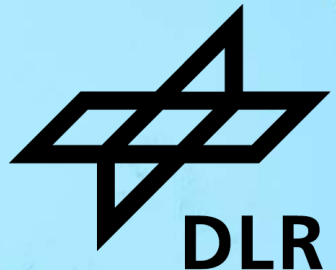


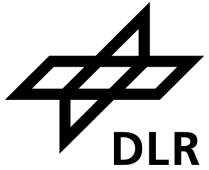
# HIGH-FIDELITY MODELLING OF COMPOSITE SPECIMENS MANUFACTURED WITH THE AUTOMATED FIBRE PLACEMENT TECHNIQUE

M. Vinot, L. Raps, N. Toso

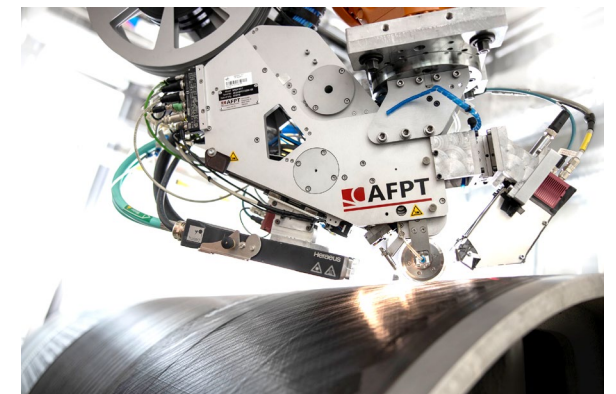
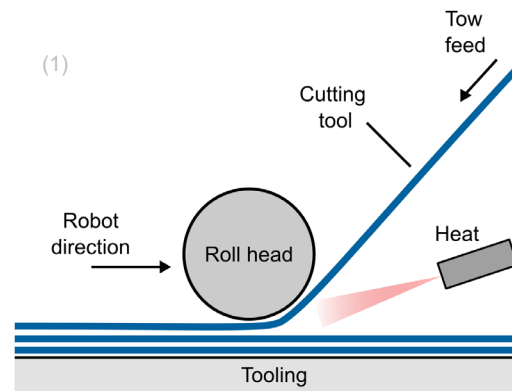


# Automated Fibre Placement

## Process description



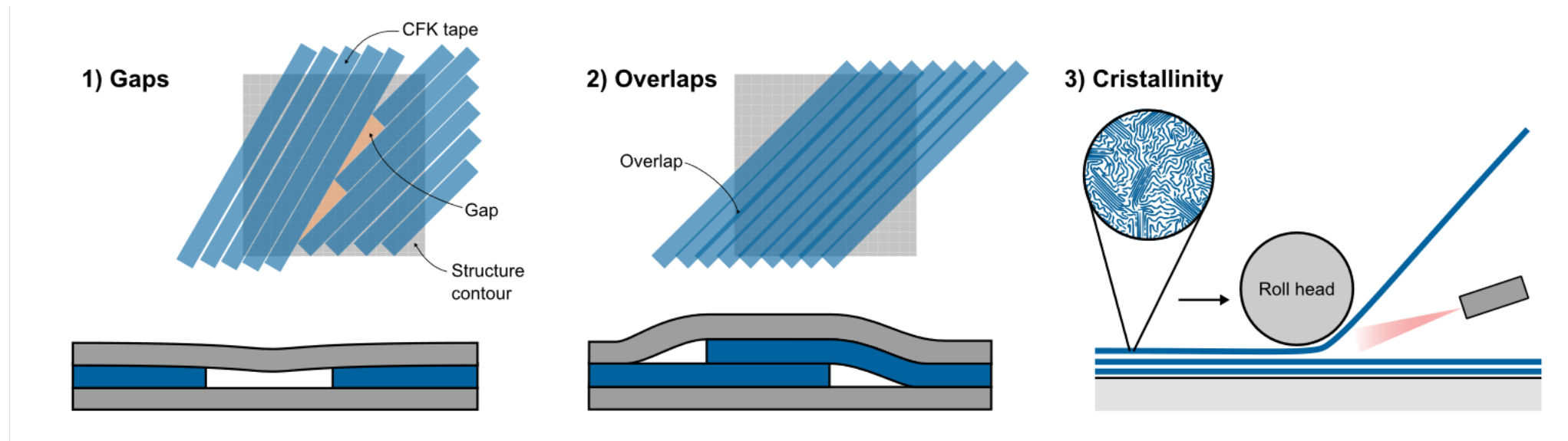
- Large increase of worldwide hydrogen needs in the next years
- High improvement potential through materials, manufacturing and design
- Automated fibre placement
  - ↳ enable the production of type V linerless tanks
  - ↳ increased tank recycling via thermoplastics
  - ↳ increased design freedom (non-geodesic fiber orientations)



# Automated Fibre Placement

Manufacturing effects and inherent defects

Potential influence of manufacturing parameters on the quality of the end product



- Estimation of defects via direct measurement (robot data) or indirect measurement (derivation through data analytics, ultrasonic scans...)
- Structuring of data concerning manufacturing and defects via metadata and ontology

