

# DIGITAL TWIN FOR COMPOSITE MATERIAL TESTING

**Bridging the gap between manufacturing and testing**

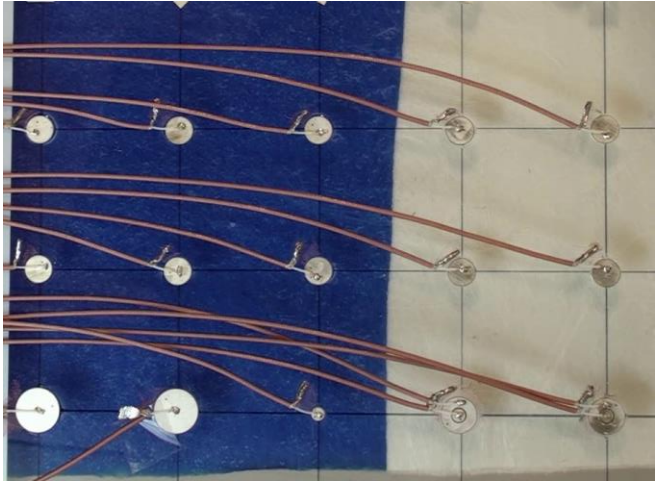
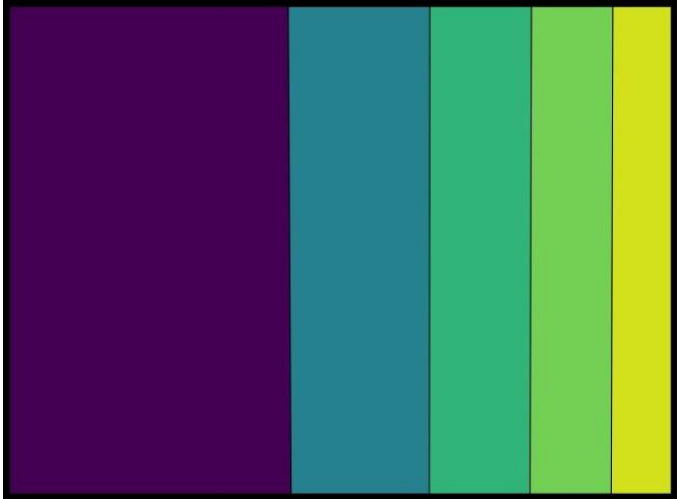
Nico Liebers, Dominic Bertling, Markus Kleineberg



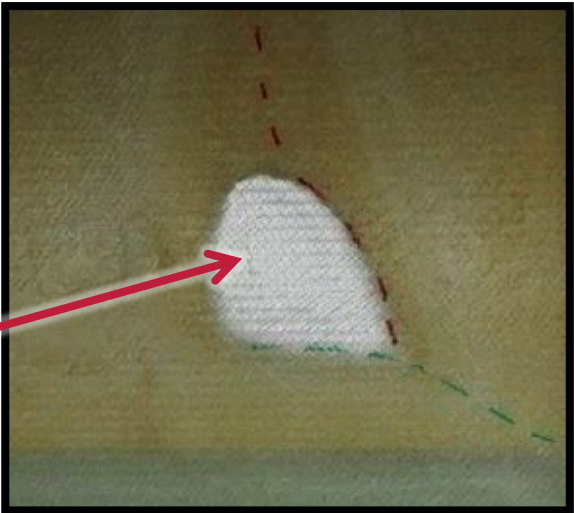
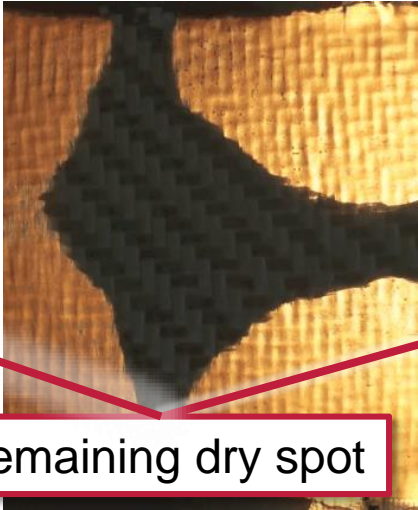
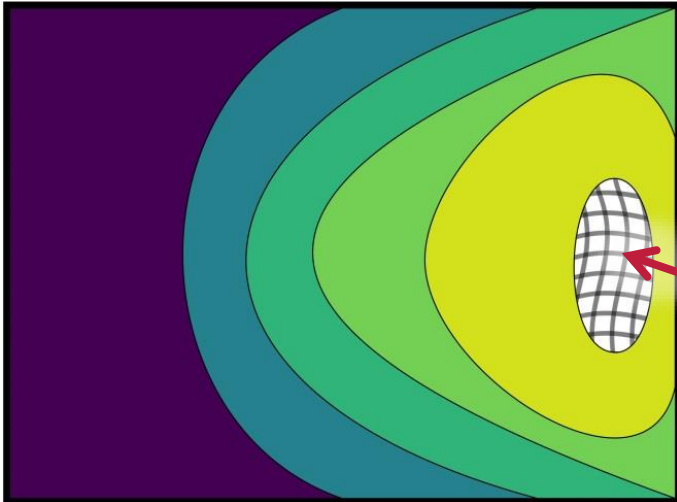
# Challenges in composite production



Ideal



Reality



Remaining dry spot

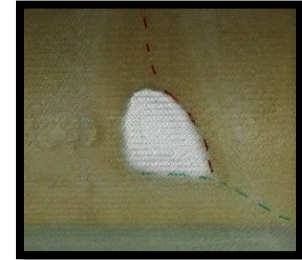
# Challenges in composite production

Raw materials have high variations

- Fibre fabrics (gaps, wrinkles, area weight etc.)
- Resin (age, humidity, mixture ratio, batch etc.)

Influence on process evolution

- Insufficient cure, different cure history over part
- Pores and dryspots due to racetracking etc.



Variations in property → Scattered test results

Conservative part design → Heavier structures

# Challenges in composite production

Raw materials have high variations

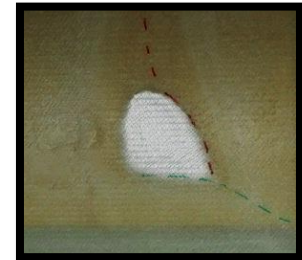
- Fibre fabrics (gaps, wrinkles, area weight etc.)
- Resin (age, humidity, mixture ratio, batch etc.)

