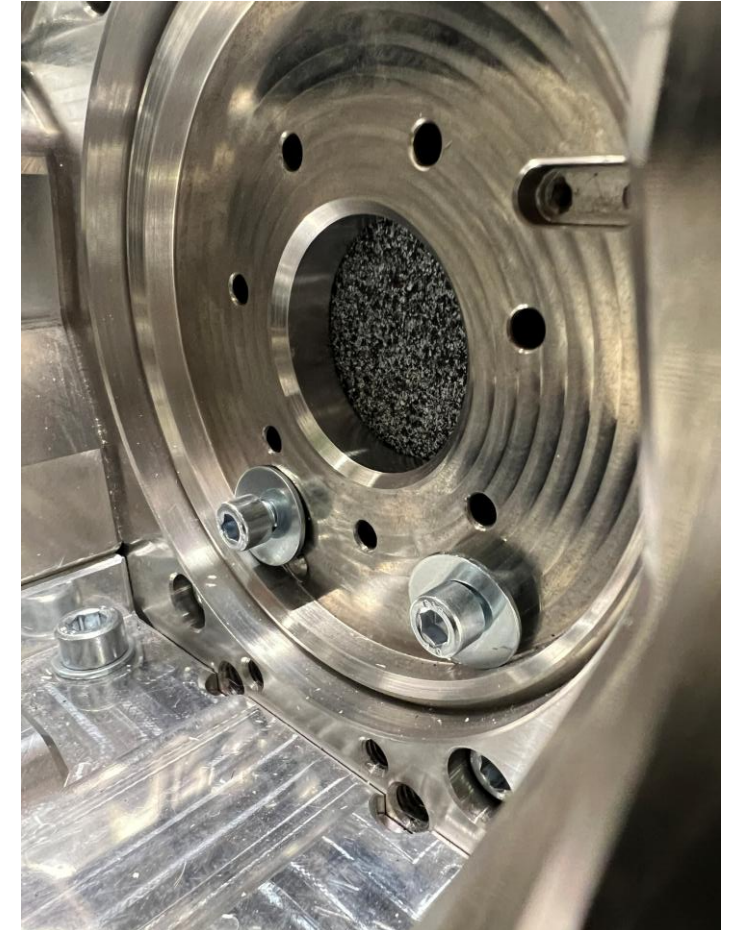
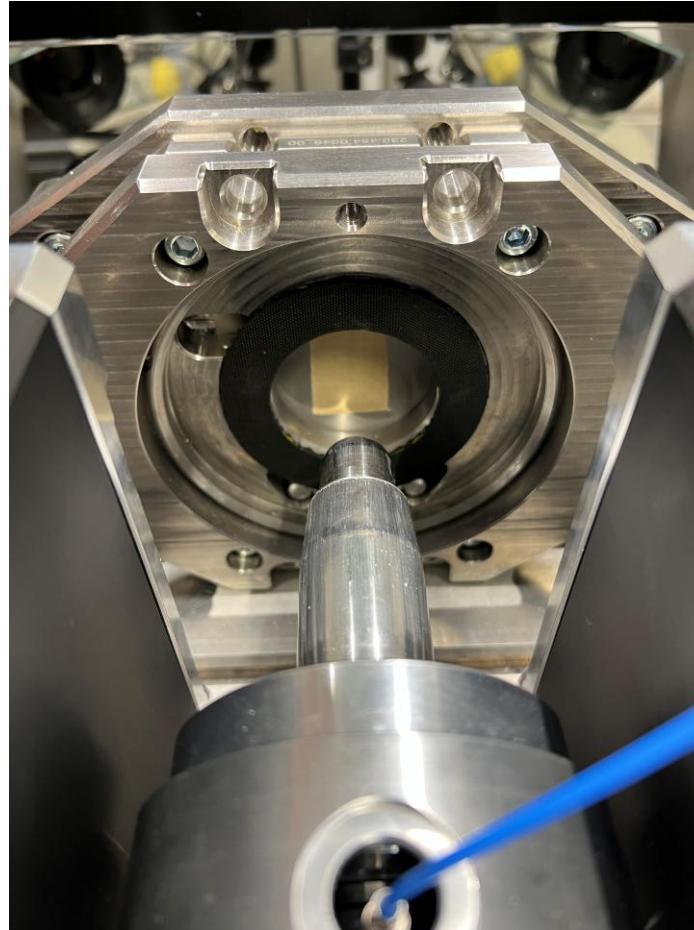
Punch test setup - specimen

- Example: HSLA steel
 - Thickness: 0.8mm
 - Size: 80mm x 80mm
 - Punch diameter: 20mm
 - Support diameter: 40mm



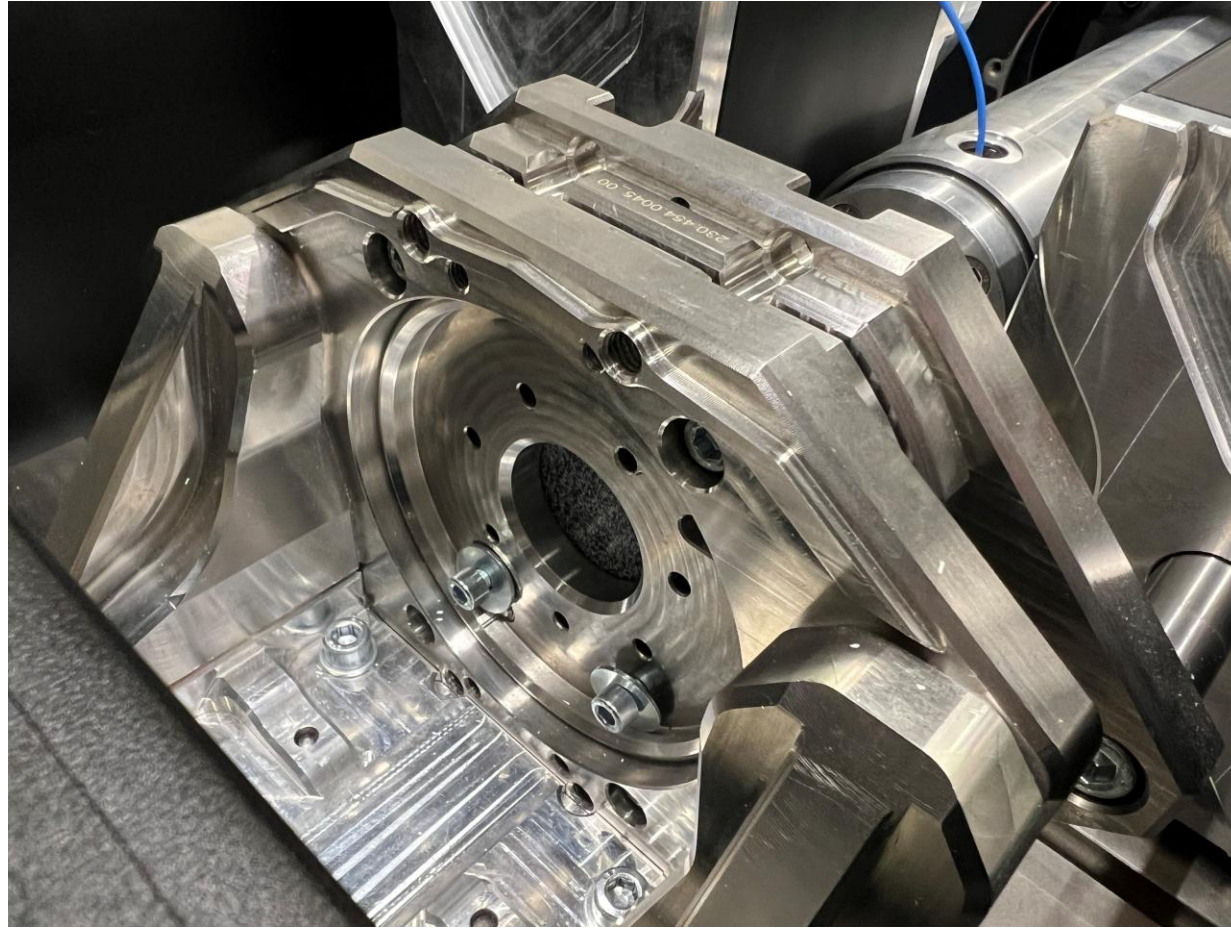
Punch test setup - specimen

- Example: HSLA steel
 - Thickness: 0.8mm
 - Size: 80mm x 80mm
 - Punch diameter: 20mm
 - Support diameter: 40mm



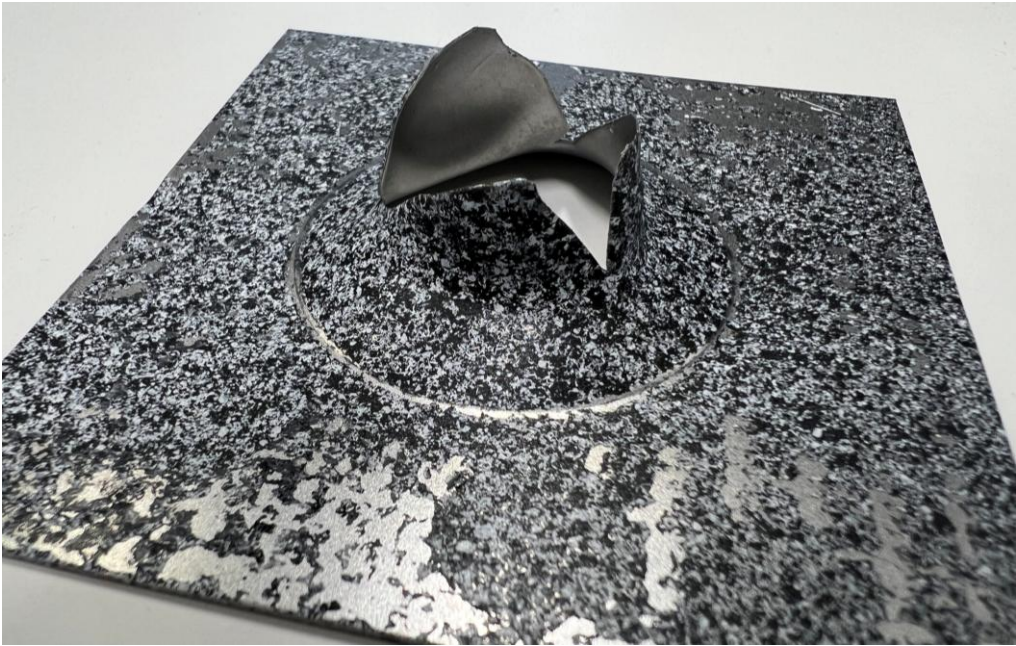
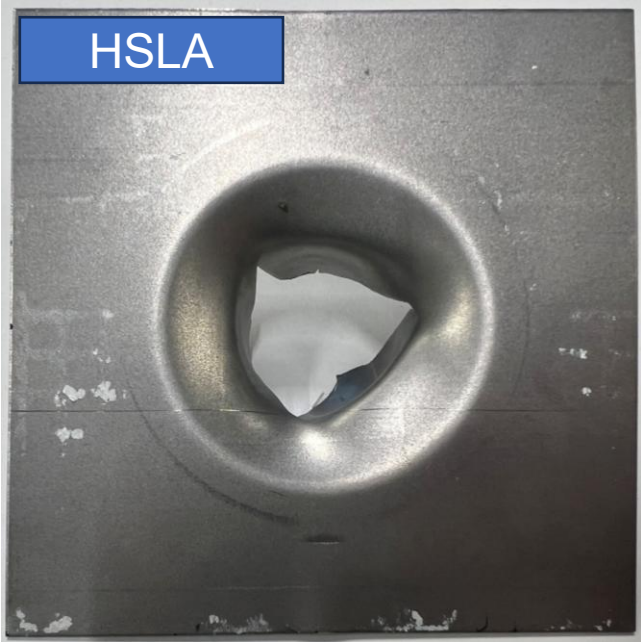
Punch test setup - specimen