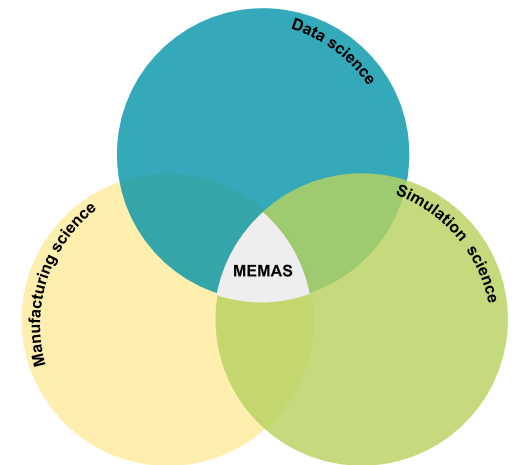
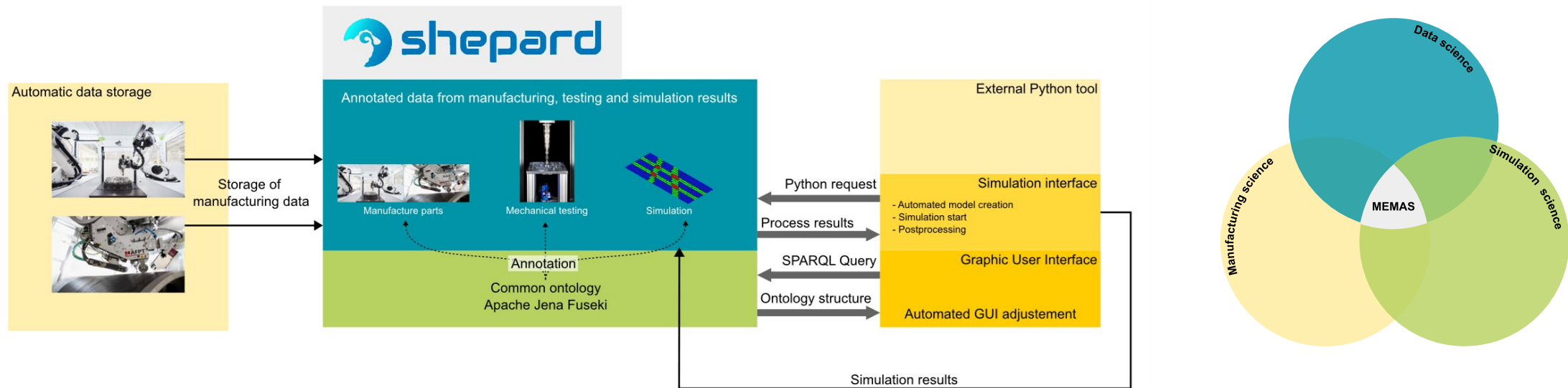
# Manufacturing data and metadata in simulation

Multidisciplinary framework



## MEMAS: Metadata Enriched Manufacturing data for Automated Simulation

- Framework to unite manufacturing, testing and simulation
- Acquisition and structured storage of manufacturing and test data/metadata
- Automatic generation of high-fidelity FE models based on manufacturing data

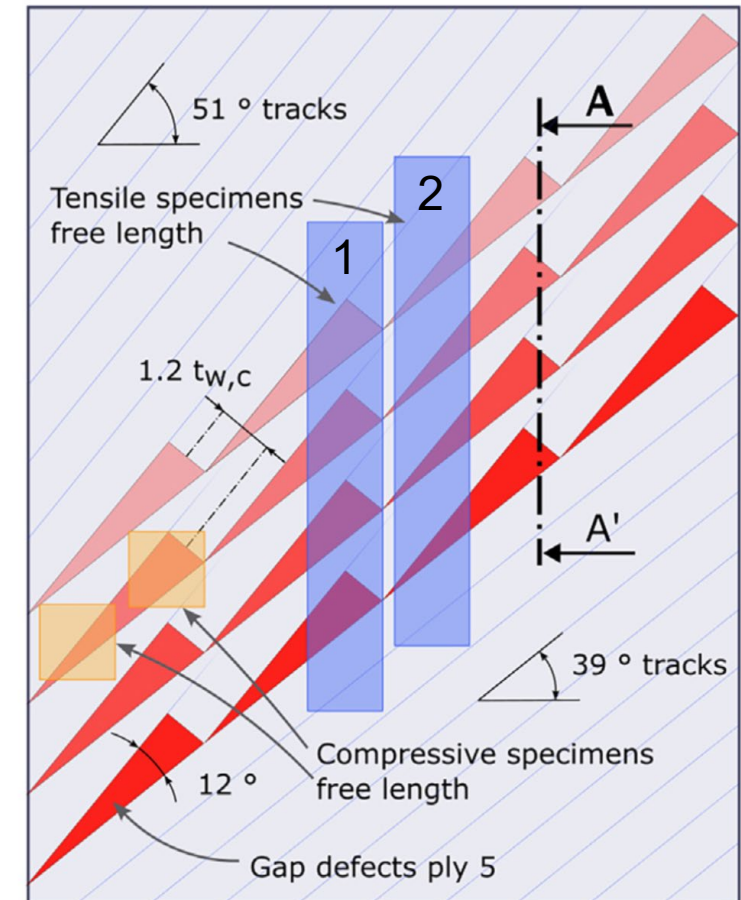


# Experimental test campaign

Investigation of geometrical defects

## Investigation of compression specimens

- Material: AS7/LM-PAEK 55 % fibre content
- Layout:  $[0^\circ/-45^\circ/90^\circ/(51^\circ|39^\circ)]_{2s}$
- Specimens extracted from CFRP plate
- Geometry: AITM 1-0008-A2
- Reference specimen without defects
- Two defect patterns (1, 2)
- Storage of tape paths for each ply into a research data management system



Lukas Raps, Fynn Atzler, Ashley R. Chadwick, Heinz Voggenreiter, In-situ automated fiber placement gap defects filled by fused granular fabrication, Manufacturing Letters,

# Structured storage of manufacturing data

Research data management system shepard (<https://gitlab.com/dlr-shepard>)