Influence on production

- Insufficient cure, different curing times
- Pores and dryspots

Counter Measure: Digital twin of composite part  
→ Link variations to part production history  
→ Understand influence and reduce variations

Variations in

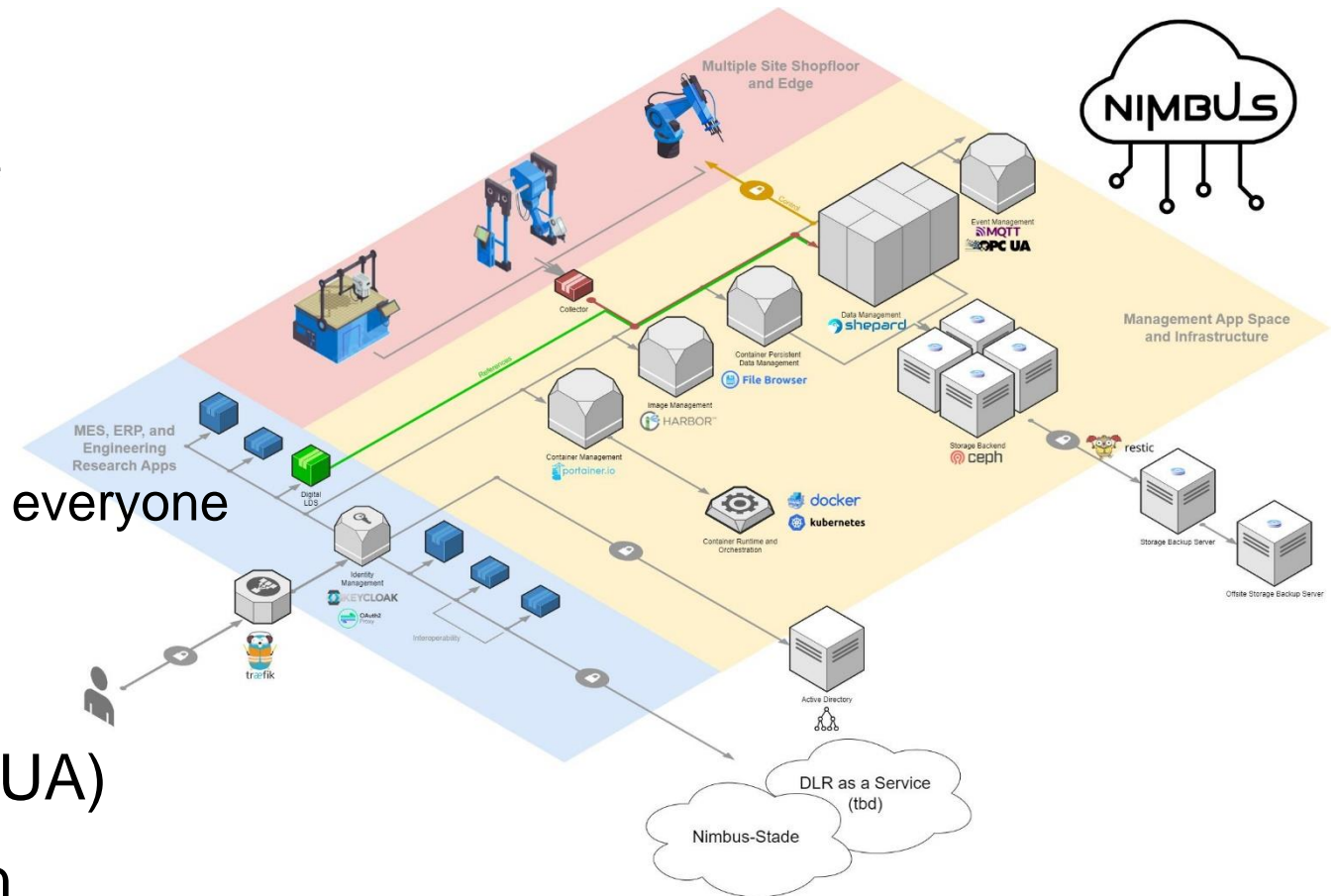


Conservative part design → Heavier structures

# Infrastructure: Server

## Server infrastructure:

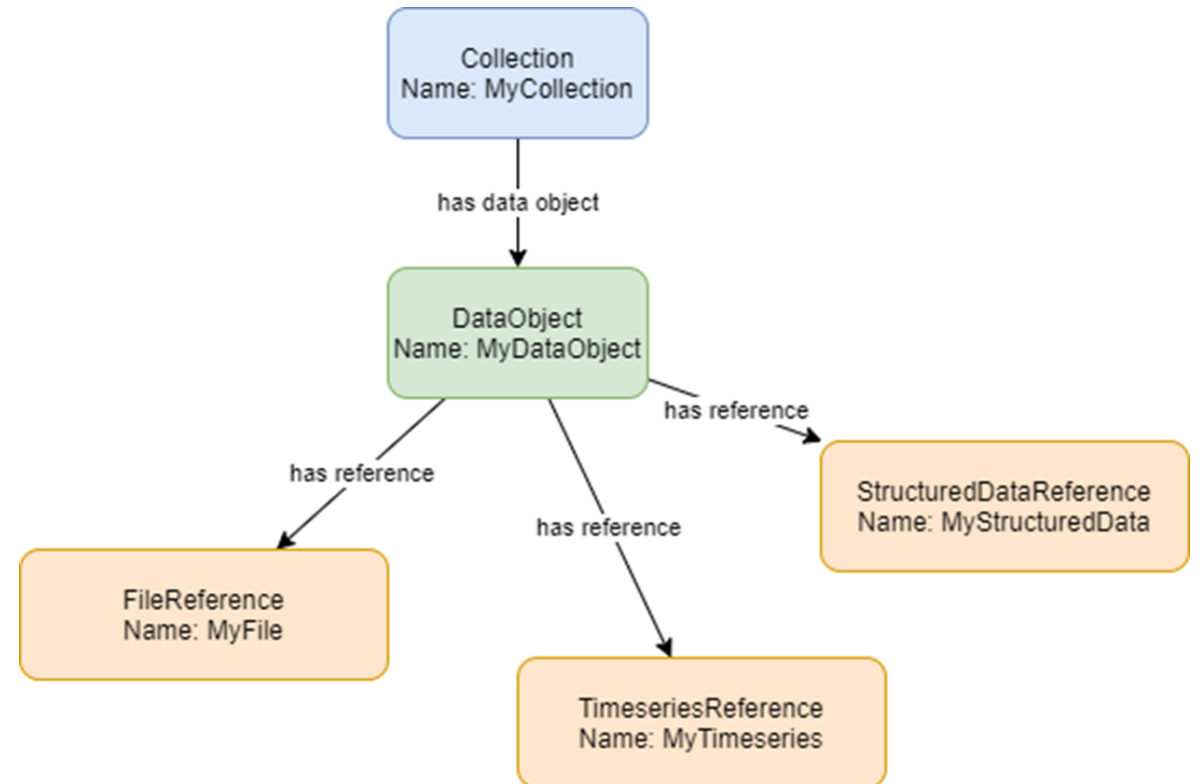
- „Demilitarized zone“ to integrate devices
- Deployment of services
  - Access by APIs / browser GUIs
  - Make expert systems available for everyone
  - If possible usage of FOSS
- Datastorage
- Message Brokers (MQTT, OPC UA)
- Authentication, SSL-Encryption



# Infrastructure: Digital Twin in Shepard



- DLR development (Institute of Structures and Design)
- Database management system
- Data storage + referencing data objects
- Production history data ↔ test data