- Example: HSLA steel
 - Thickness: 0.8mm
 - Size: 80mm x 80mm
 - Punch diameter: 20mm
 - Support diameter: 40mm



Punch test - results

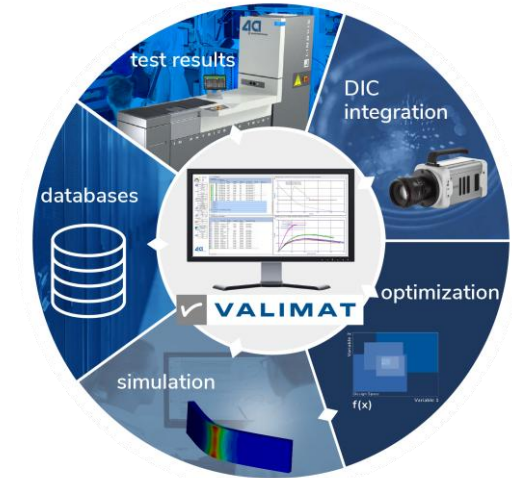
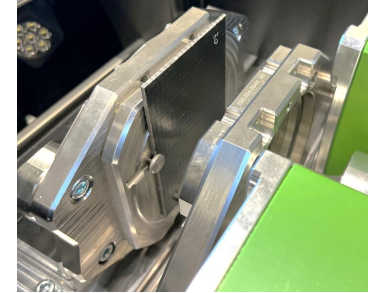
Case	failed samples	v0 [m/s]	lw [mm]	S _{max} [mm]	F _{max} [N]	Energy loading [J]
PT	2/2	0.001	42	12.75	14327	93.94



Punch test – results: Generation of FLD

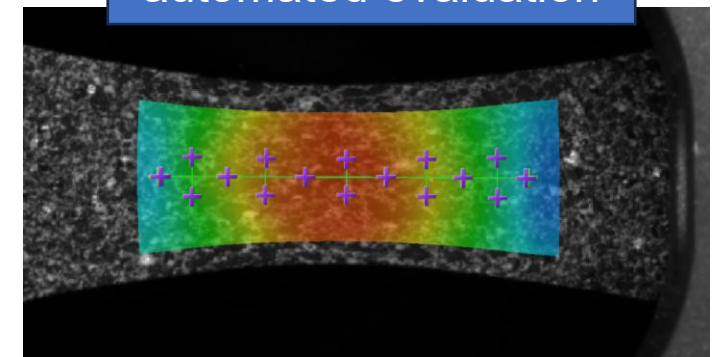
testing prodecure

- Sample preparation with the speckle pattern
- Put the specimen into the machine
- Automated pneumatic clamping (no bolts)
- Perform the test



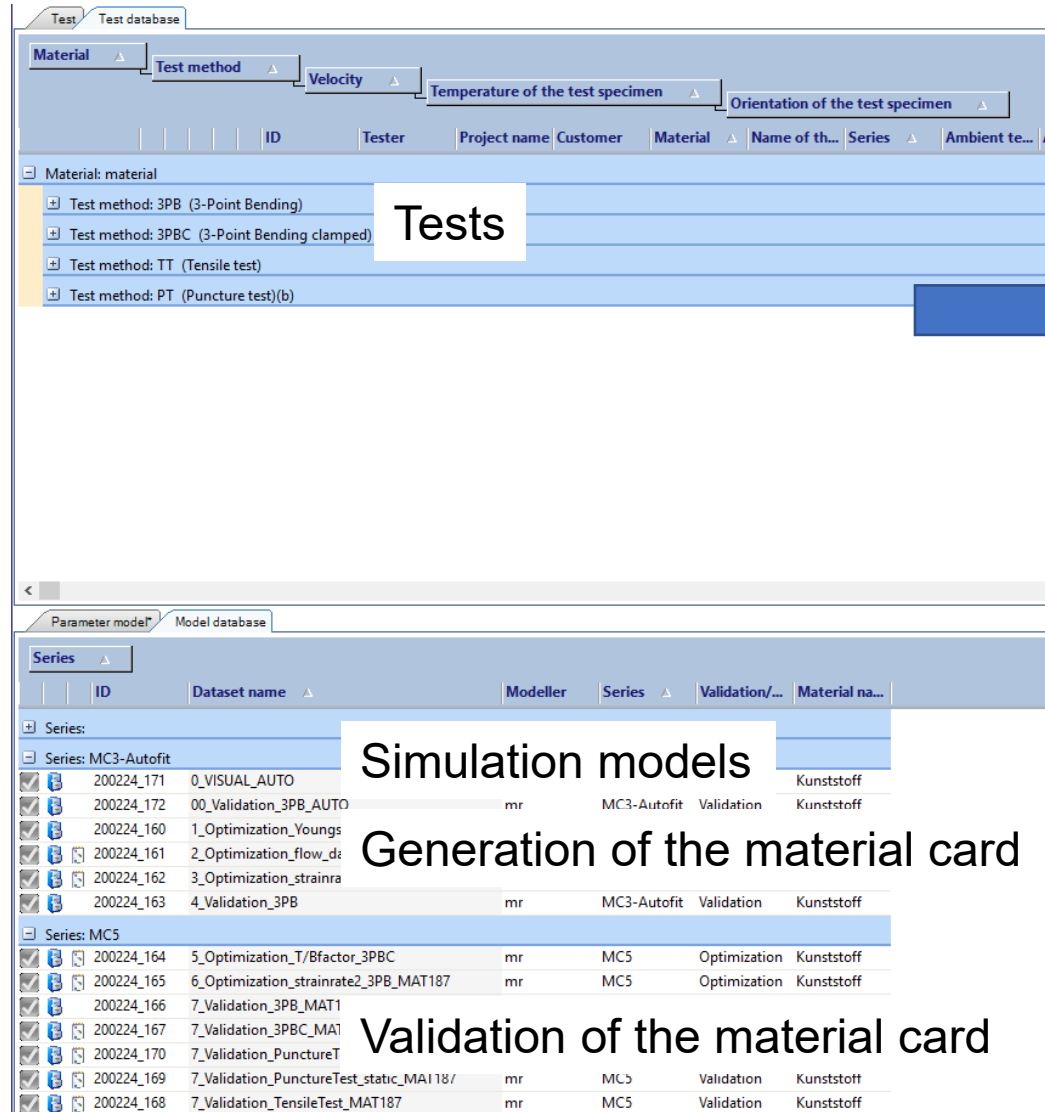
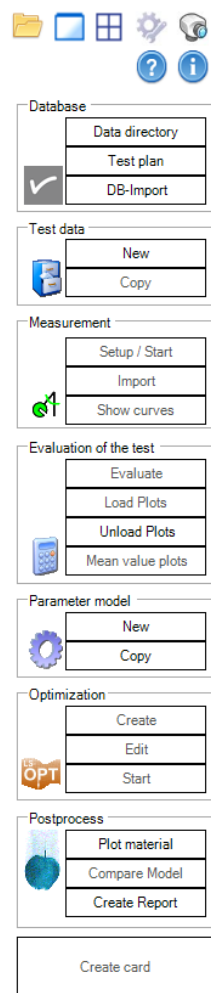
automated evaluation

- Activate the bright lights
- Start the recording of the high-speed camera
- Immediately evaluate the DIC images
- Finally store the recorded data in the VALIMAT database