## Structured storage for efficient data analysis and referencing

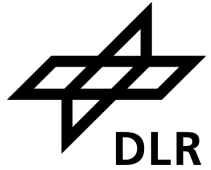
The screenshot displays the shepard data management system interface, showing the structured storage and referencing of manufacturing data. It is divided into three main sections:

- Left Panel (ZLPA0071-01):** Shows the main data object with ID 699947, created and updated by Vinot, Mathieu. It lists 1 Parent, 15 Children, 0 Predecessors, and 0 Successors. It is an instance of 'Part' and is manufactured by 'Automated fibre placement process'. The 'Parent' section shows 'Part ID: 699945'. The 'Related Objects' section lists Ply3 (ID: 700005), Ply4 (ID: 700097), Ply7 (ID: 700219), and Ply8 (ID: 700311).
- Middle Panel (Ply3):** Shows the selected data object with ID 700005, also created and updated by Vinot, Mathieu. It lists 1 Parent, 15 Children, 0 Predecessors, and 0 Successors. It is an instance of 'Ply'. The 'Parent' section is empty. The 'Related Objects' section lists Track1 (ID: 700007), Track2 (ID: 700013), Track3 (ID: 700019), Track4 (ID: 700025), and Track5 (ID: 700031).
- Right Panel (Structured Data Reference):** A tree view showing the internal structure of the selected object. It contains an 'object' with a '\_id' of 1 and a 'chunk\_eval\_results' array of 24 elements, indexed from 0 to 10.

Blue arrows indicate the relationships: one arrow points from the 'Ply3 ID: 700005' entry in the 'Related Objects' list of the left panel to the 'Ply3' header in the middle panel; another arrow points from the 'Track1 ID: 700007' entry in the 'Related Objects' list of the middle panel to the 'Track1' entry in the 'Structured Data Reference' tree view.

# Model generation based on manufacturing data

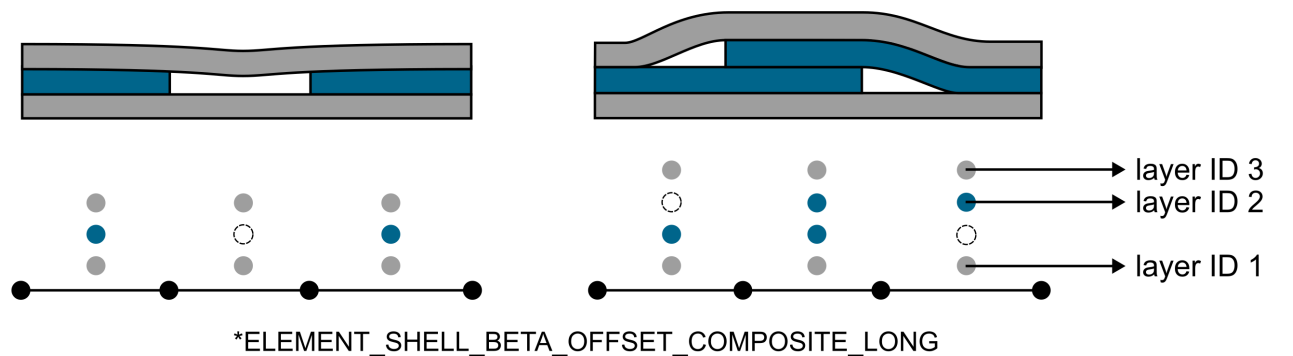
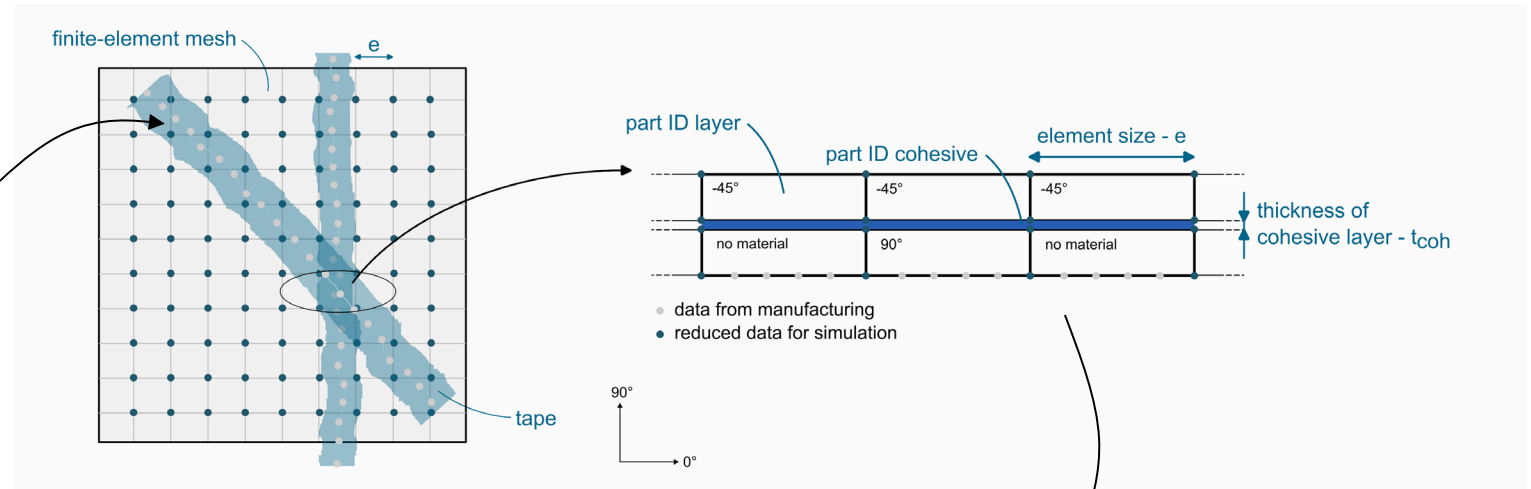
Mapping procedure and model generation