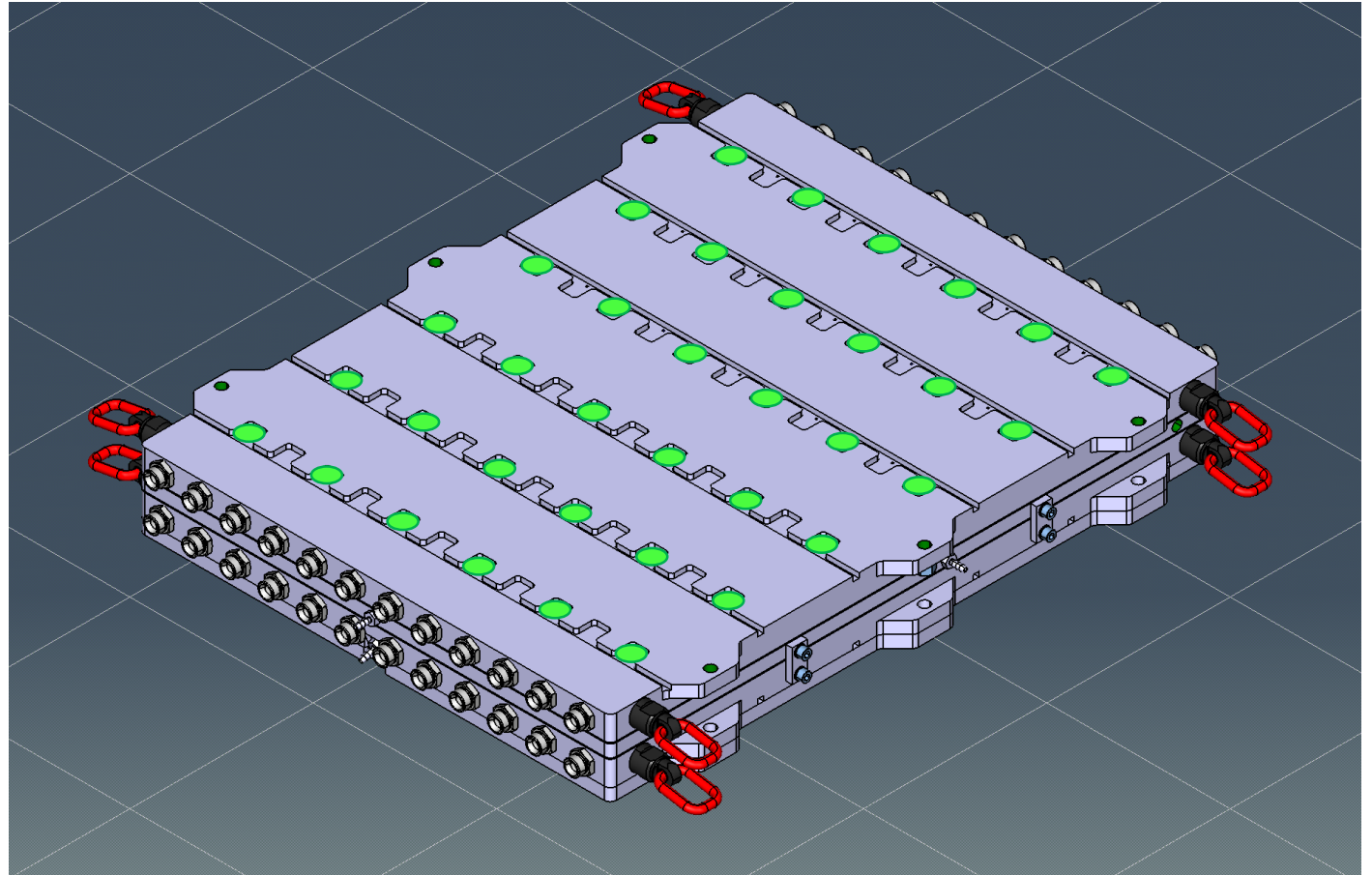


<https://gitlab.com/dlr-shepard/>

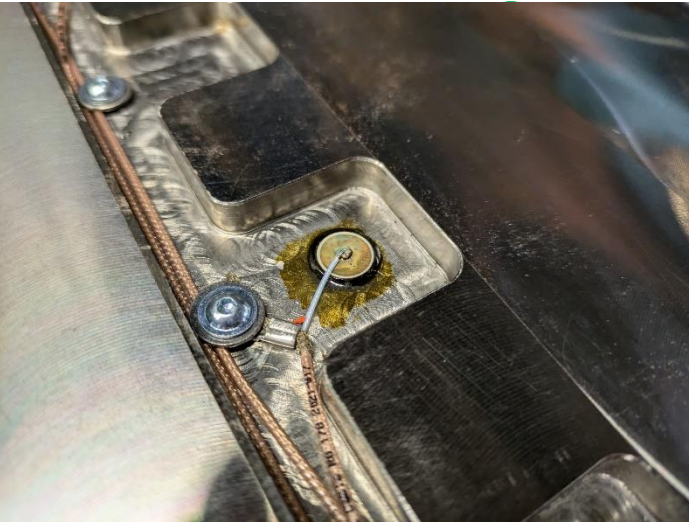
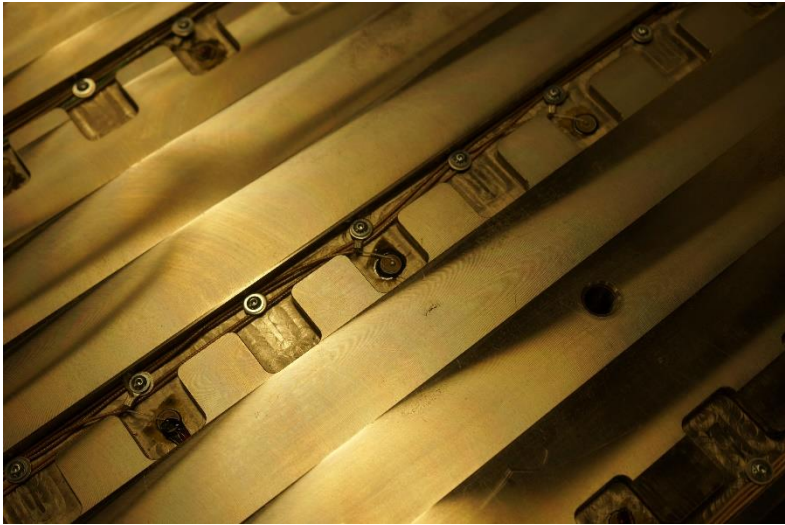
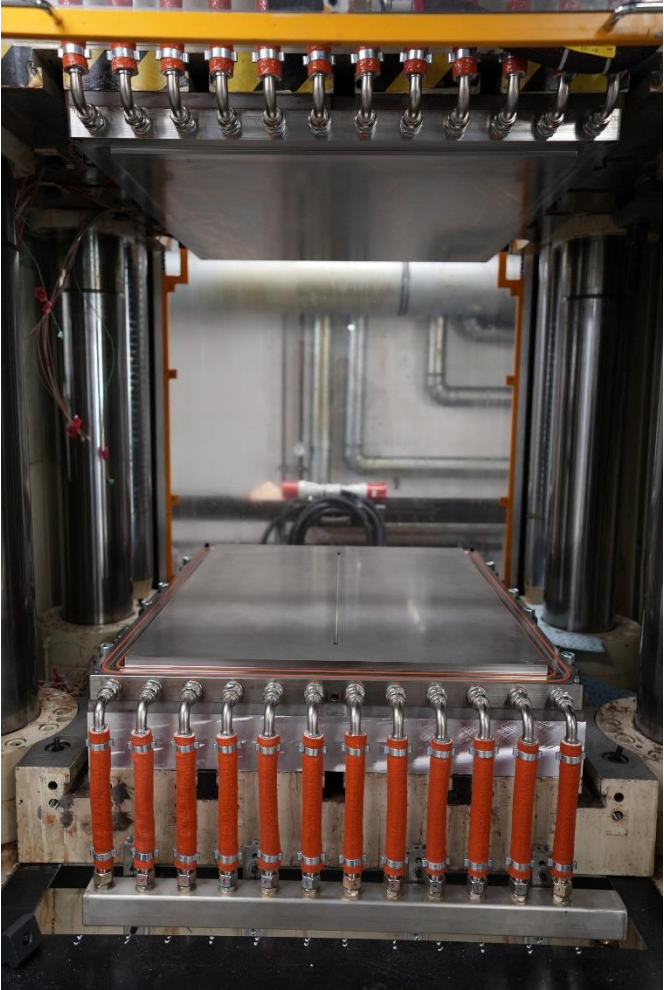
# Infrastructure: Sensor equipped mold for test panel production