Punch test – results: Generation of FLD

Valimat ver. 3.7

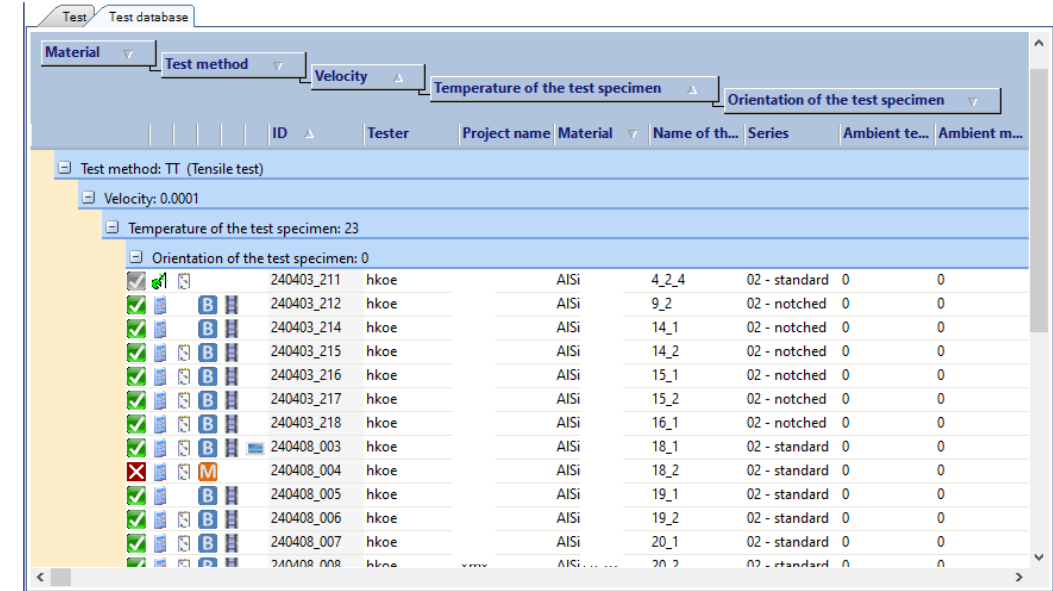


Tests

Simulation models

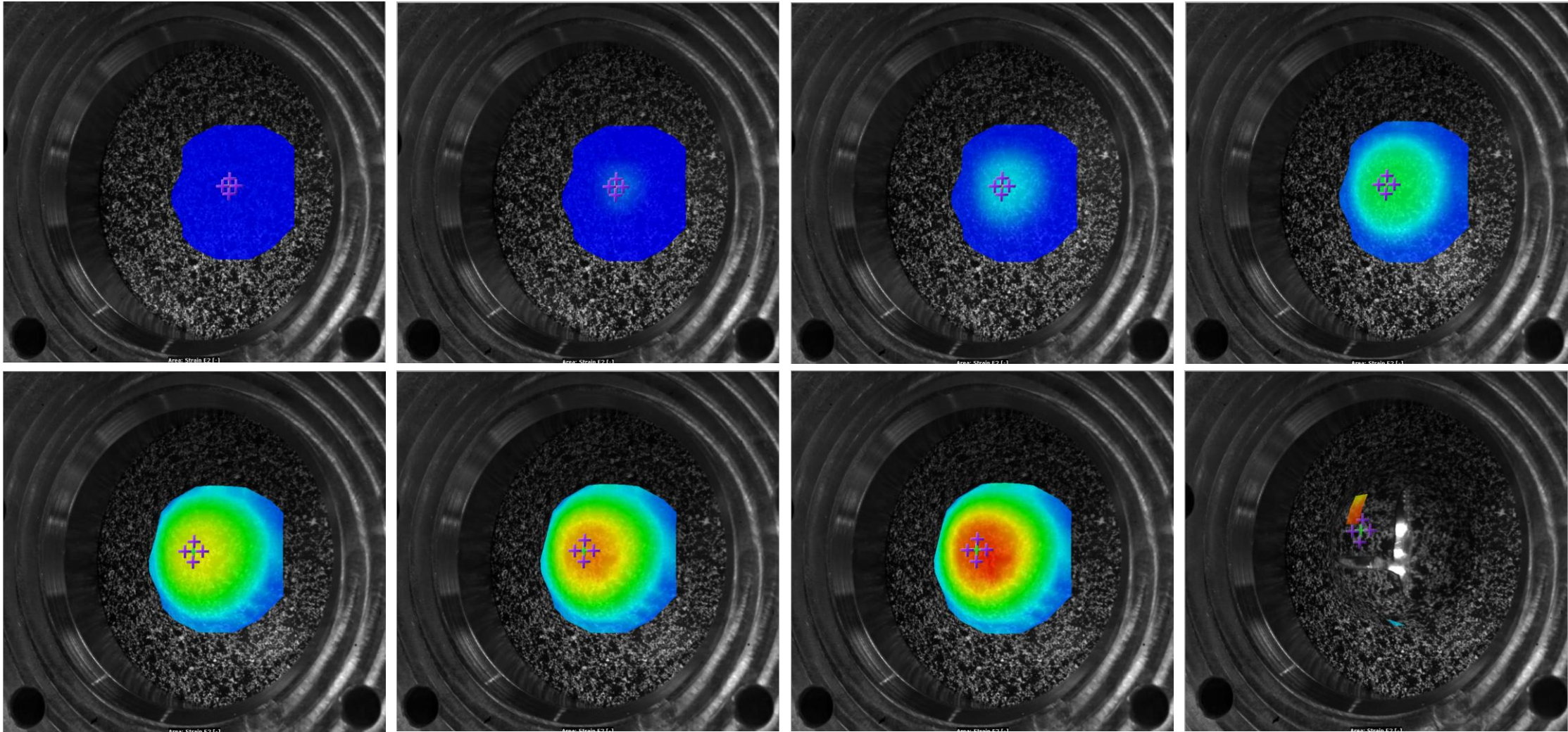
Generation of the material card

Validation of the material card

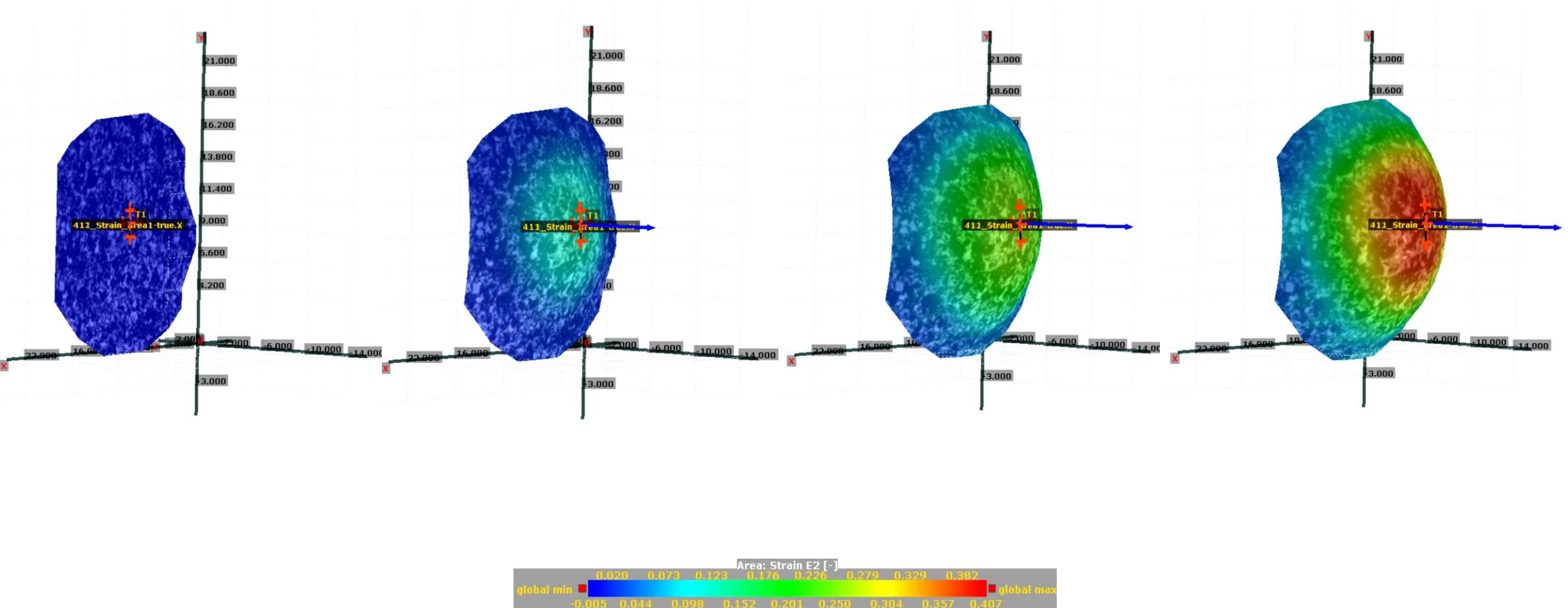


Direct link between simulation models and test data

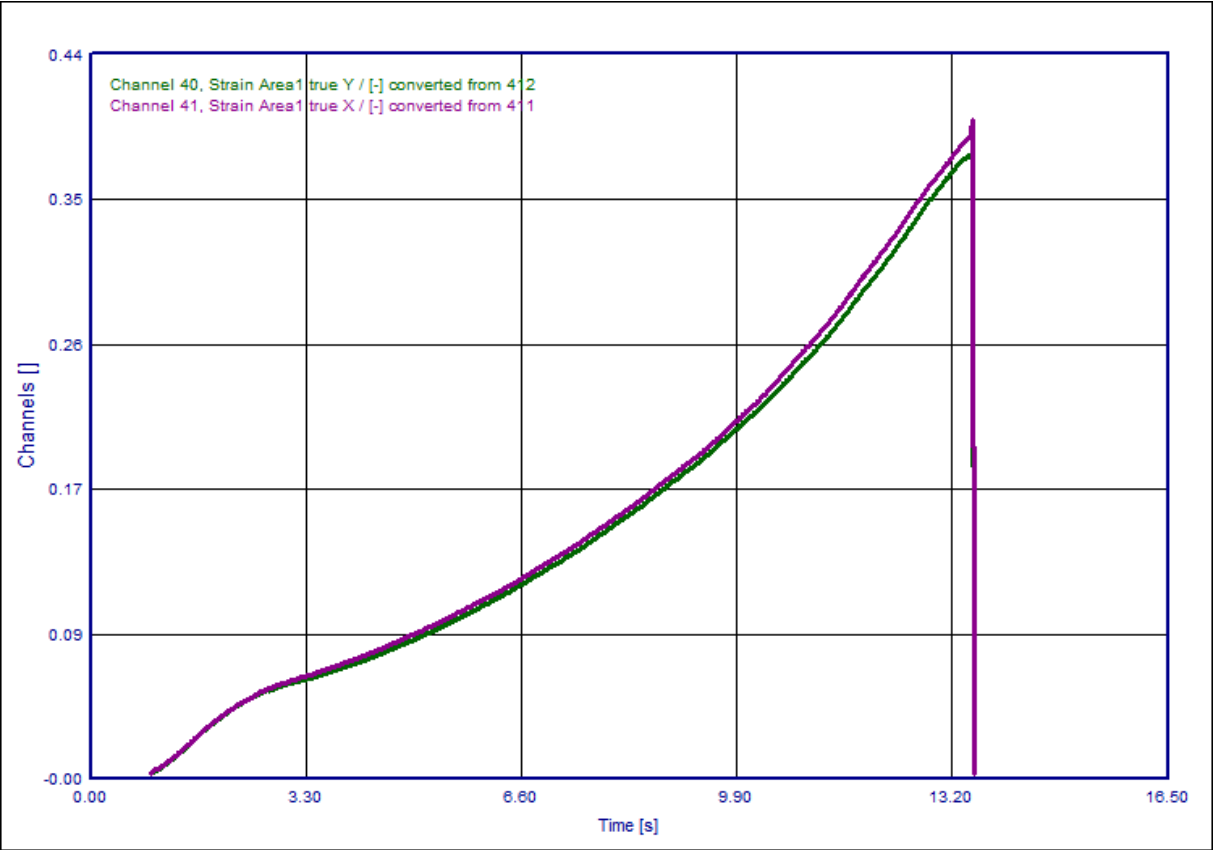
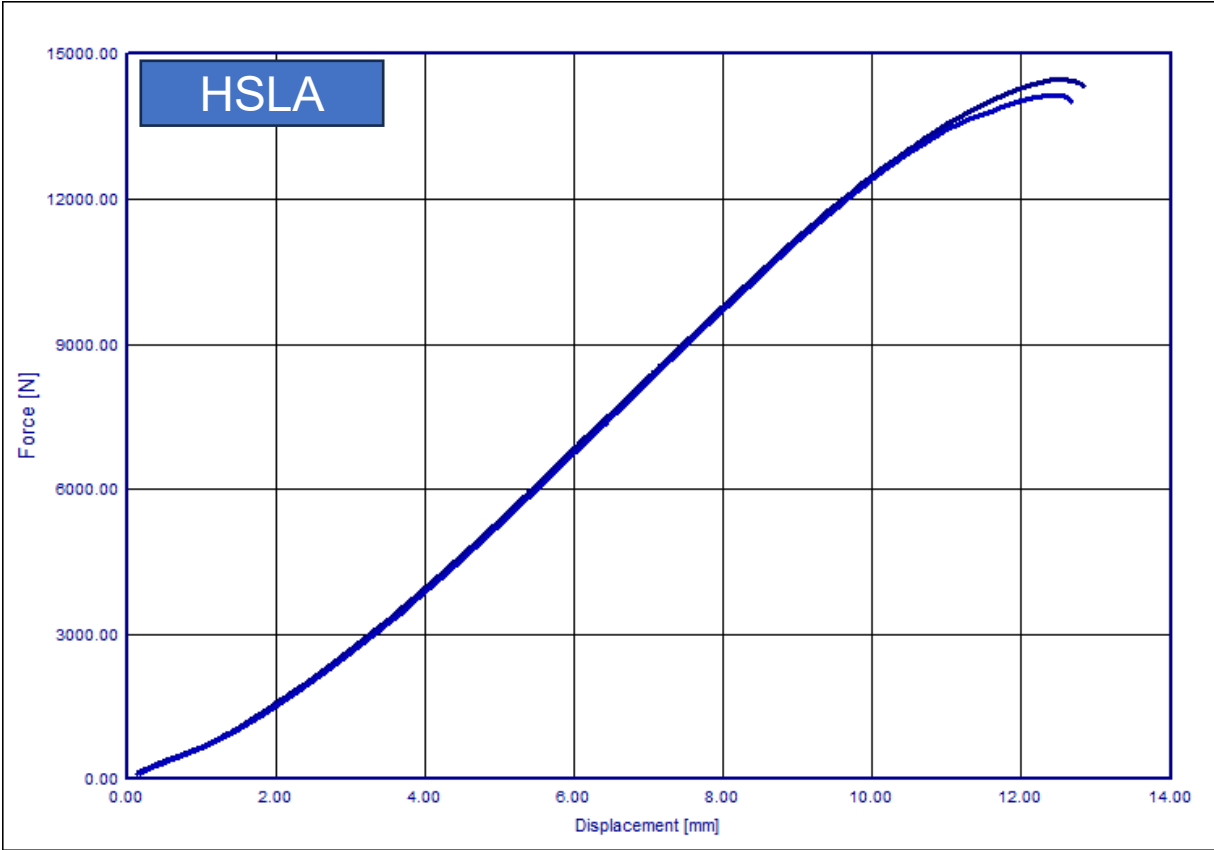
Punch test – results: 3D DIC