## Mapping of tape information from database on elements with closest point algorithm

Structured Data Reference

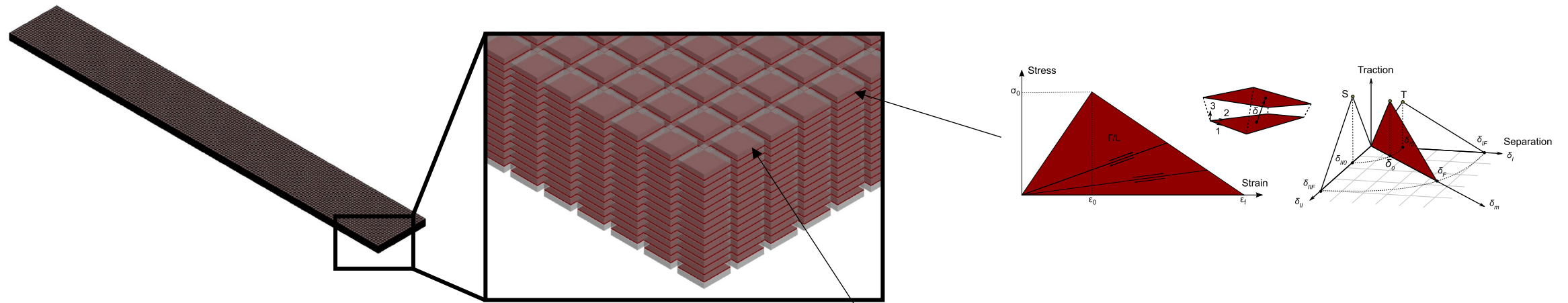
```
object ▶ chunk_eval_results ▶ 0 ▶ one_profile_eval_results ▶ 0 ▶ tow_border_eval_results ▶ 0 ▶  
  info_text : :value:  
  n_rows : 100  
  one_profile_eval_results [100]  
    0 {8}  
      fsd_a : 89.999985  
      fsd_b : 0  
      fsd_c : -179.999908  
      fsd_x : 793.299  
      fsd_y : 120.408  
      fsd_z : 0.551  
      row_idx : 50  
    tow_border_eval_results [4]  
      0 {9}  
      1 {9}  
        area : null  
        classification : g  
        displacement : -2.105832225  
        fitCorrelation : null  
        fitError : null  
        height : null  
        numericClassification : 1  
        tow_border_idx : 1  
        width : 0.90531105  
      2 {9}  
        area : null
```



\*ELEMENT\_SHELL\_BETA\_OFFSET\_COMPOSITE\_LONG

# Modelling strategy and material models

## Mapping of tape information from database on elements with closest point algorithm

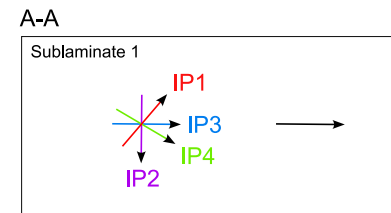
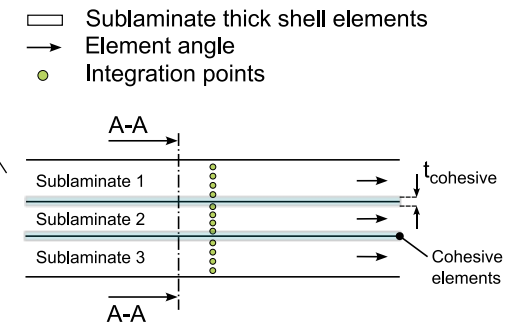


### Cohesive zone model \*MAT\_240

- strain-rate independent strengths and fracture toughness
- independent on fibre angle of bound layers

### Orthotropic continuum damage model from Camanho \*MAT\_262

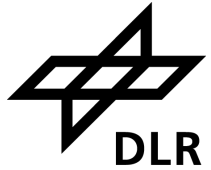
- strain rate dependent strengths and fracture toughnesses
- physically-based failure and damage criterion