## Factsheet

- Panel size 900 x 680 x 1/2/4 mm
- Water heated and cooled
- 72 ultrasonic sensors
- 8 thermocouples
- 1 pressure sensor

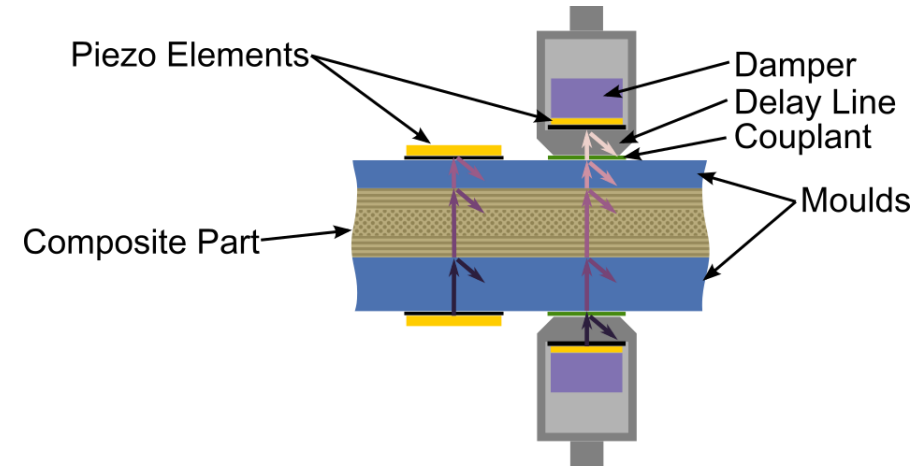


# Sensor equipped mold for test panel production

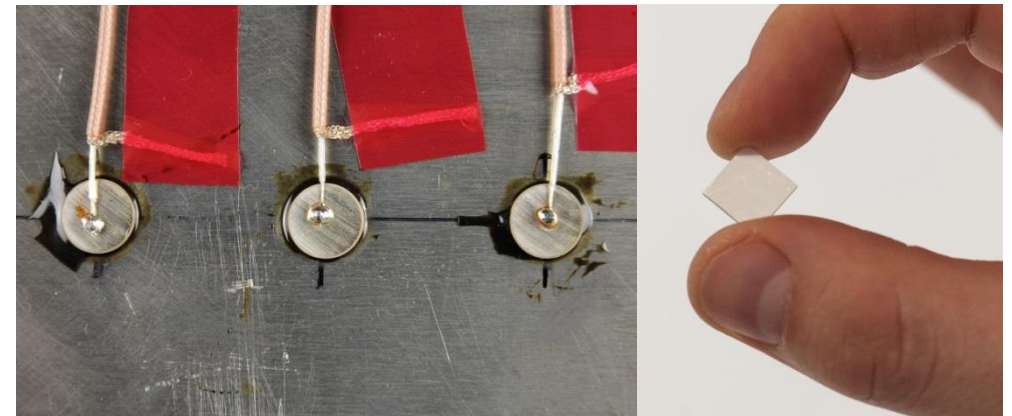


# Ultrasonic Sensors (Flowfront and Cure Monitoring)

- Ultrasonic Process Monitoring:
  - No direct contact to part required
  - Monitoring of almost all relevant parameters
- Adapted Sensors:
  - Bare piezoelectric elements mounted on mold
  - High reliability and measurement performance
- Compared to Conventional Transducers:
  - Amplitude  $\uparrow 40x$
  - Low cost (Price  $\downarrow 20x$ )



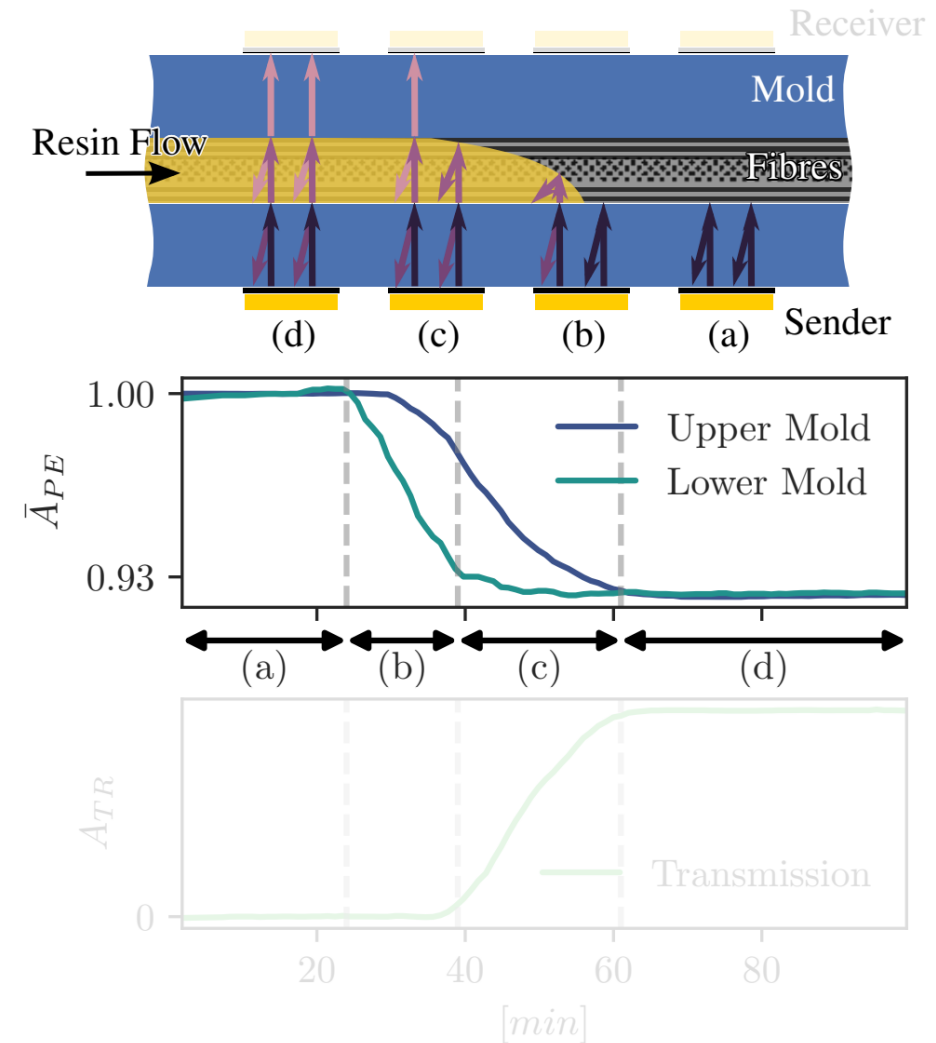
Conventional sensors versus tool mounted piezo elements