Punch test – results: 3D DIC



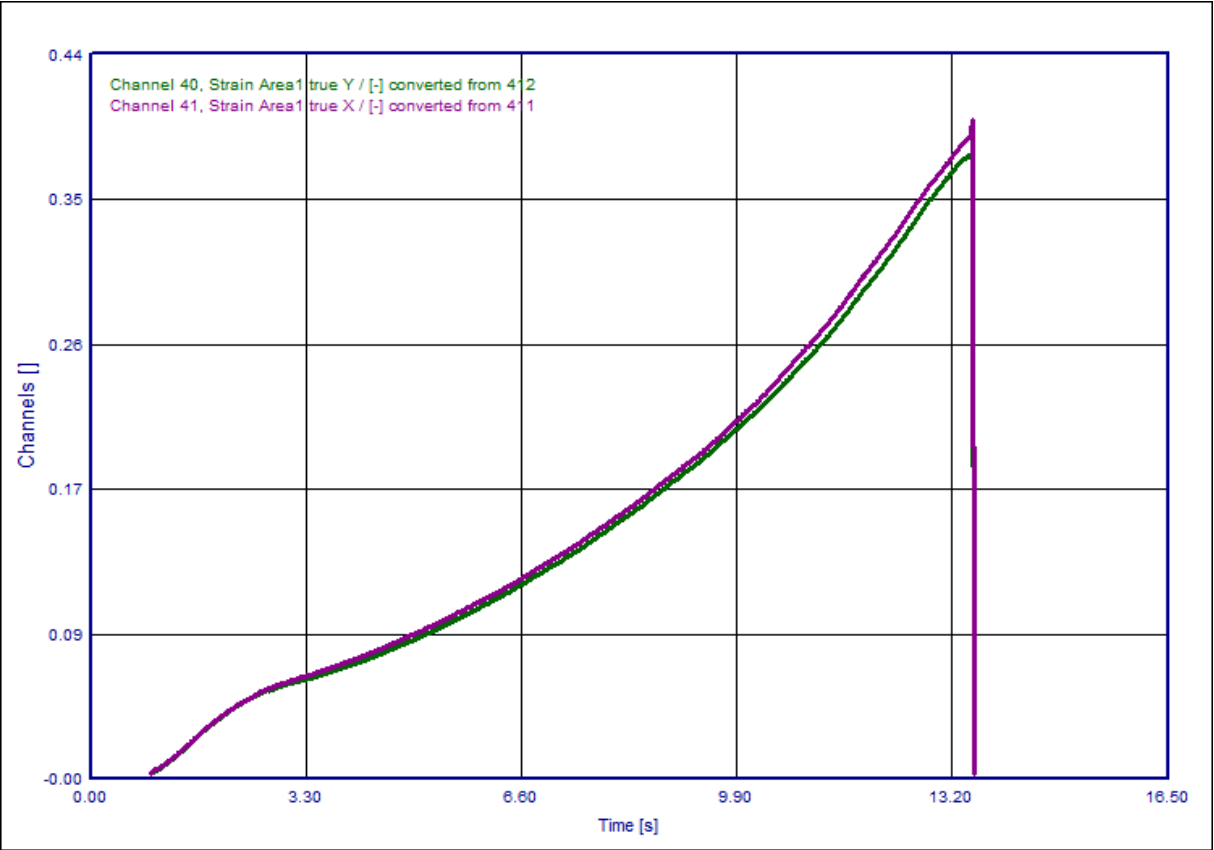
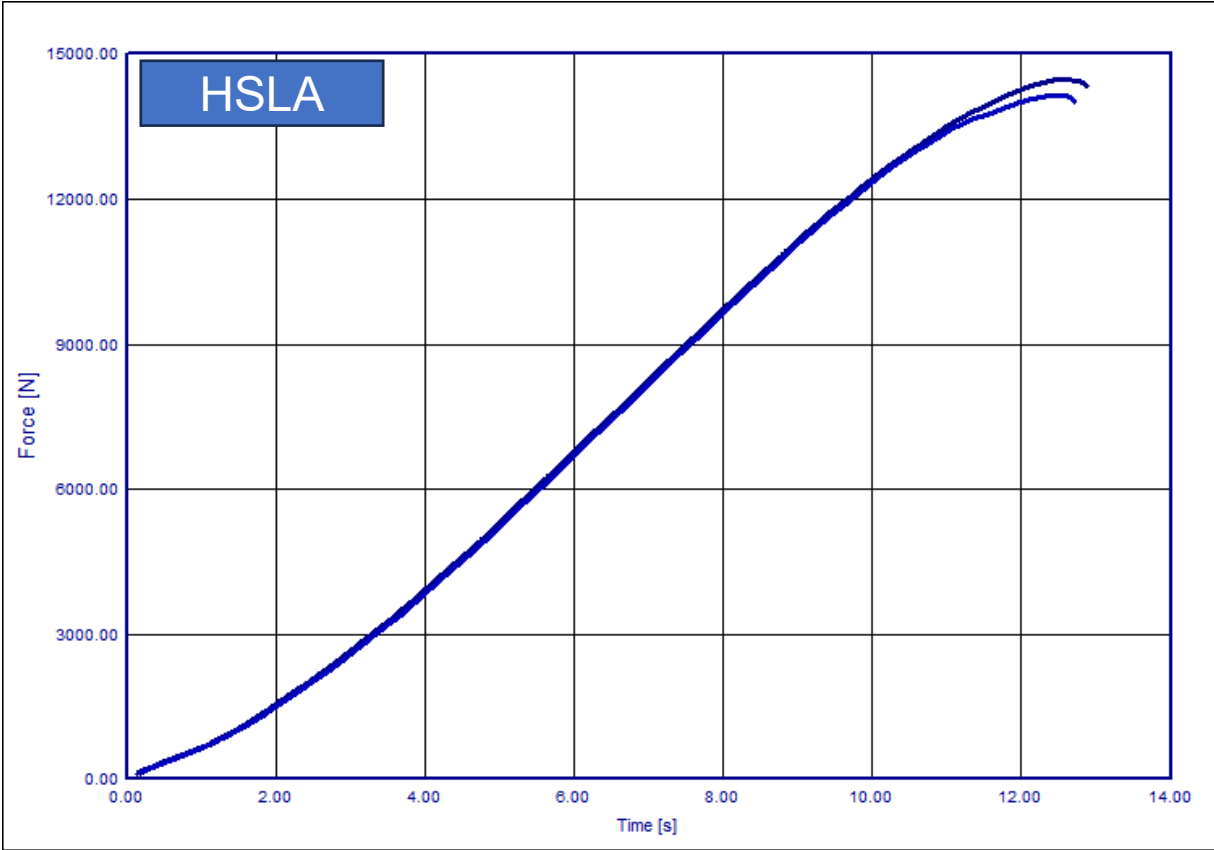
Punch test - results



Local strain on horizontal and vertical line segment at center of punch

Case	failed samples	v_0 [m/s]	l_w [mm]	b [mm]	t [mm]	l [mm]
PT	2/2	0.001	42	80.00	0.80	80.00