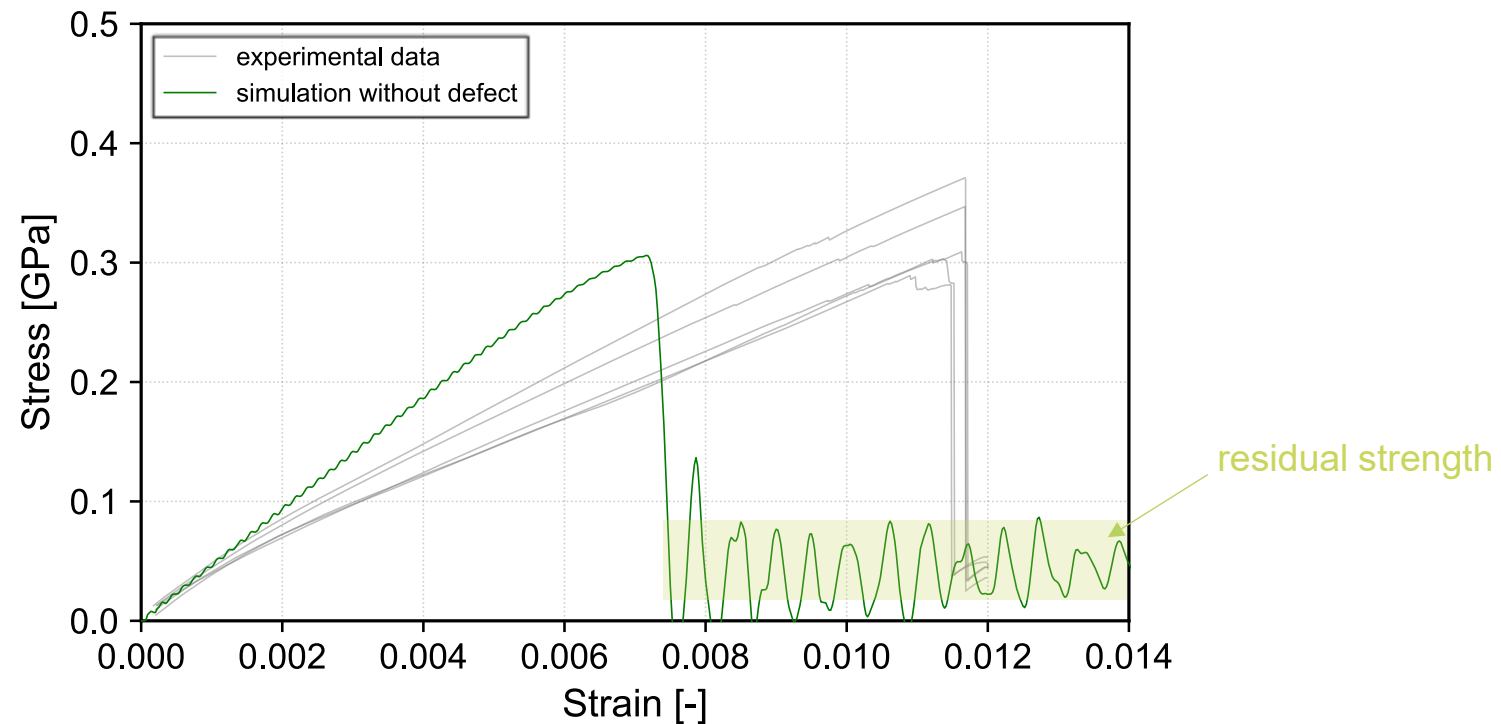


# Virtual compression tests

Validation of reference model – preliminary results



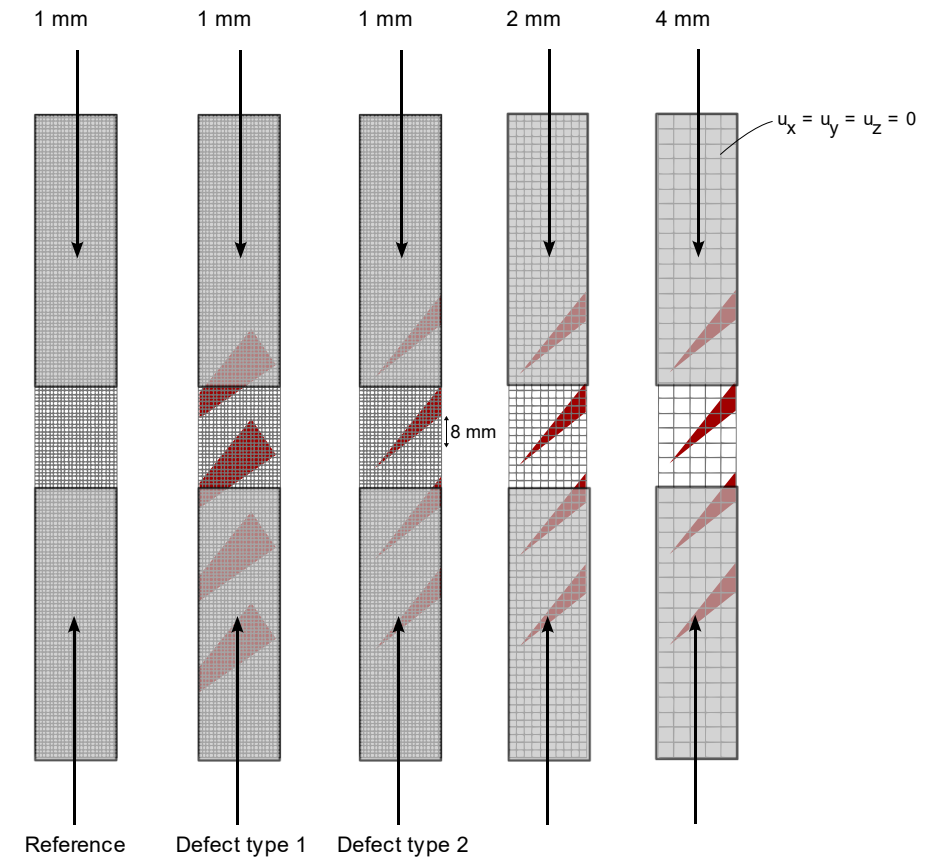
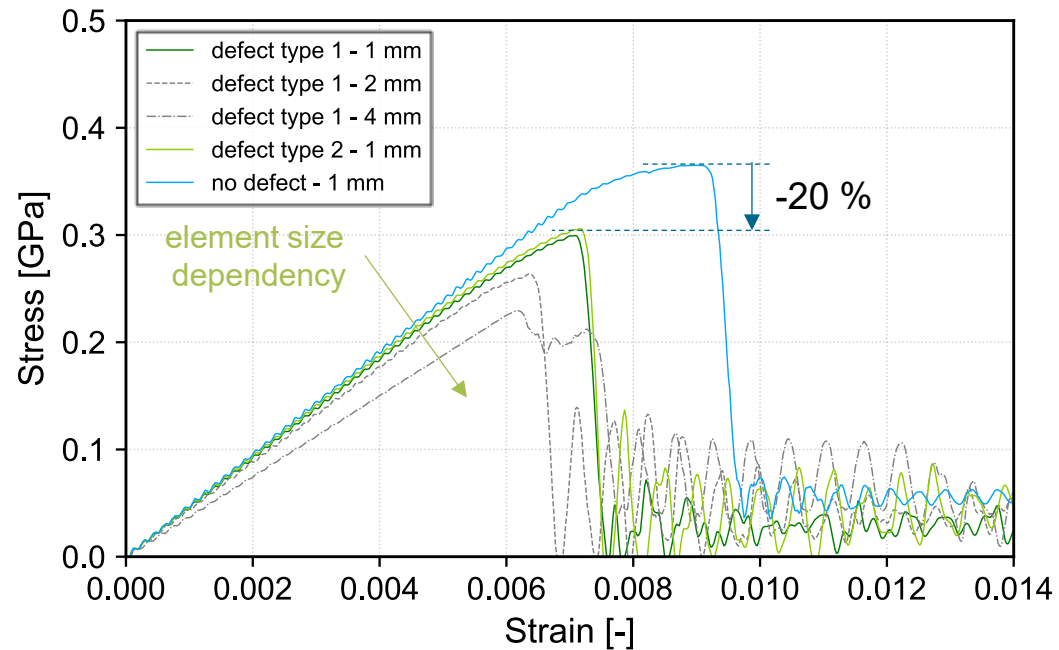
- Initial stiffness before first ply failure accurate
- Good correlation of compression strength and residual strength for pristine samples
- Non-linear behaviour of the specimen not accurately reproduced