Low cost ultrasonic process monitoring sensors

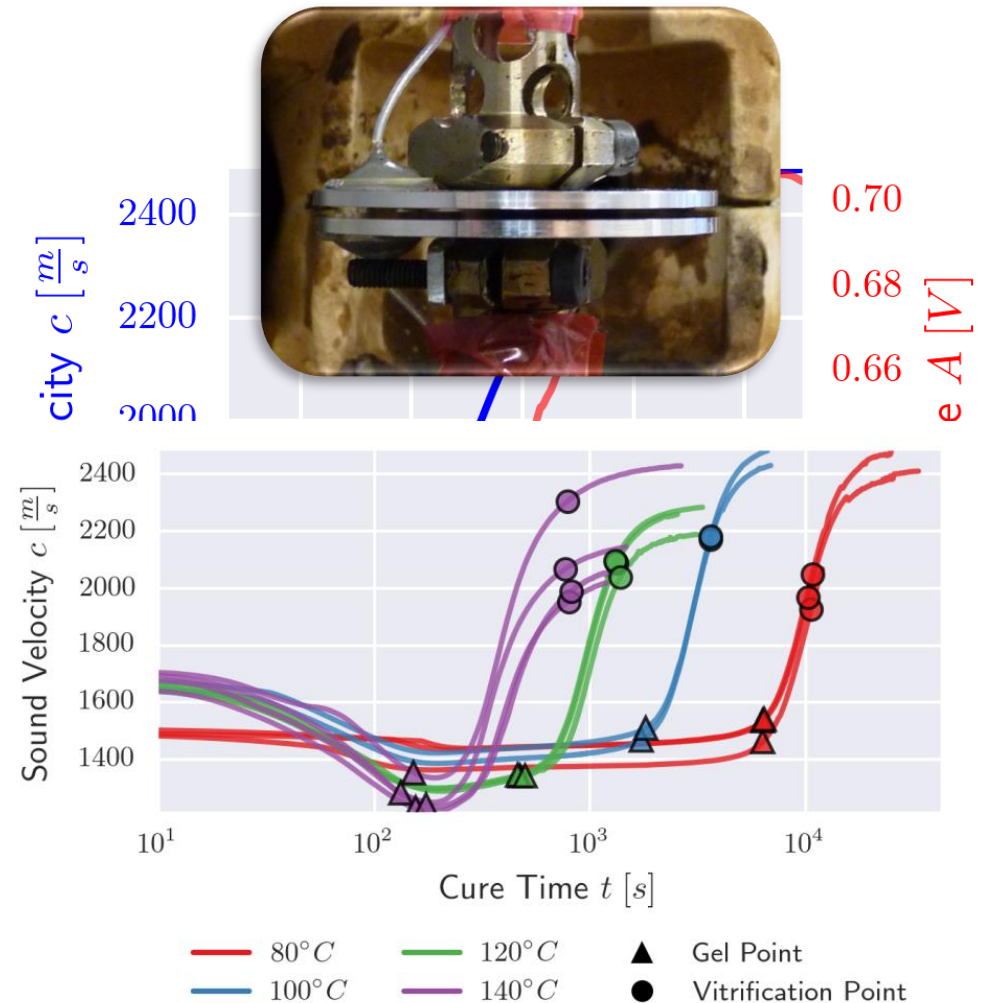
# Ultrasonic Sensors (Flowfront and Cure Monitoring)

- *Pulse-Echo:*
  - Before resin arrival → Total reflection at mould-cavity-interface
  - On resin arrival → Reflection amplitude drops until sensor cross section is completely wetted, then constant
- *Transmission:*
  - Sound can only be propagated through wetted preform
  - Amplitude increases upon resin arrival until crosssection completely filled over thickness



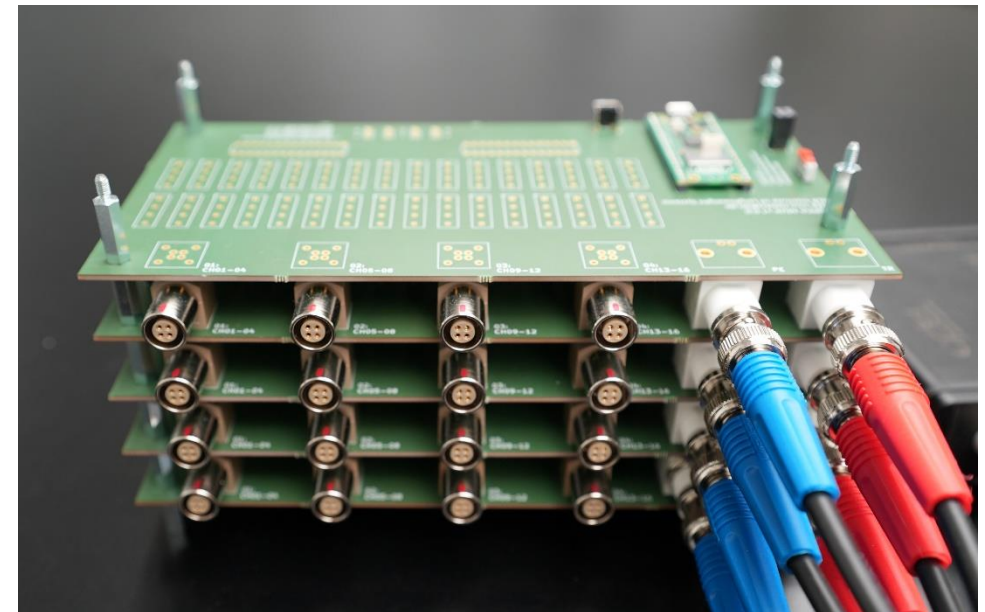
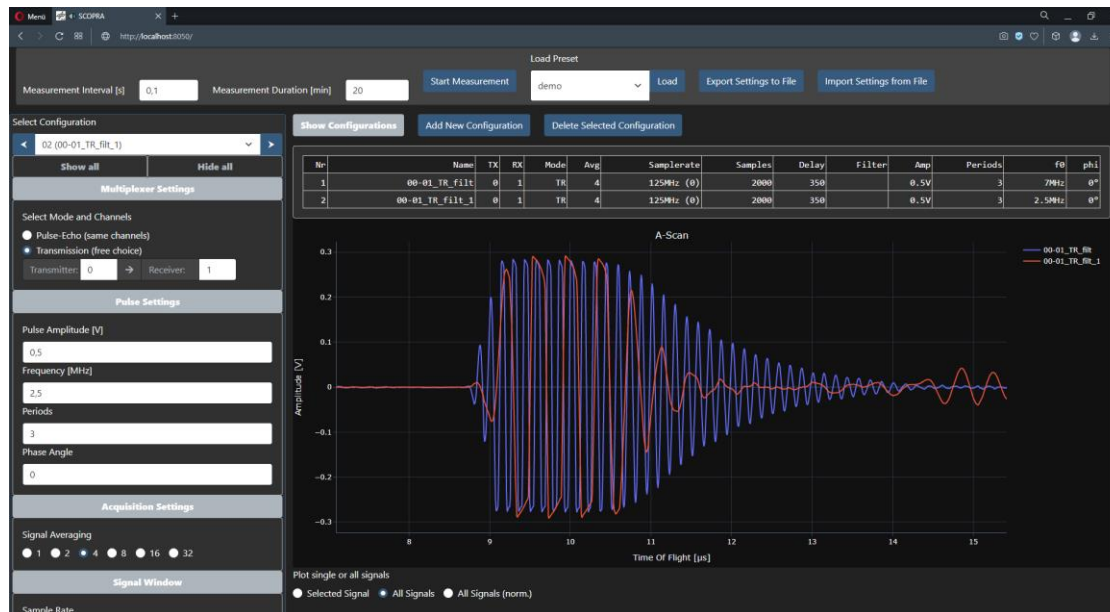
# Ultrasonic Sensors (Flowfront and Cure Monitoring)