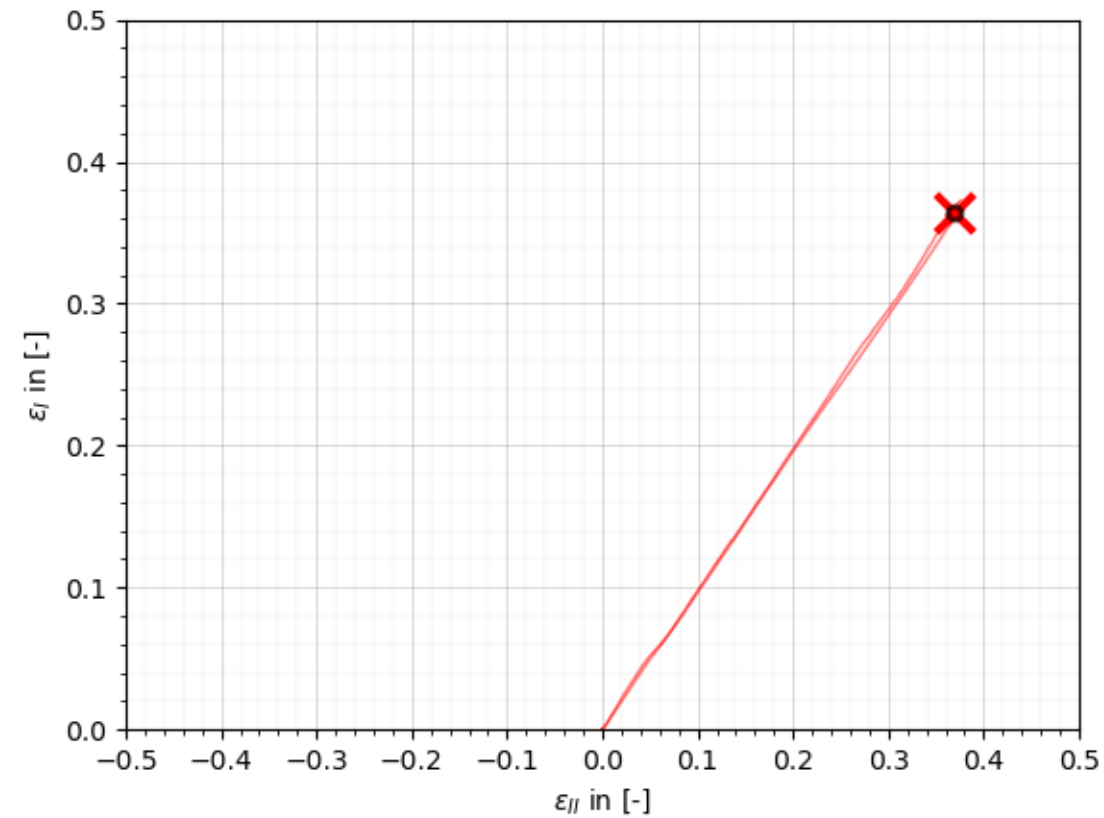
Punch test - results



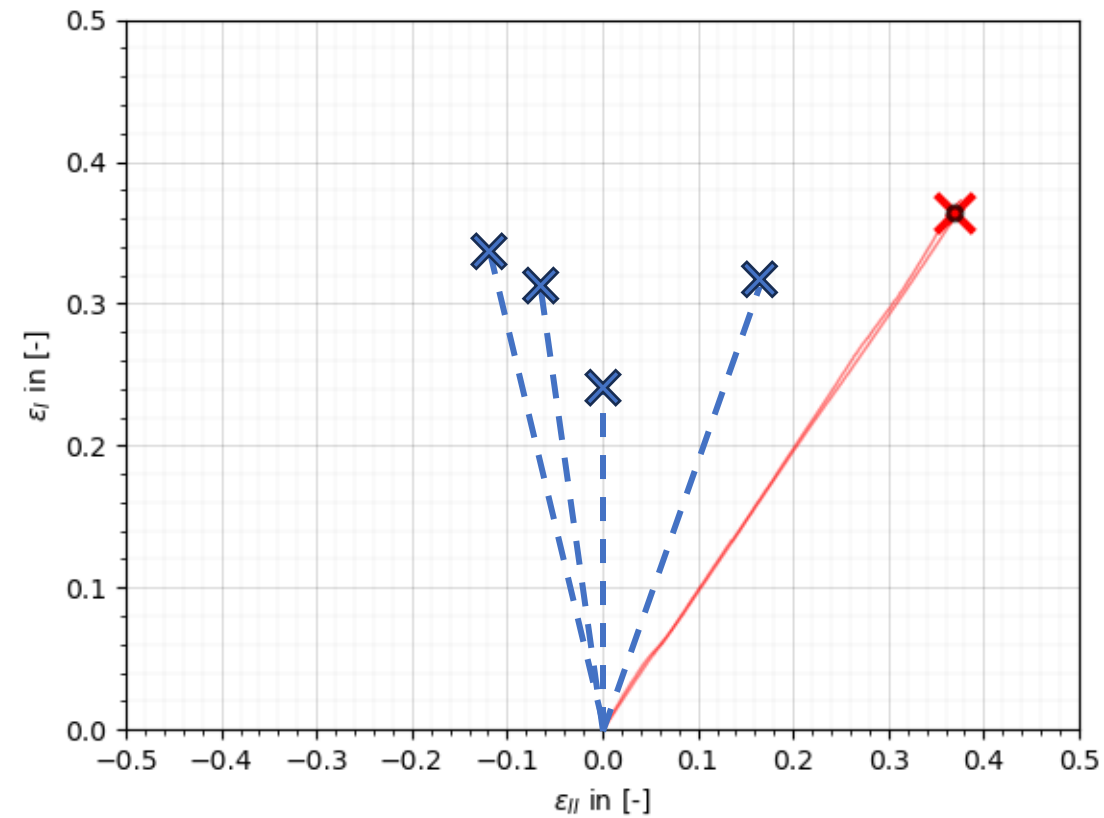
Local strain on horizontal and vertical
line segment at center of punch

Case	failed samples	v_0 [m/s]	l_w [mm]	b [mm]	t [mm]	l [mm]
PT	2/2	0.001	42	80.00	0.80	80.00

Punch test – results: Generation of FLD

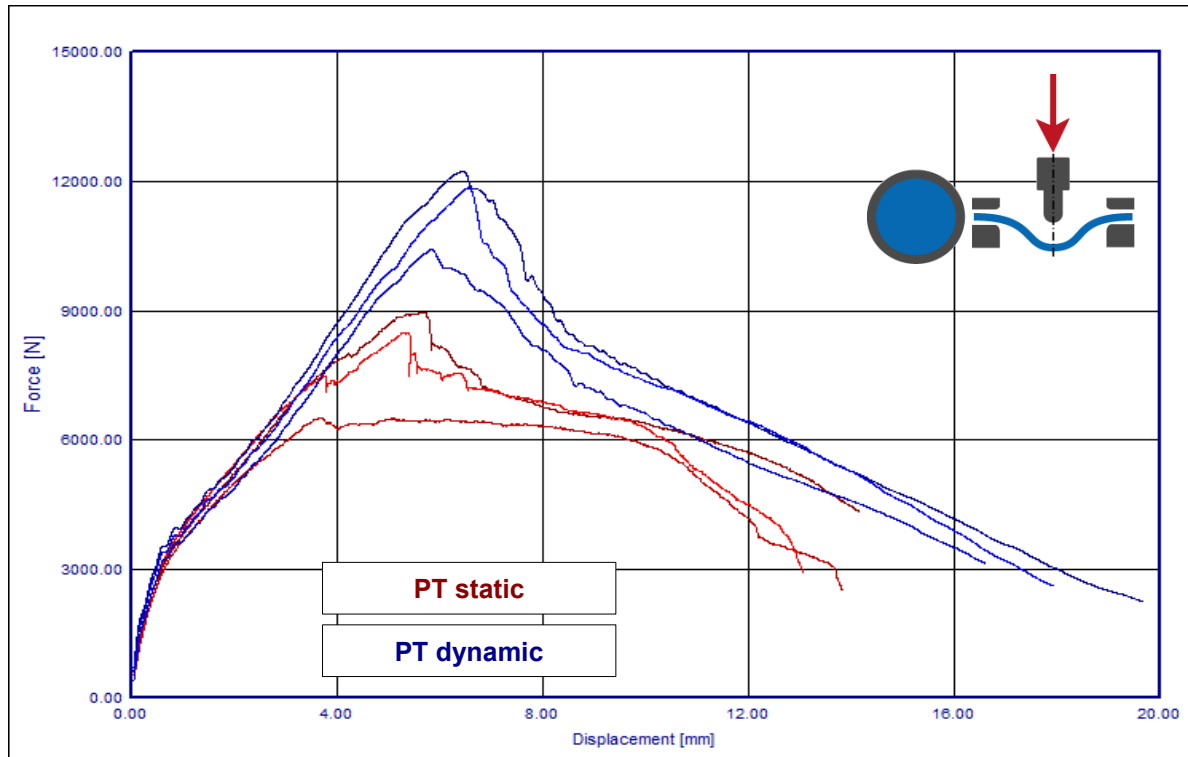


Punch test – results: Generation of FLD

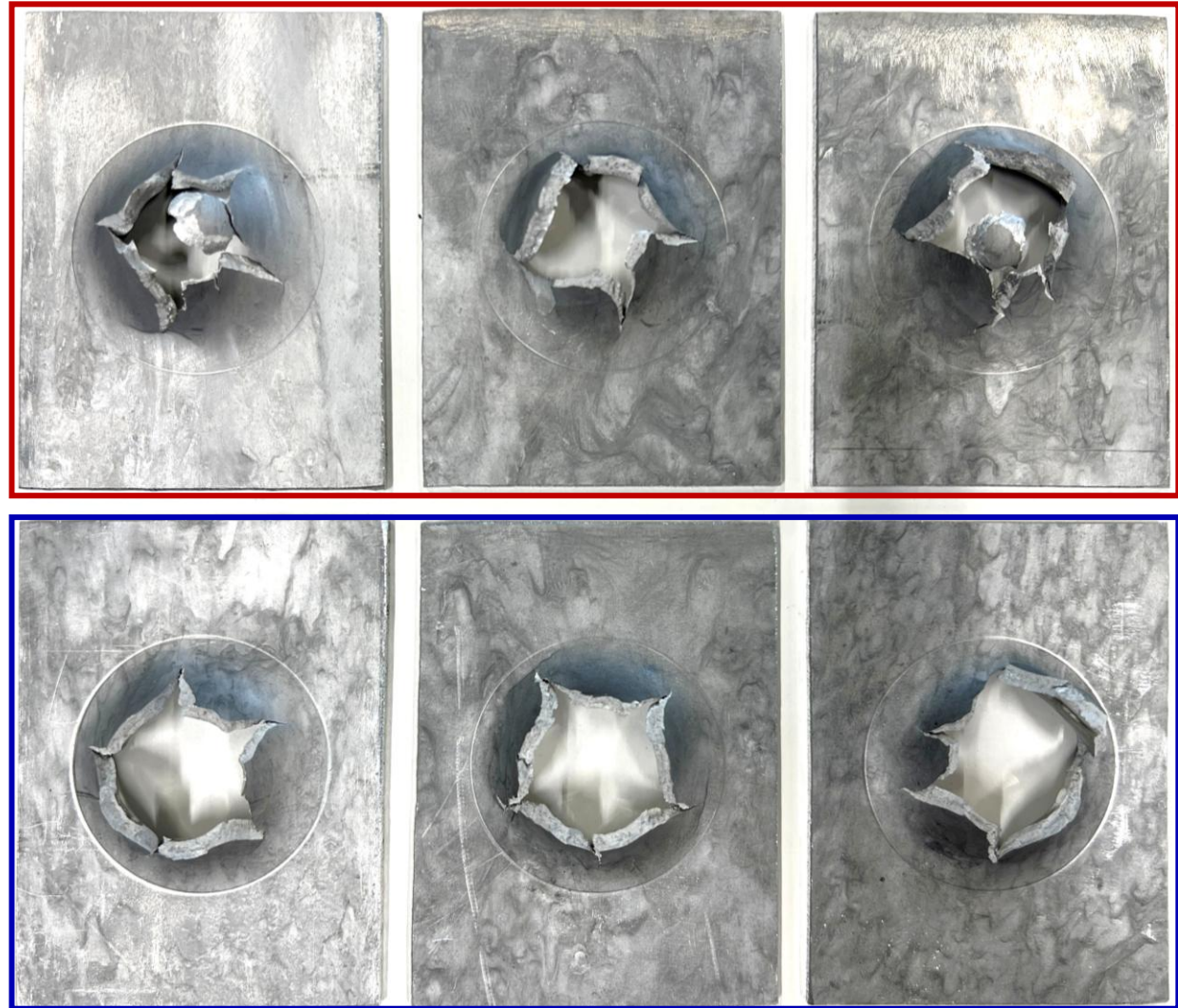


Punch test – results: strain rate effect

aluminum alloy



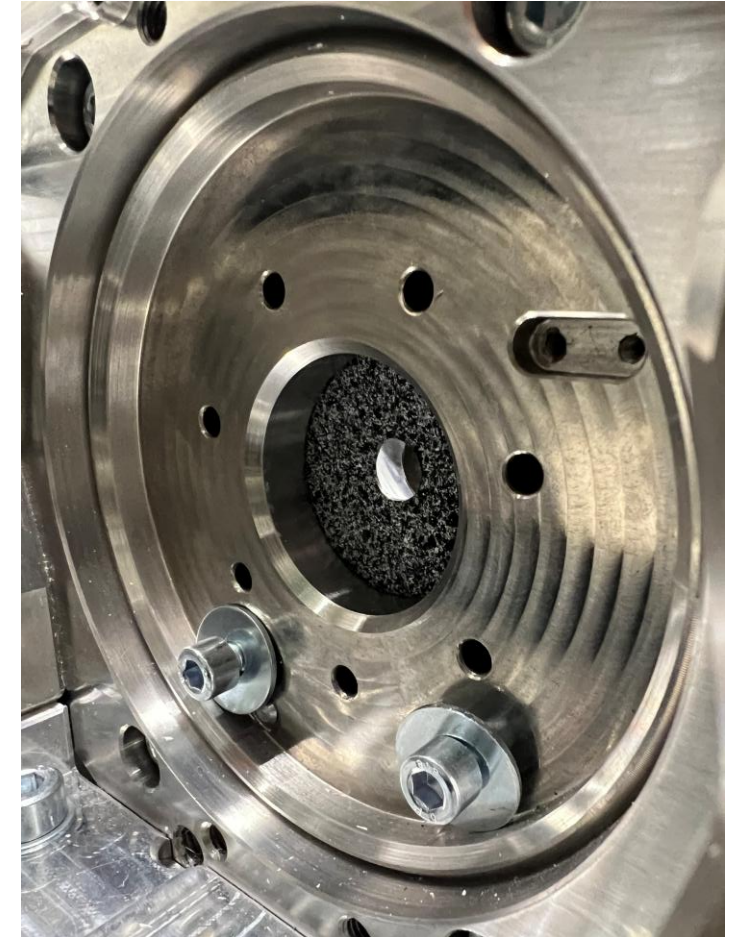
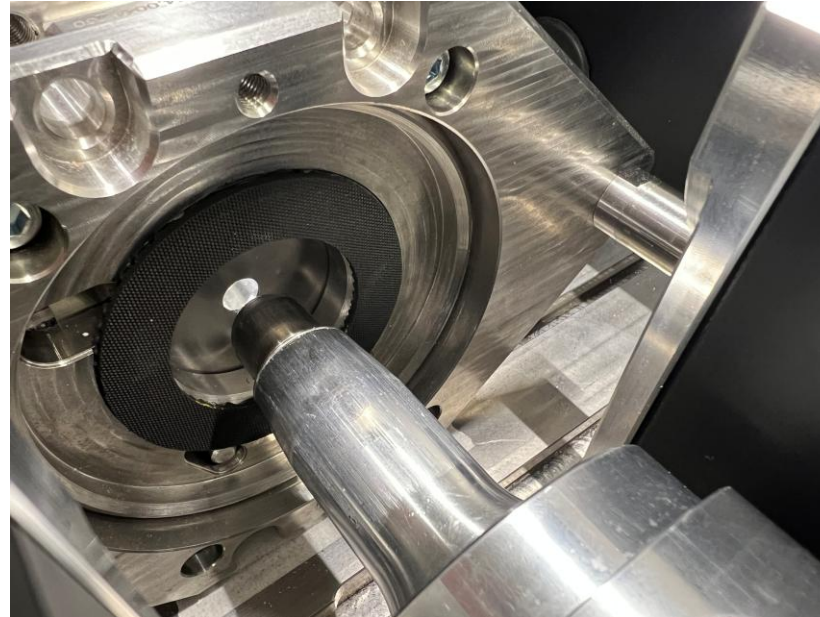
- no significant strain rate sensitivity in hardening
- pronounced strain rate sensitivity of fracture strain and max. force



Further application: Hole expansion testing with local fracture strain measurement

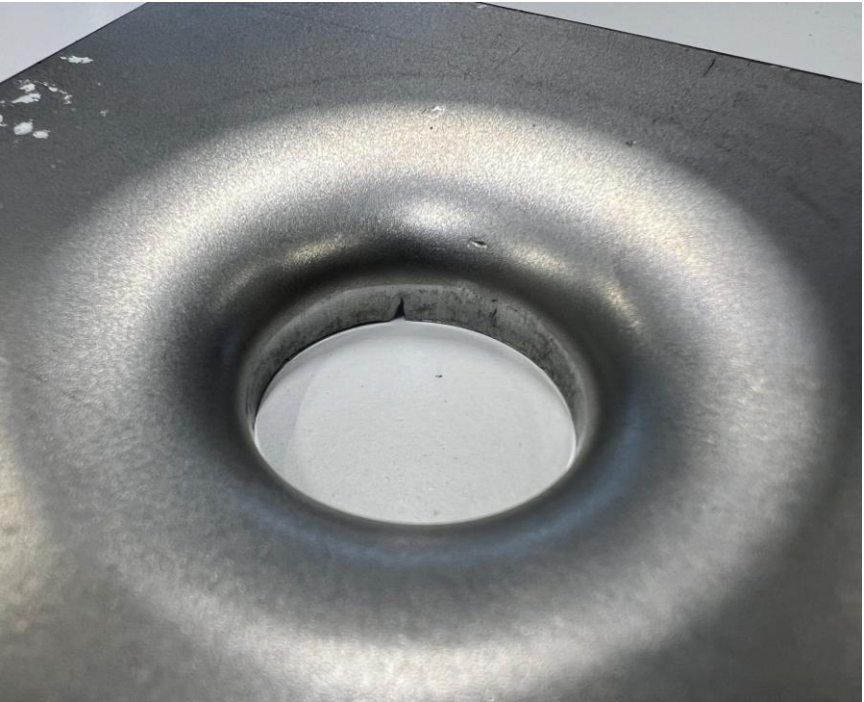
Hole expansion test setup - specimen

- HSLA steel
 - Thickness: 0.8mm
 - Size: 80mm x 80mm; initial hole diameter 10mm
 - Punch diameter: 20mm
 - Support diameter: 40mm

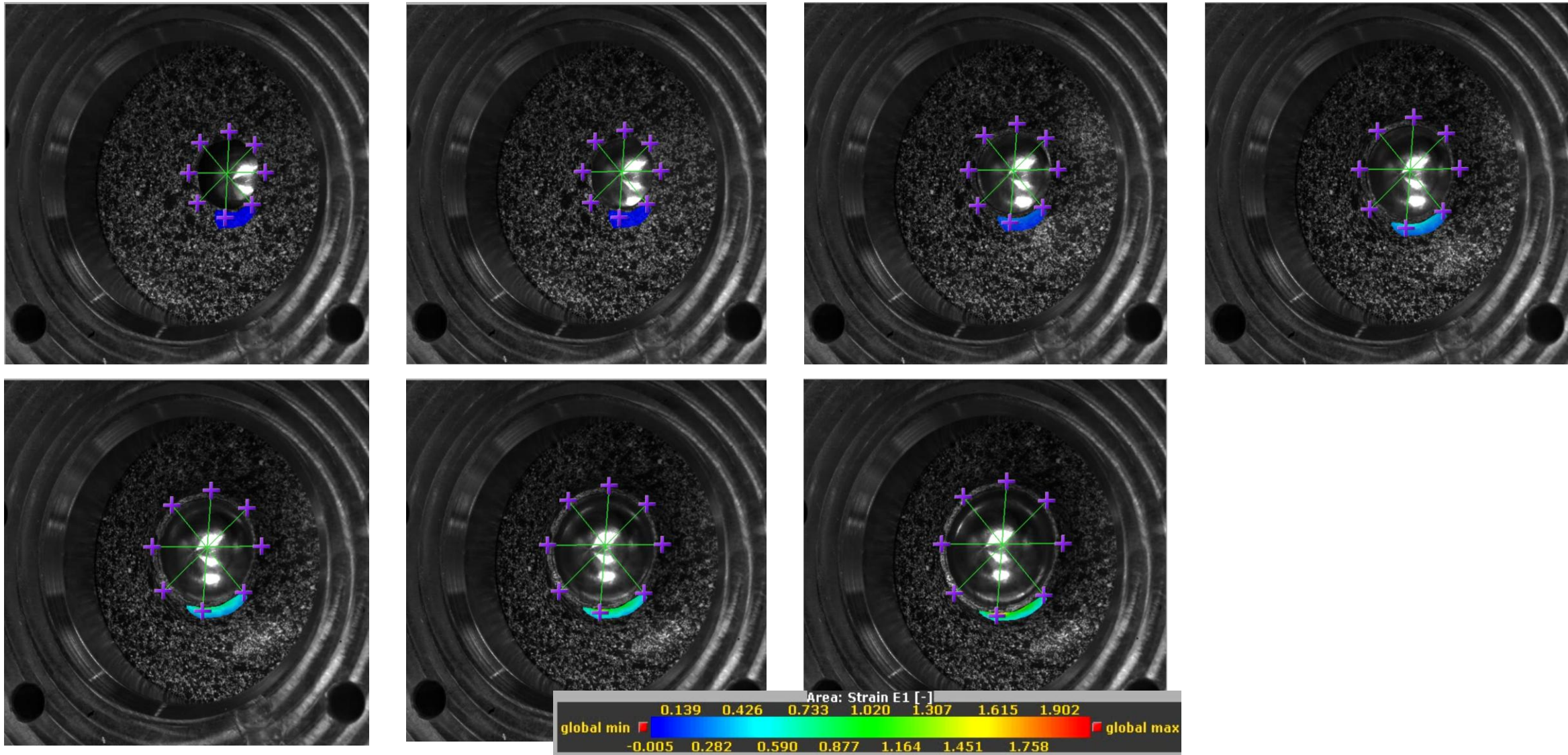


Hole expansion test - results

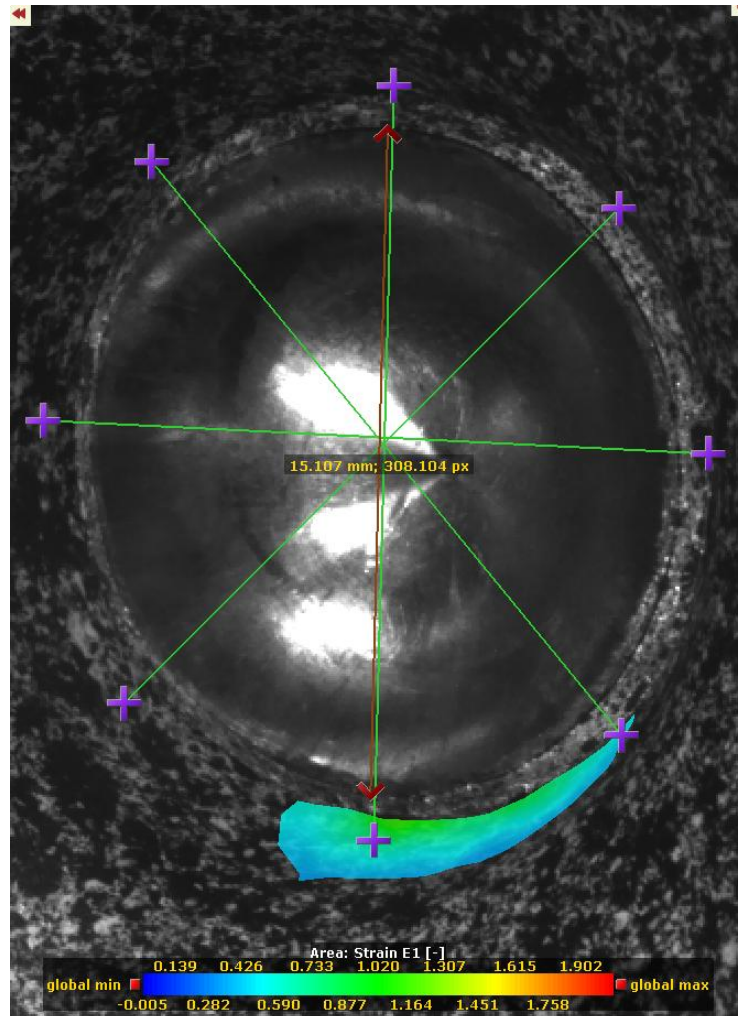
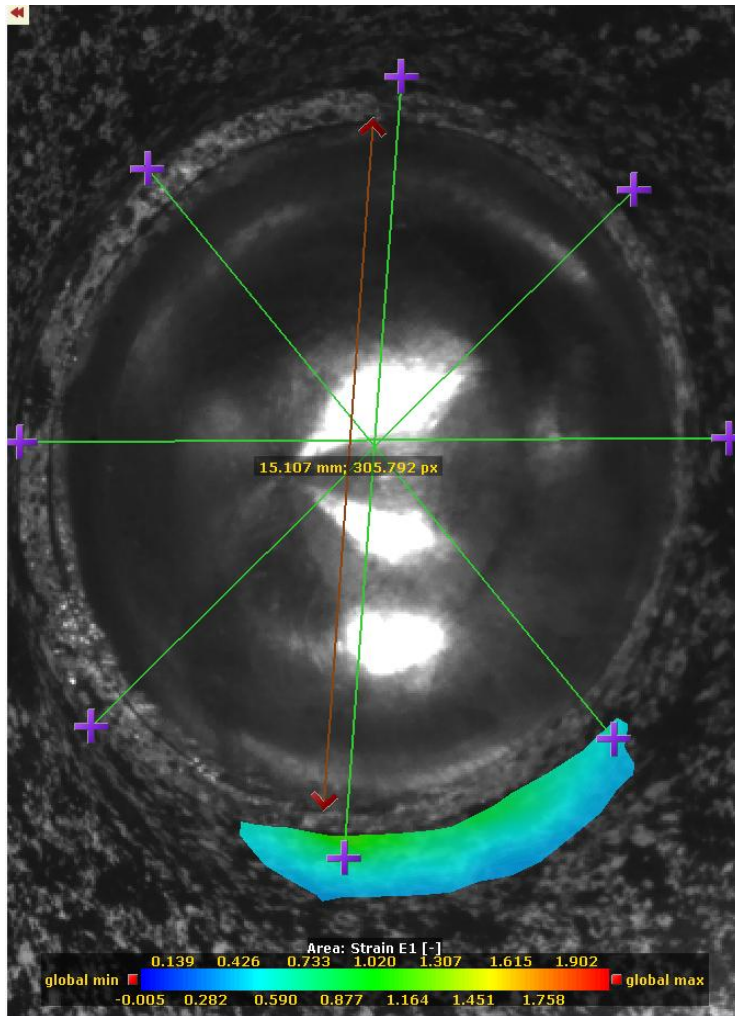
Case	failed samples	v0 [m/s]	lw [mm]	S _{max} [mm]	F _{max} [N]	Energy loading [J]
HET	2/2	0.001	42	18.41	5550	57.57



Hole expansion test – results: 3D DIC

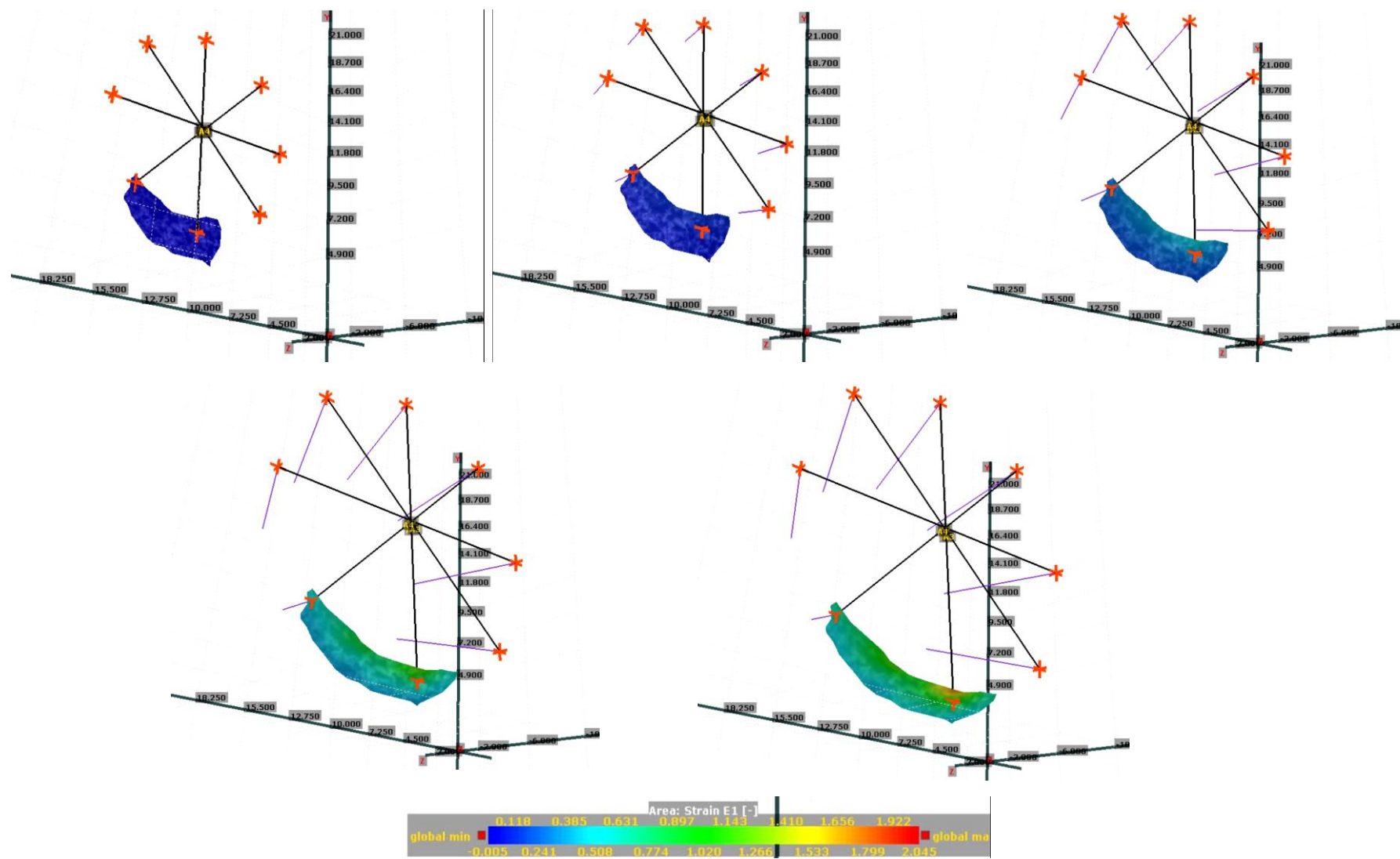


Hole expansion test – results: 3D DIC, local strain at crack initiation

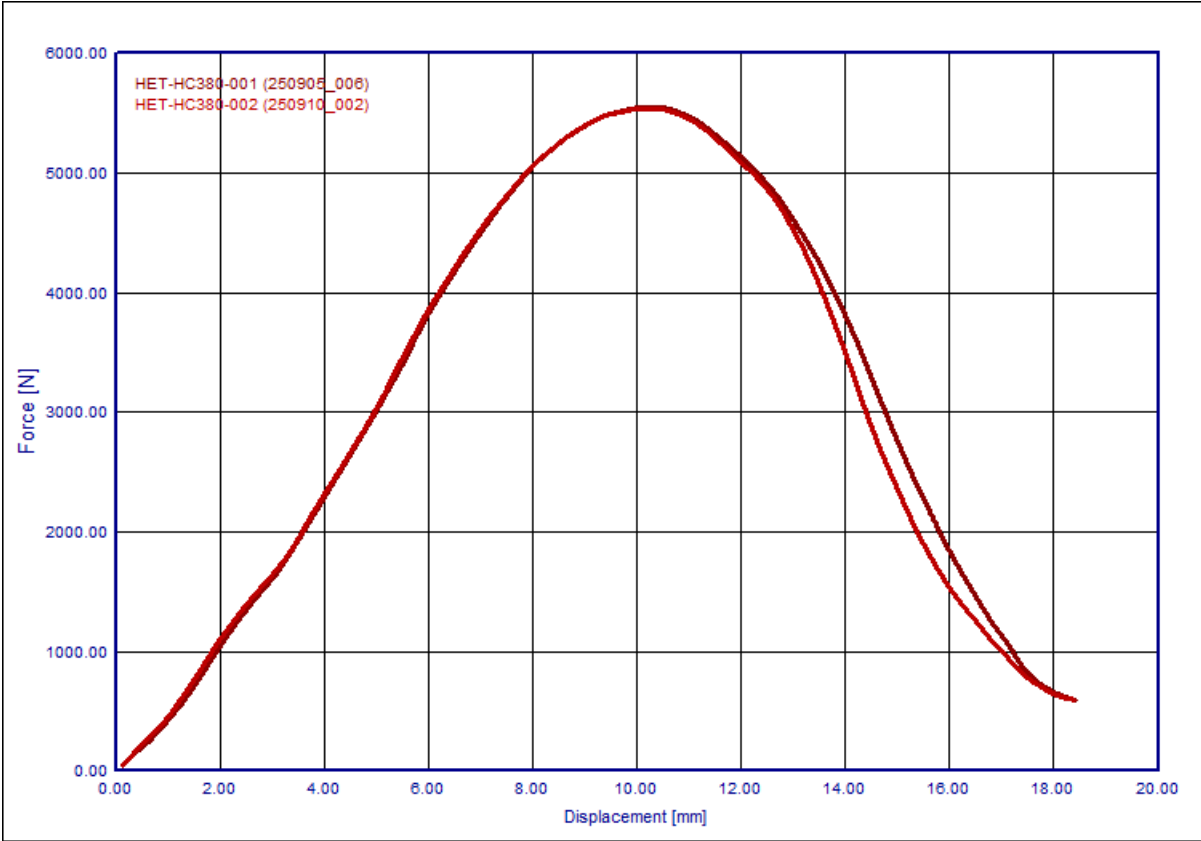


- Local strain measurement is applied at area of crack location
- 4 line segments (green color) applied to measure hole expansion
- Actual measurement of hole inside diameter at crack initiation illustrated as red line (inside diameter): 15.107mm

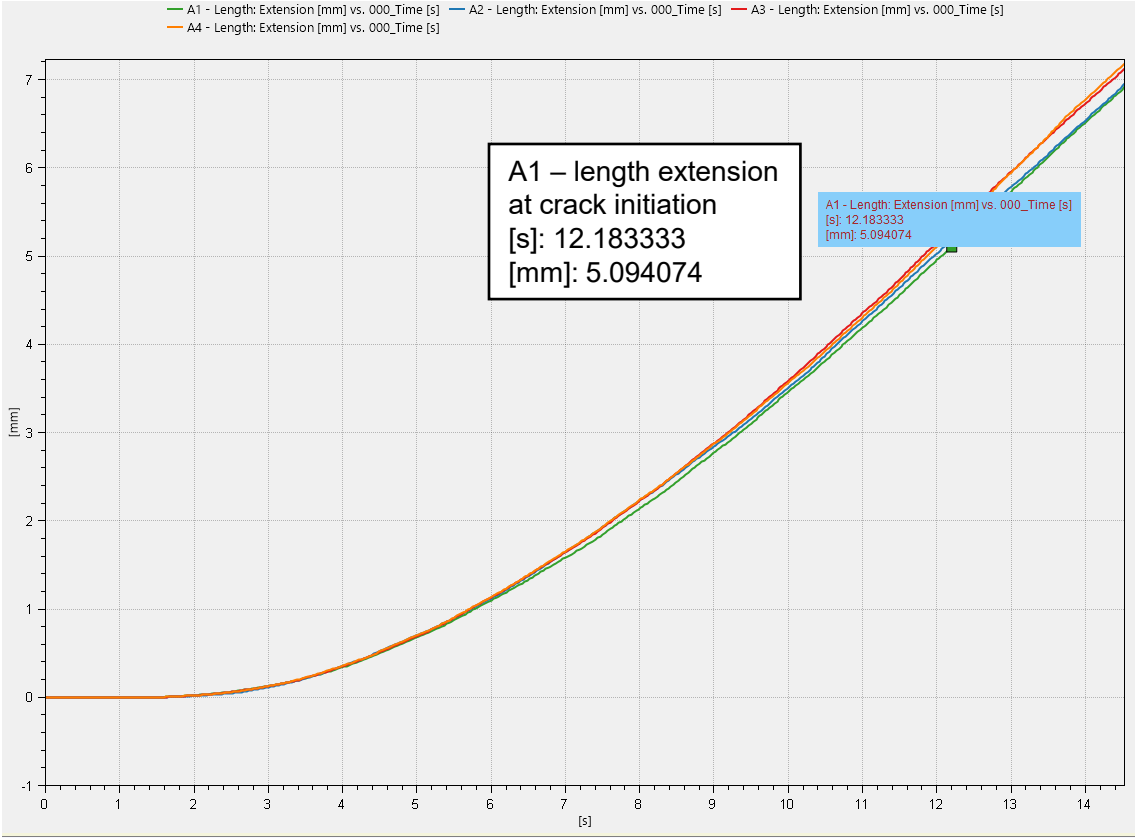
Hole expansion test – results: 3D DIC



Hole expansion test – results

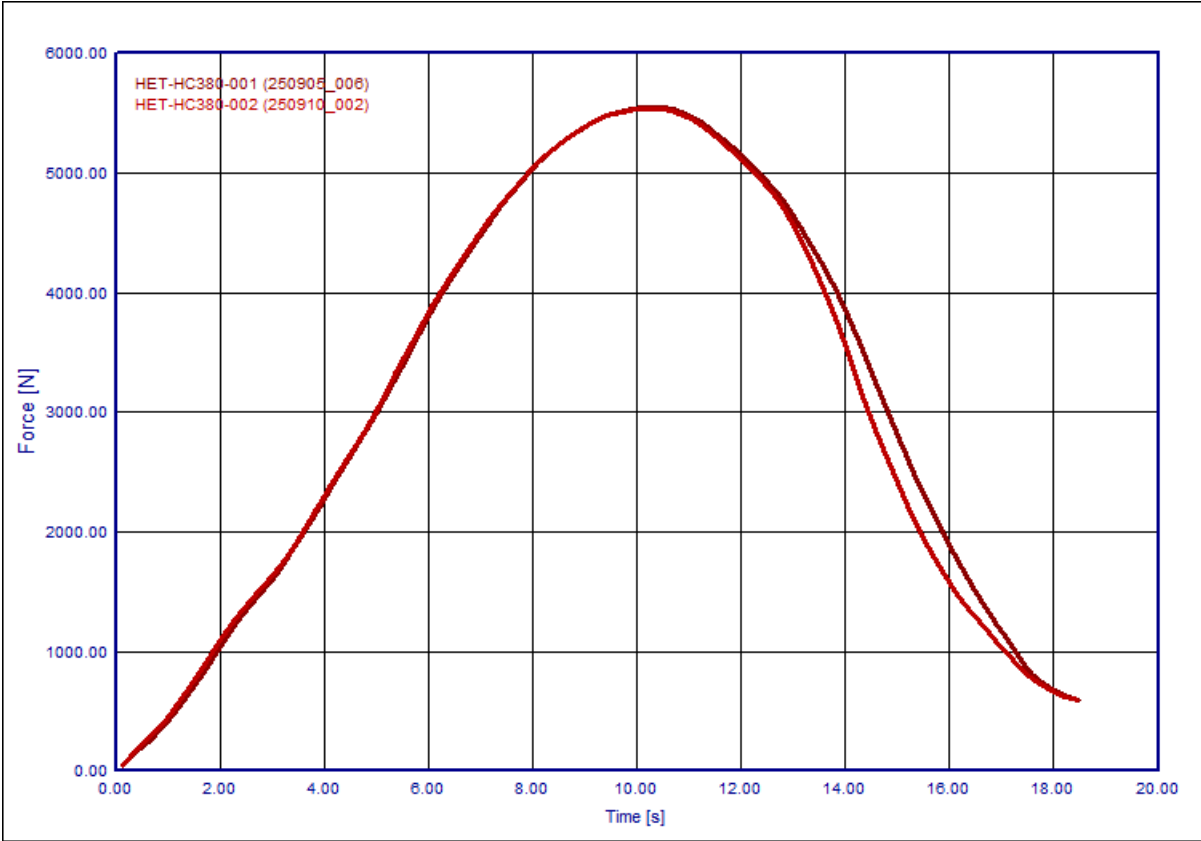


Case	failed samples	v_0 [m/s]	l_w [mm]	b [mm]	t [mm]	l [mm]
HET	2/2	0.001	42	80.00	0.80	80.00

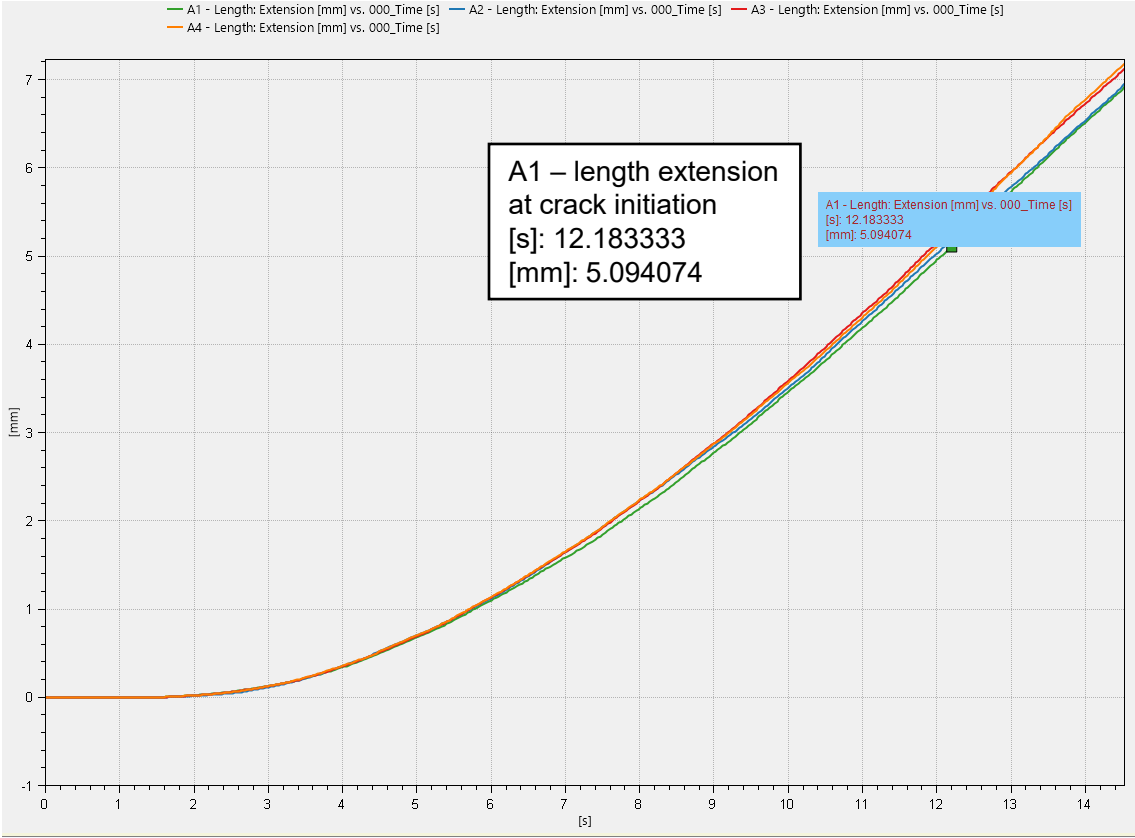


Crack extension of all 4 line segments measured via 3D DIC

Hole expansion test – results



Case	failed samples	v_0 [m/s]	l_w [mm]	b [mm]	t [mm]	l [mm]
HET	2/2	0.001	42	80.00	0.80	80.00



Crack extension of all 4 line segments measured via 3D DIC

Summary

- LINOVIS represents a highly flexible testing system for performing metal formability characterization at a wide range of loading conditions
- Punch test setup with automated clamping for high throughput testing
- Full 3D DIC integration with automated handling during test execution, as well as automated evaluation and post-processing within VALIMAT
- Strain rate effect should be considered in metal forming applications
- Automated generation of material card within VALIMAT



Complete environment from
testing to simulation input data

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+43 (664) 80106 640