# Virtual compression tests

Investigating the effect of defects on global mechanical behaviour

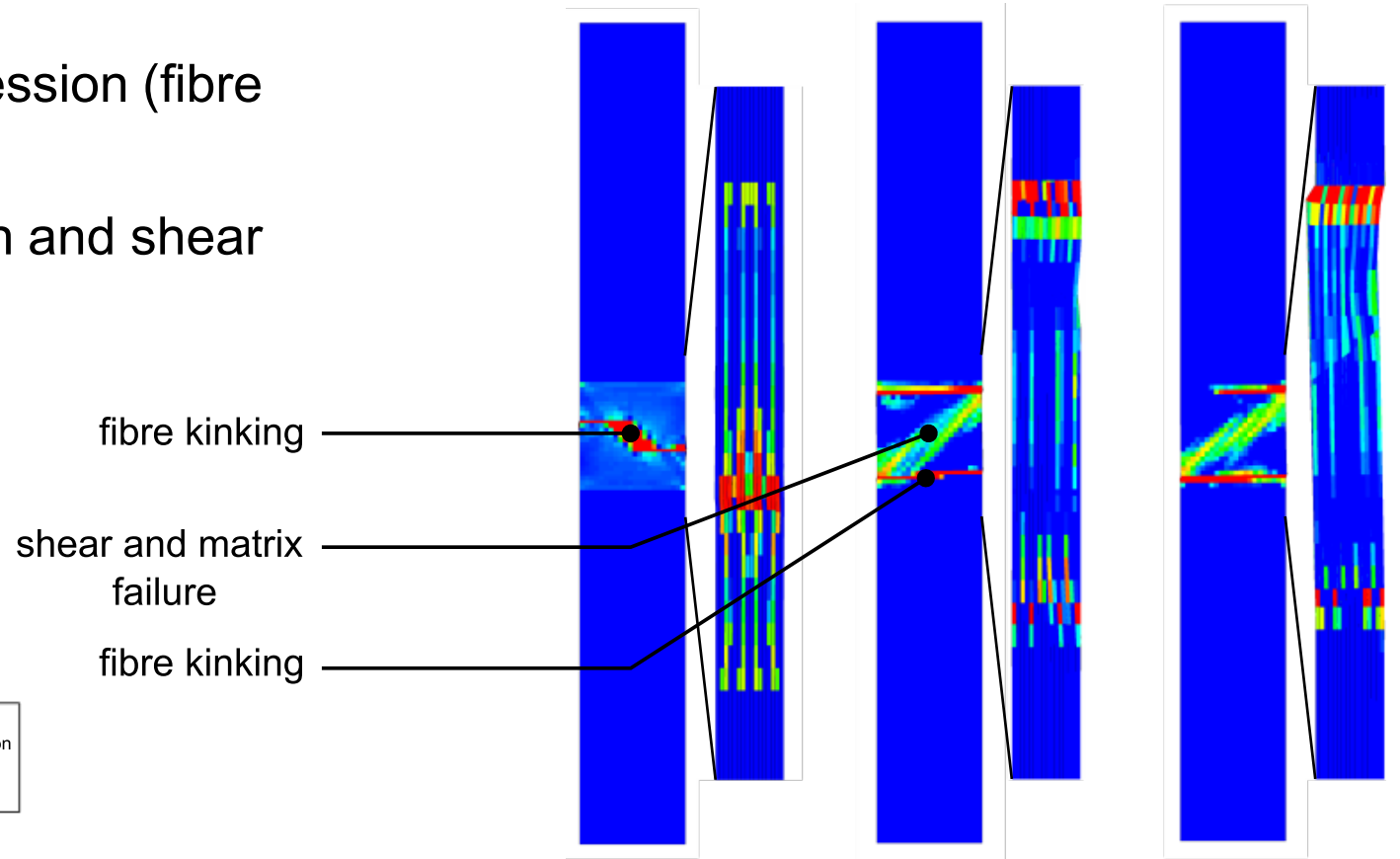
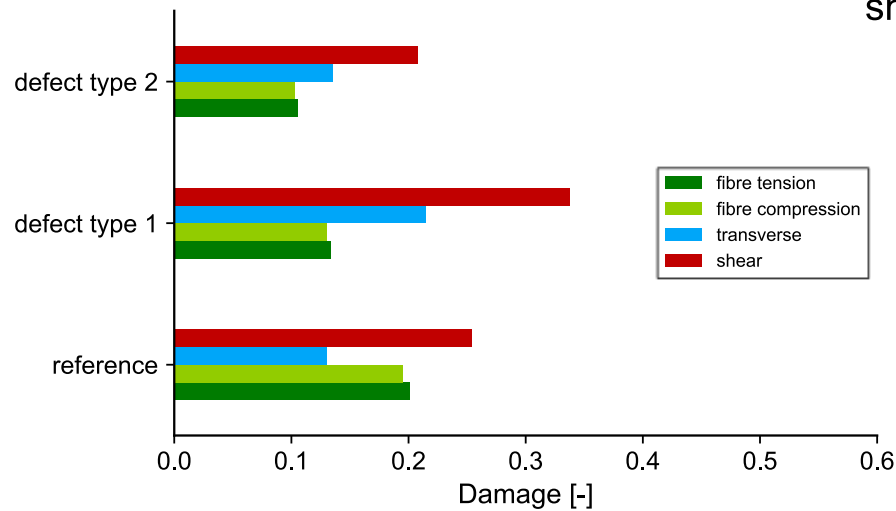
- Investigation of element size effects on predicted mechanical response
- Investigation of defect size
- For the moment, no investigation of the defect position