- Sound velocity  $\uparrow$  Degree of Cure  $\uparrow$
- Sound velocity linked to mechanical properties (elastic modulus and density)
- Gellation and vitrification



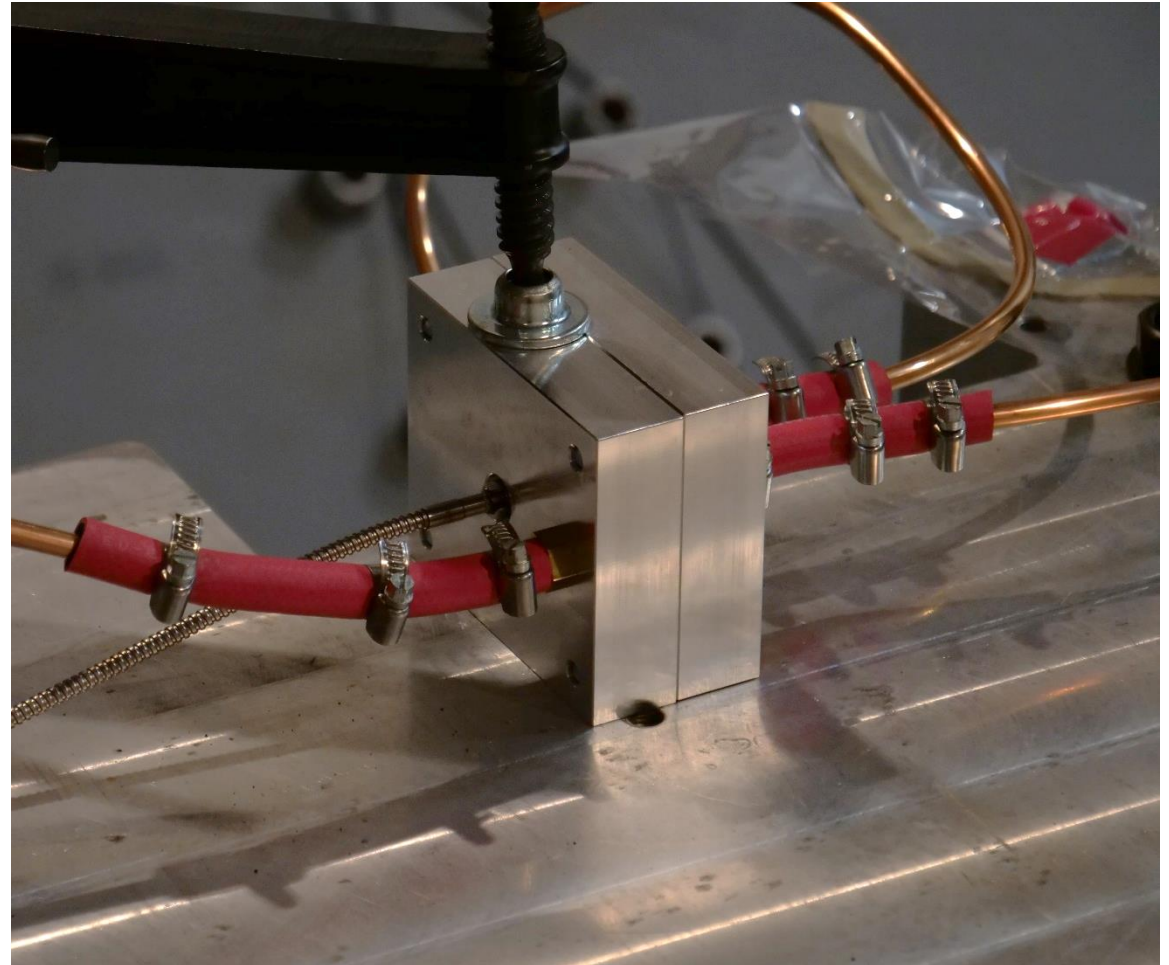
# Ultrasonic Sensors (Flowfront and Cure Monitoring)

- DLR development, software and part of hardware self developed  
→ enables data access and integration into digital twin



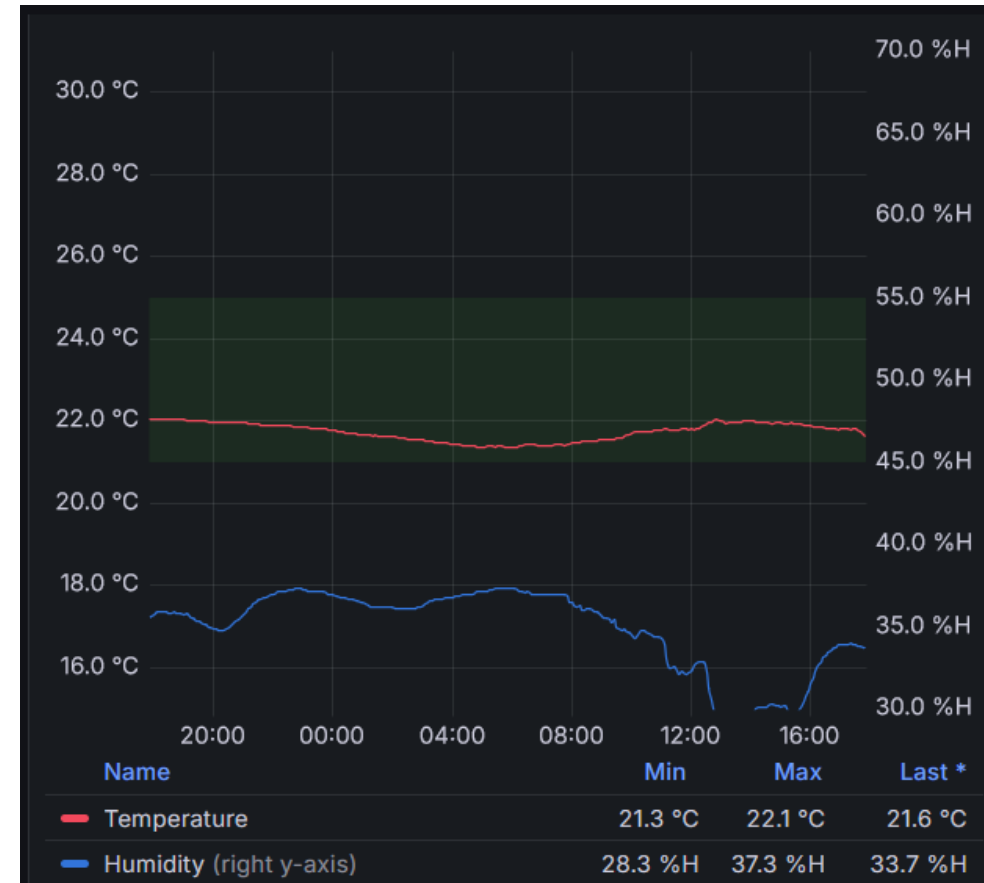
# Pressure sensors

- Pressure sensor in vacuum line
  - Measurement of resin pressure during rinsing
  - Fluctuations show gas bubbles → Frequency analysis
  - Indicator for possible porosity
  - Control of rinsing process



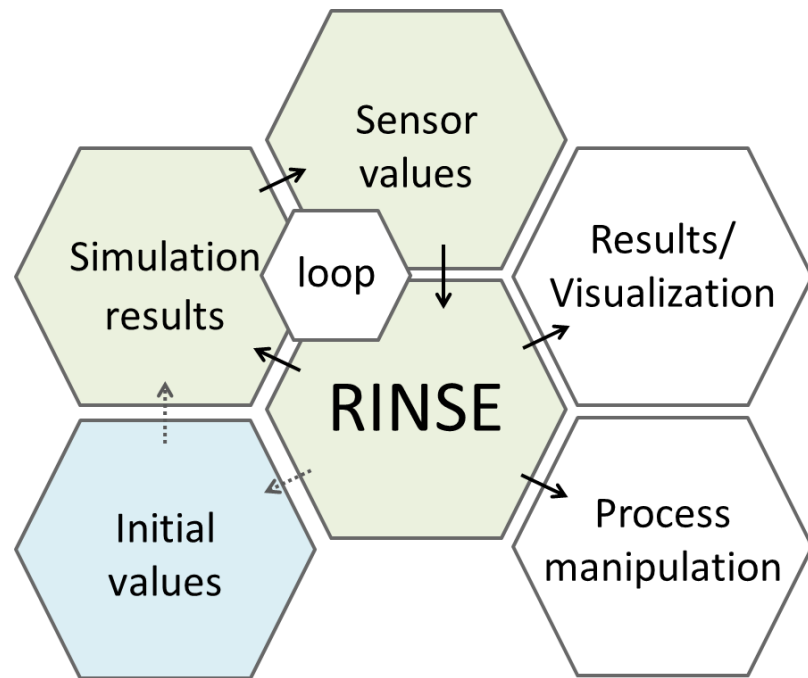
# Ambient condition sensors

- Self-Calibrating humidity and ambient temperature sensors
- Data send by MQTT, stored in Shepard, visualization in Grafana

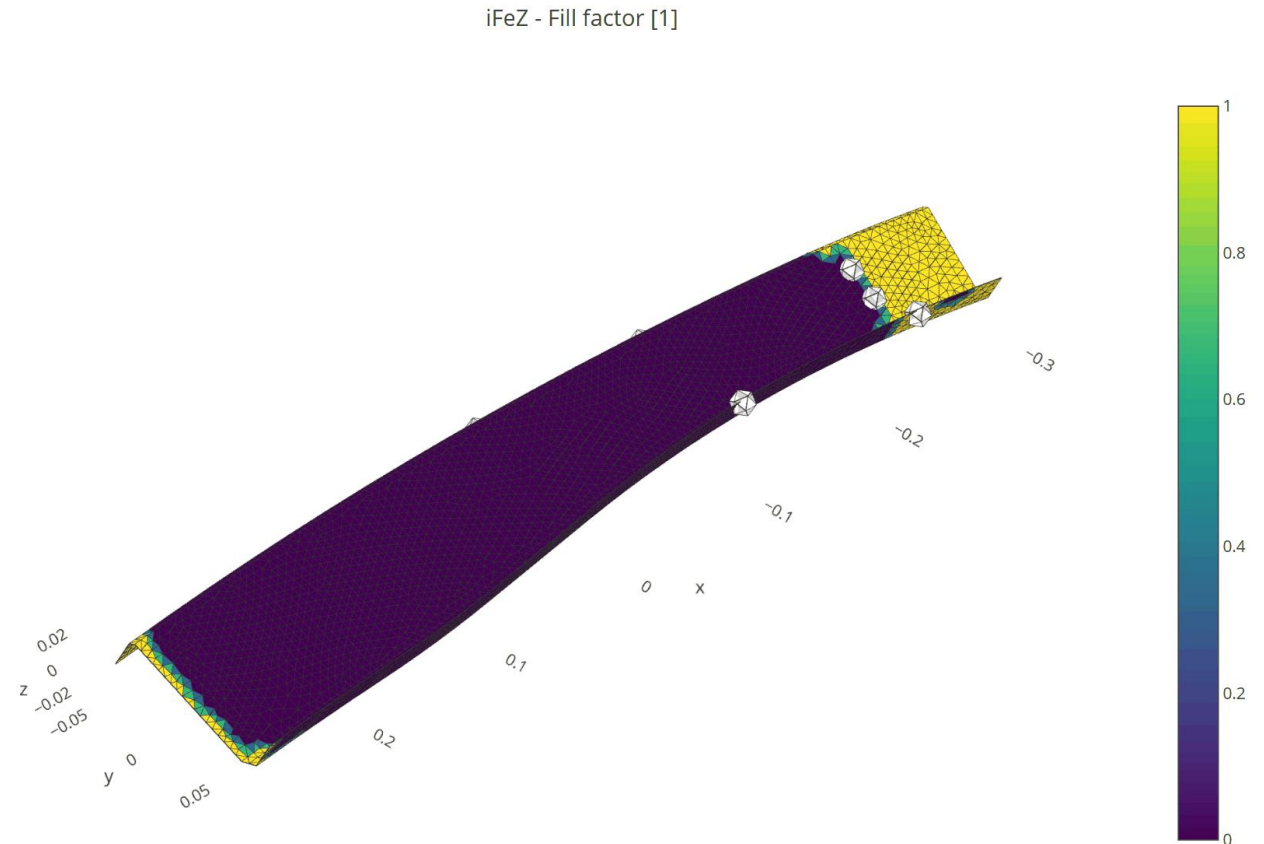


<https://shepard-grafana.nimbus.dlr.de>

# Flow simulation coupled with sensor data



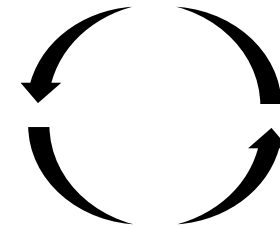
*RINSE*: „Resin Impregnation System“



Pointwise sensor data → 3D representation

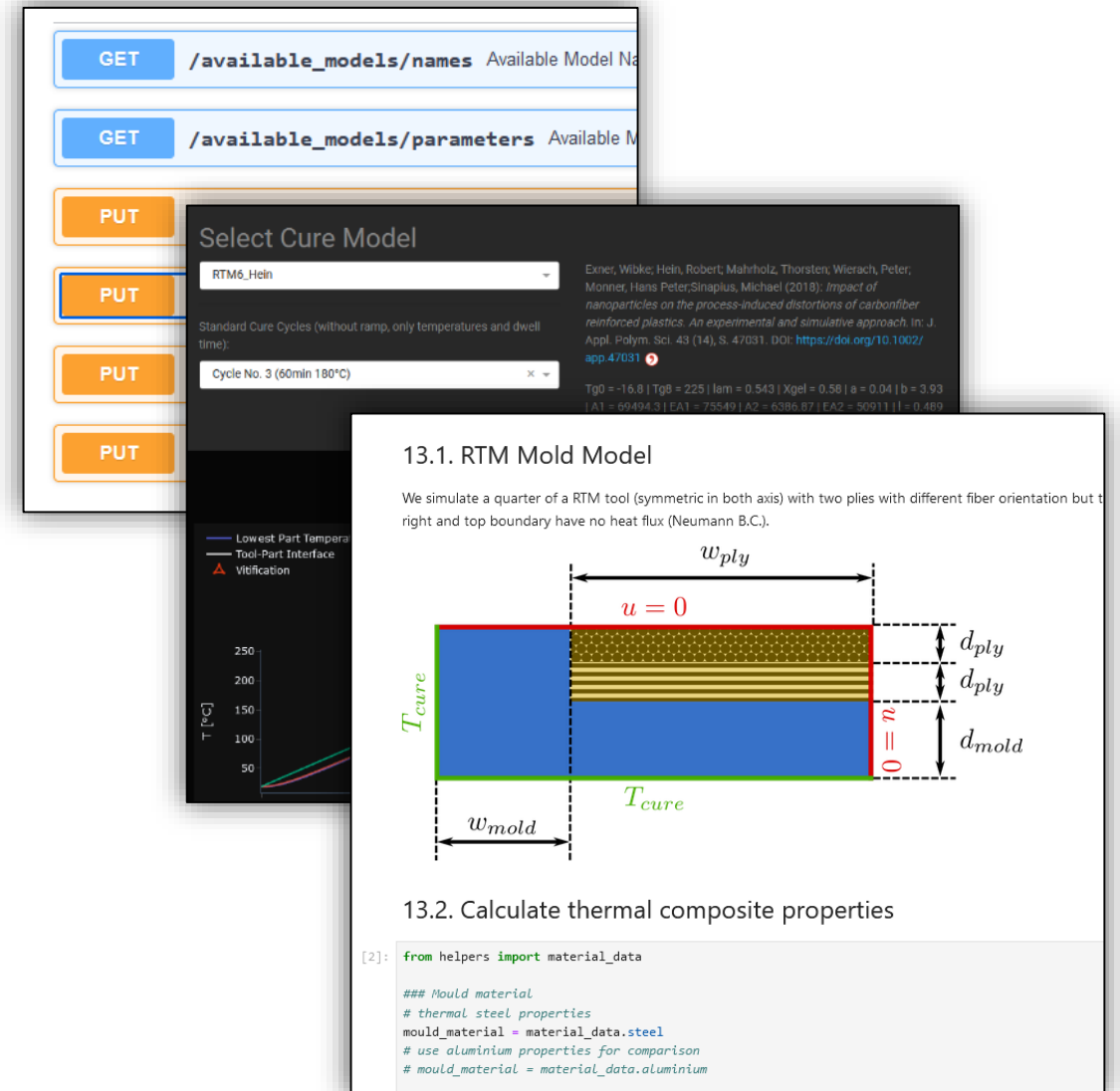
- Thermal and cure simulation in pure Python

$$\frac{dX}{dt} = k_1(1 - X)^l + k_2 X^m (1 - X)^n$$



$$\frac{\partial T}{\partial t} = \nabla (\alpha \nabla T) + s$$

- Thermal and cure simulation in pure Python
- API + Graphical User interface + Jupyter Notebooks
- Available as DLR-wide service
  - <https://curesim.fa-services.intra.dlr.de/>
- API offers online coupling of sensor data (temperature → degree of cure + transitions)



GET /available\_models/names Available Model Na

GET /available\_models/parameters Available M

PUT

PUT

PUT

PUT

Select Cure Model

RTM6\_Hein

Exner, Wibke, Hein, Robert; Mahrholz, Thorsten; Wierach, Peter; Monner, Hans Peter; Sinapius, Michael (2018): *Impact of nanoparticles on the process-induced distortions of carbonfiber reinforced plastics. An experimental and simulative approach.* In: J. Appl. Polym. Sci. 43 (14), S. 47031. DOI: <https://doi.org/10.1002/app.47031>

Standard Cure Cycles (without ramp, only temperatures and dwell time):

Cycle No. 3 (60min 180°C)

Tg0 = -16.8 | Tg8 = 225 | lam = 0.543 | Xgel = 0.58 | a = 0.04 | b = 3.93  
EA1 = 65494.3 | CA1 = 75549 | A2 = 6286.07 | EA2 = 50911 | l1 = 0.489

— Lowest Part Temperature  
— Tool-Part Interface  
▲ Vitrification

250  
200  
150  
100  
50

$T_{cure}$

$w_{mold}$

$w_{ply}$

$u = 0$

$d_{ply}$

$d_{ply}$

$d_{mold}$

$0 = n$

$T_{cure}$

13.1. RTM Mold Model

We simulate a quarter of a RTM tool (symmetric in both axis) with two plies with different fiber orientation but the right and top boundary have no heat flux (Neumann B.C.).

13.2. Calculate thermal composite properties

```
[2]: from helpers import material_data

### Mould material
# thermal steel properties
mould_material = material_data.steel
# use aluminium properties for comparison
# mould_material = material_data.aluminium
```

# Summary



- Digital twin infrastructure
  - Server with Software as a Service, Message broker
  - Shepard database management system
- Test panel tool equipped with sensors
- Simulations linked with sensor data
- Data stored and referenced in Shepard → Digital twin
  
- Analyse for test result variations
- Collect data for future AI application

Thank you for your attention!  
Questions?



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