# Virtual compression tests

Investigating the effect of defects on failure patterns

- Global failure under fibre compression (fibre kinking) in the pristine specimen
- Shift towards matrix compression and shear failure in the defect specimens

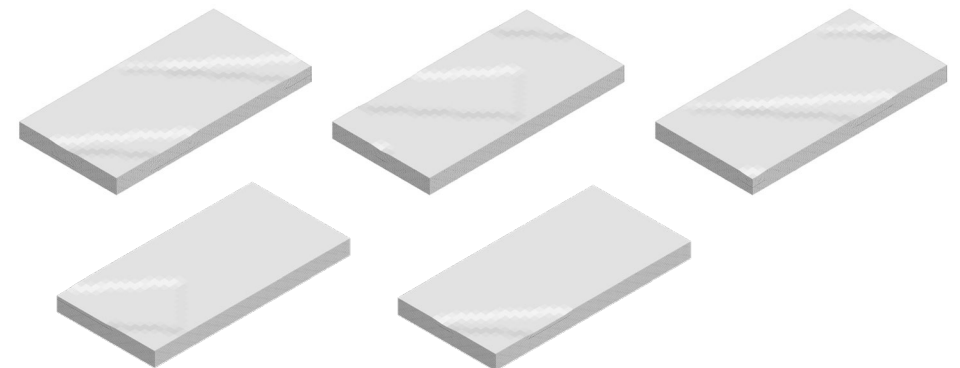
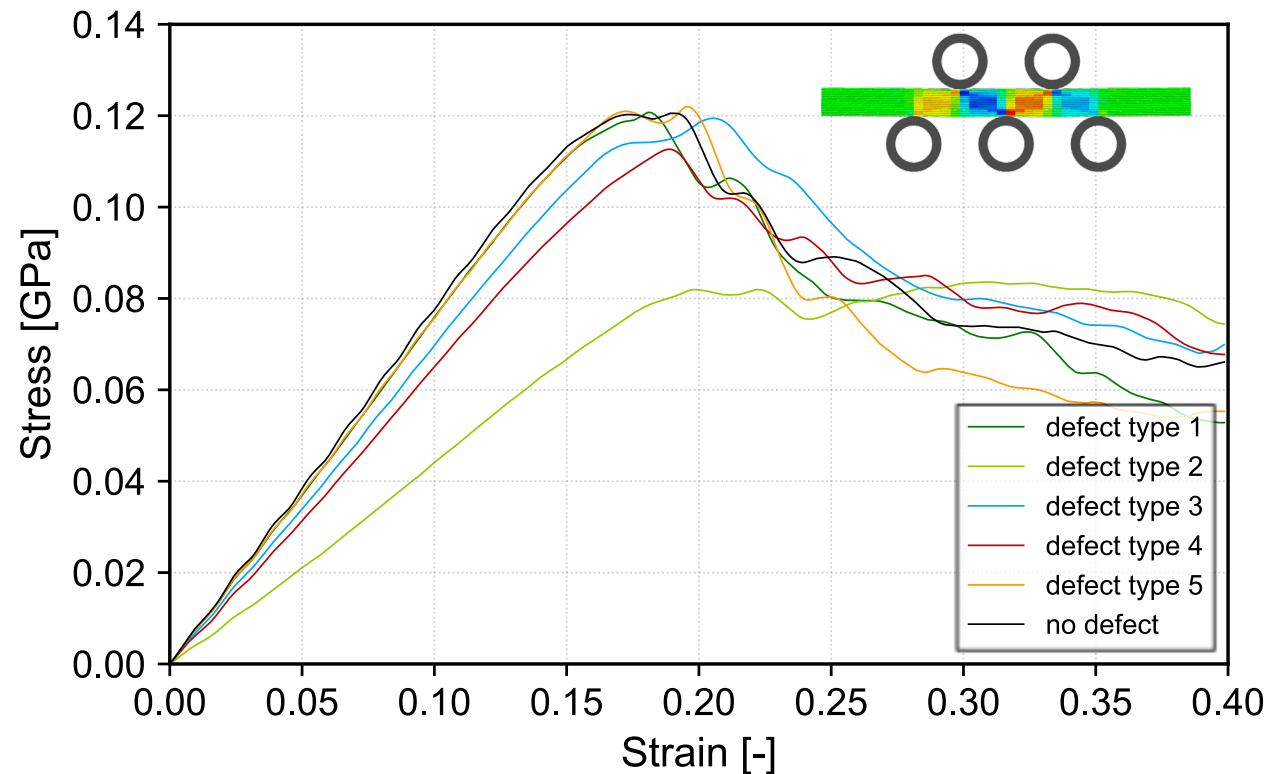
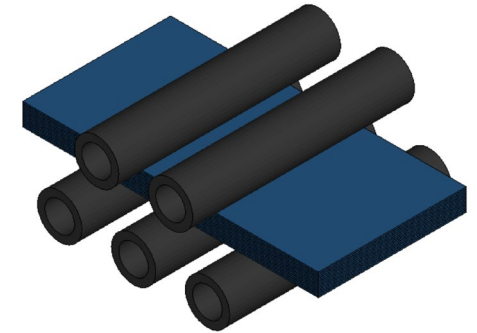


# Extension to more loading cases

Estimating the interlaminar shear strength (ILSS) of thermoplastic materials



- Double beam shear test to measure ILSS of composites
- Property strongly dependent on sample quality (planarity, defects etc.)

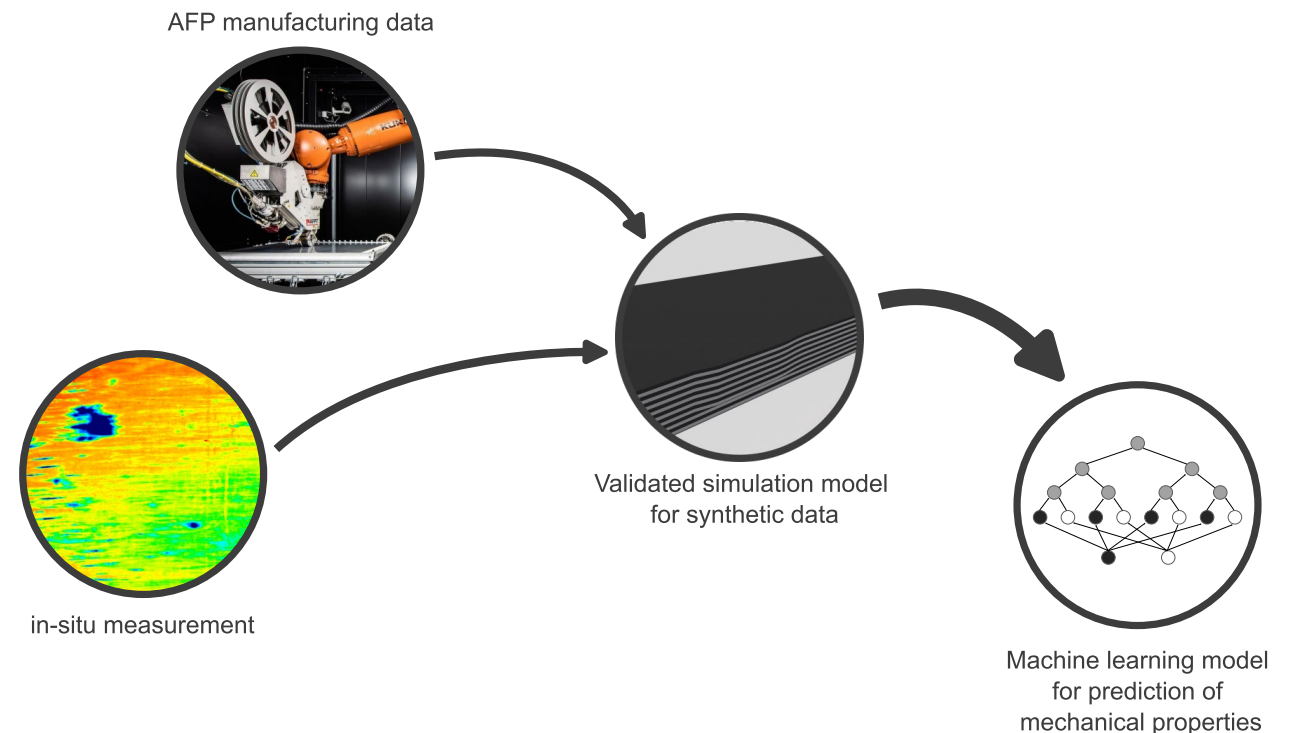


# Conclusion and outlooks

- Digital framework for storage and further use of manufacturing data in simulation
- Simulation approach for prediction of thermoplastic materials with manufacturing defects
- Partial validation under compression loading

## What is to come?

- Extensive experimental validation
- Training of machine learning model for live performance prediction



# Thank you for your attention!

## BT-SIN – department for structural integrity

### Ground-based transportation systems



**Tobias Behling**  
Research scientist



**Nicole Betz**  
Research scientist



**Sanghyun Yoo**  
Research scientist



**Mathieu Vinot**  
Team leading



**Nathalie Toso**  
Head of department

The authors wish to acknowledge the funding provided by the Helmholtz Metadata Cooperation within the research project MEMAS - Metadata Enriched Manufacturing data for Automated Simulation (grant number ZT-I-PF-3-055).

Vinot Mathieu  
Institute of Structures and Design, Stuttgart  
Department for Structural Integrity  
[mathieu.vinot@dlr.de](mailto:mathieu.vinot@dlr.de)

Topic: **High-fidelity modelling of composite specimens manufactured with the automated fibre placement technique**

Date: 2024-10-16

Author: Mathieu Vinot

Institute: Institute of Structures and Design

Image sources: