DIGITAL TWIN FOR COMPOSITE MATERIAL TESTING

Bridging the gap between manufacturing and testing

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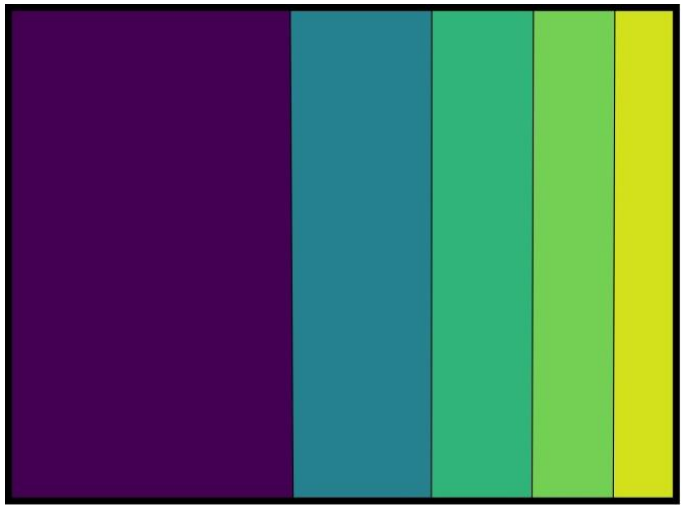
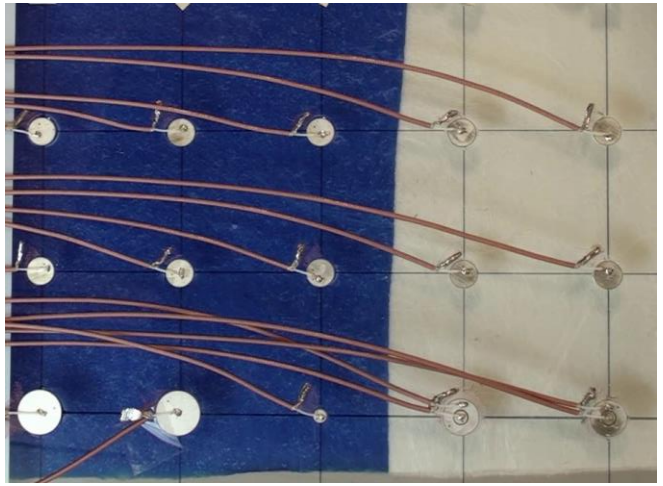
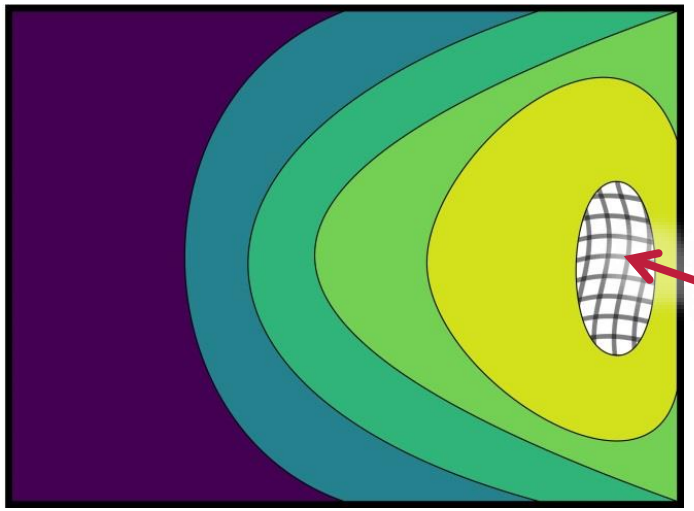
Challenges in composite production

Ideal

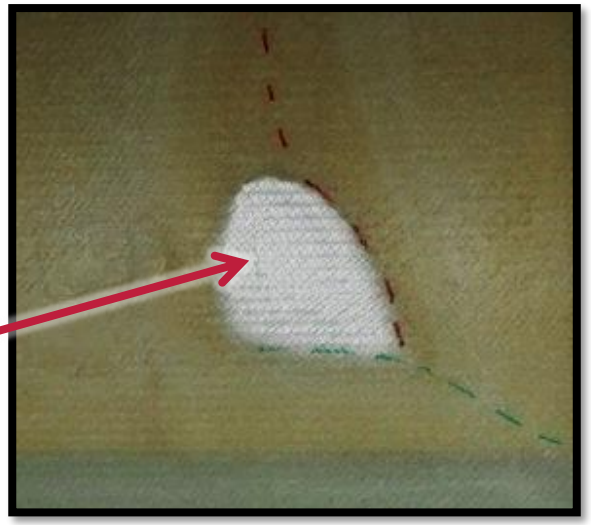




Reality



Remaining dry spot



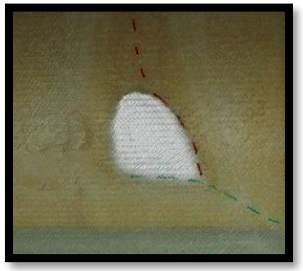
Challenges in composite production

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

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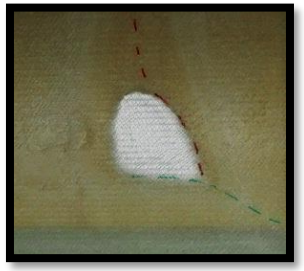
Influence on proc

- Insufficient cure, dif
- Pores and dryspots

Variations ir

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

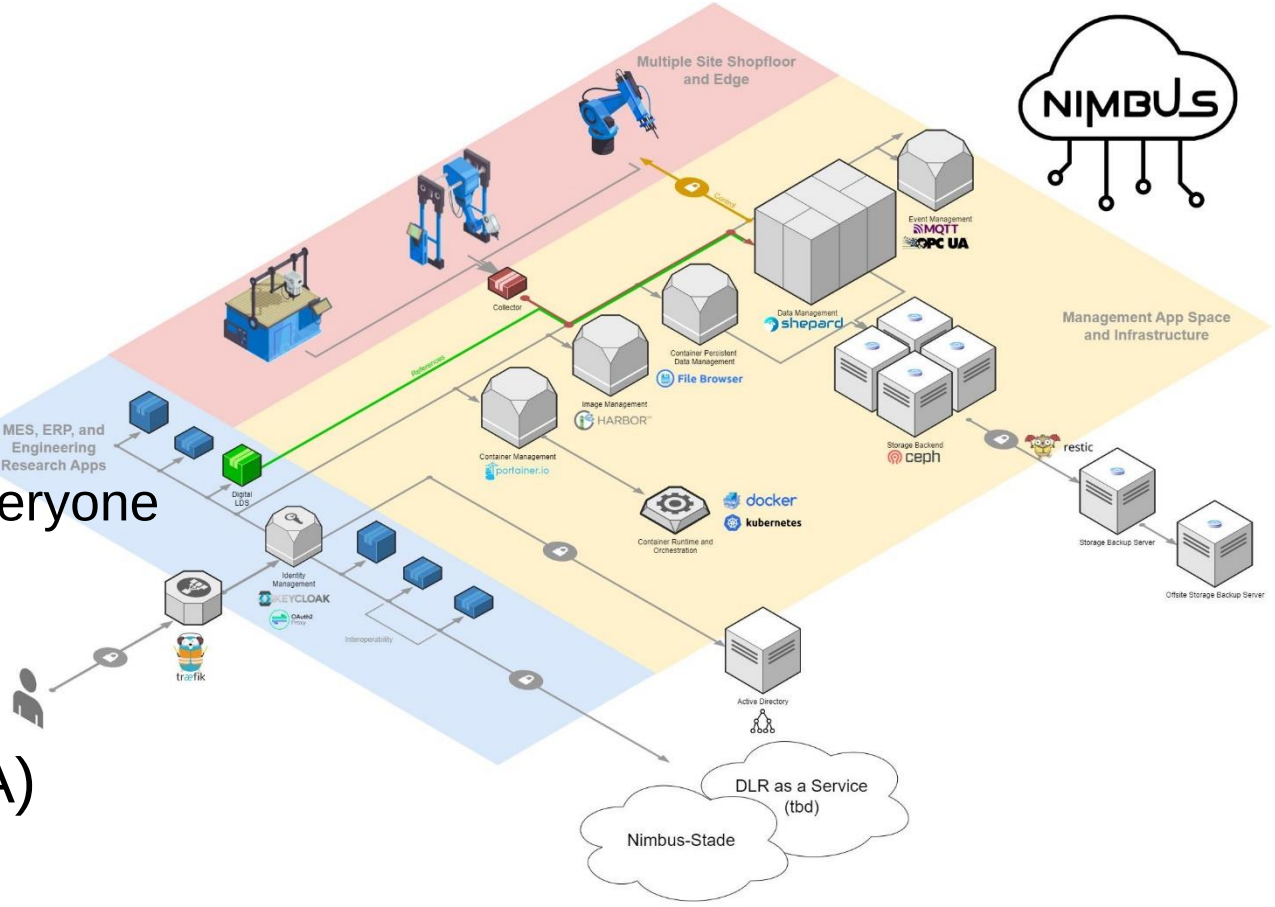


Conservative part design → Heavier structures

Infrastructure: Server

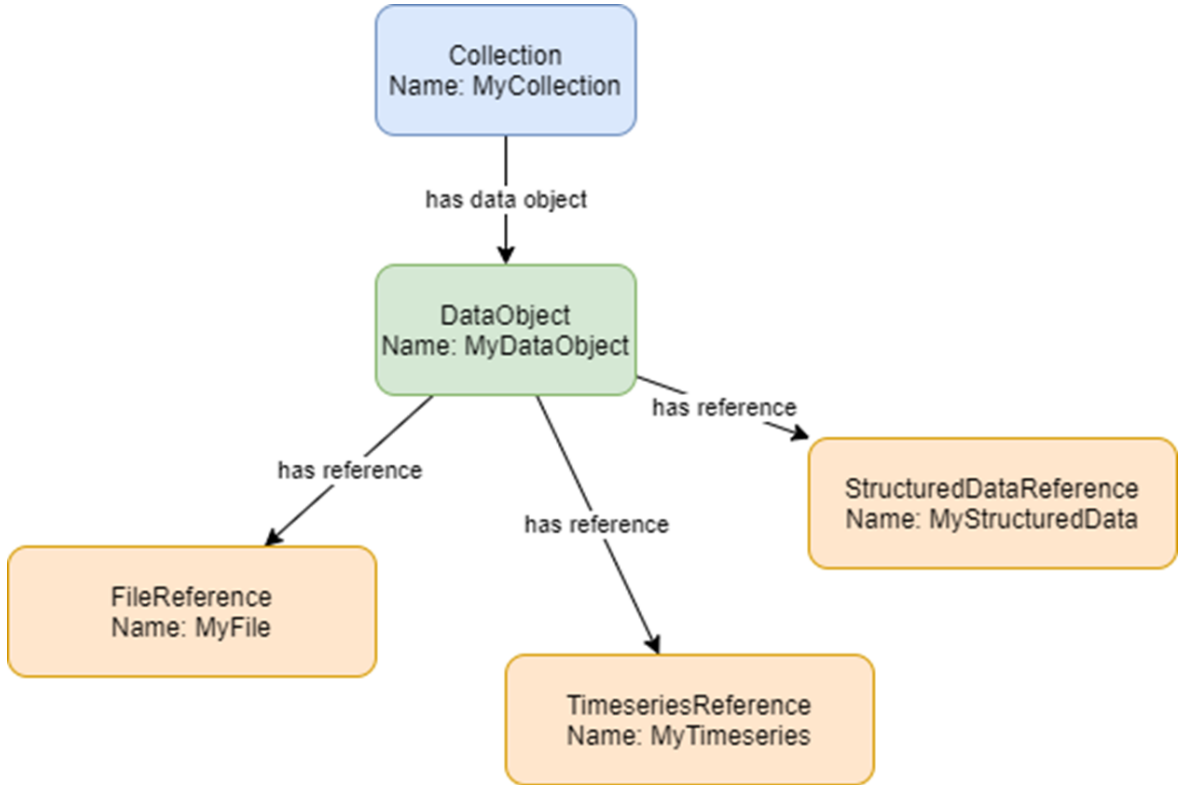
Server infrastructure:

- „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)
- Authentification, 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



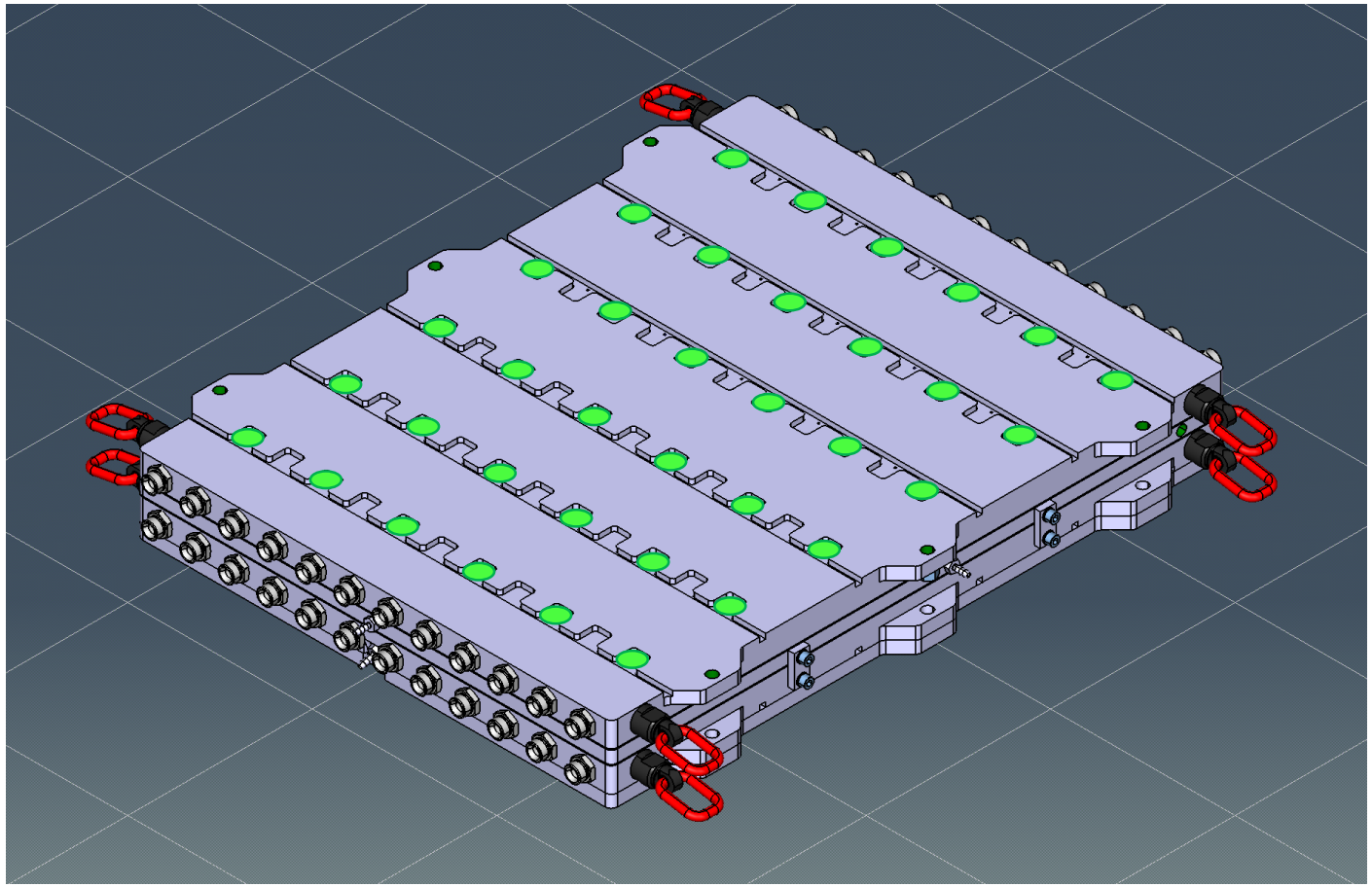
shepard

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

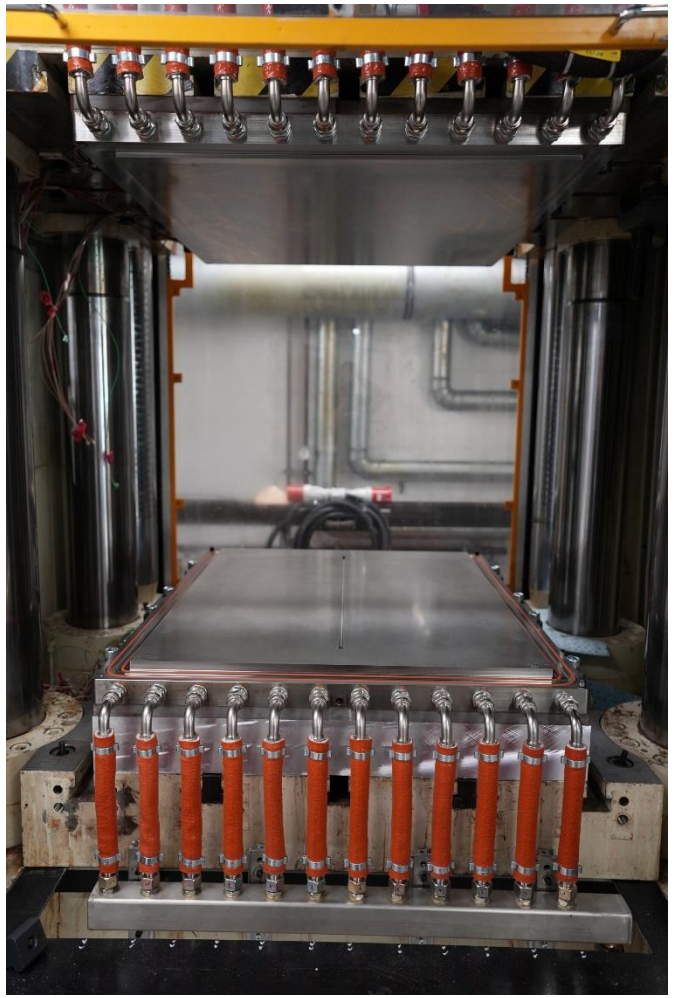
Infrastructure:
Sensor equipped mold for test panel production

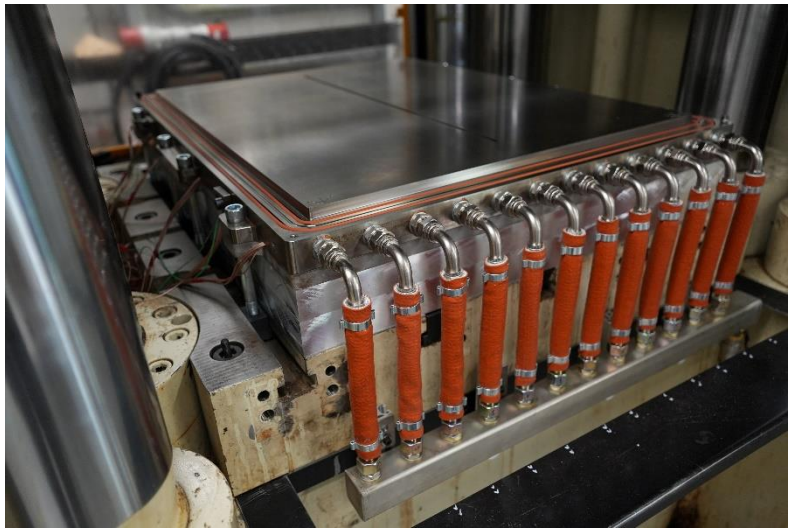
Factsheet

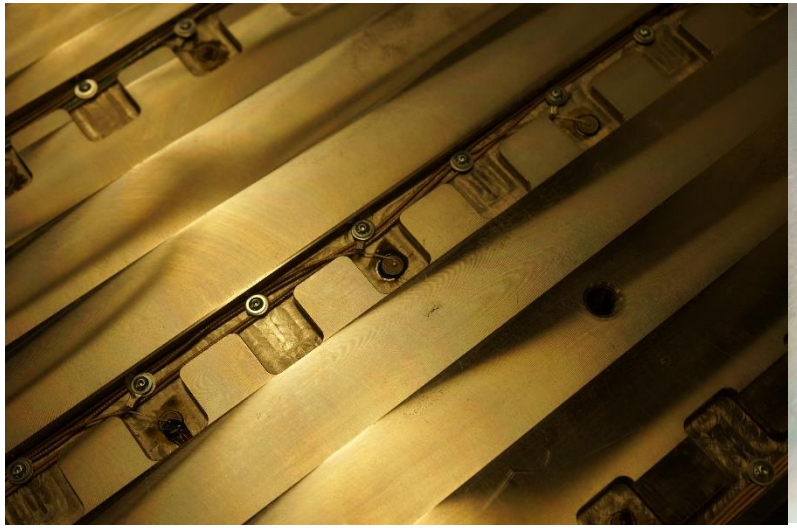
- Panel size 900 x 680 x 1/2/4 mm
- Water heated and cooled
- 72 ultrasonic sensors
- 8 thermocouples
- 1 pressure sensor

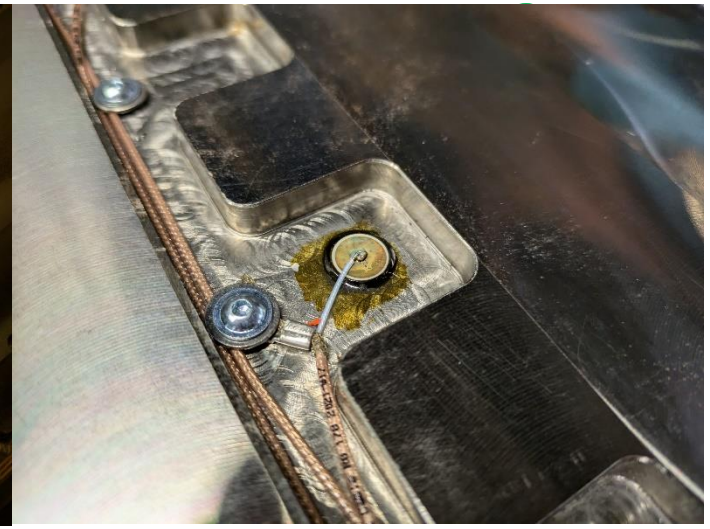


Sensor equipped mold for test panel production



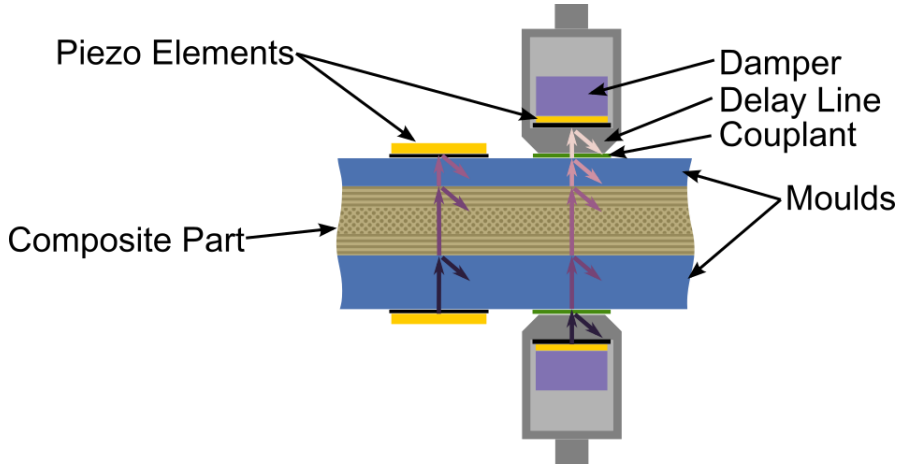




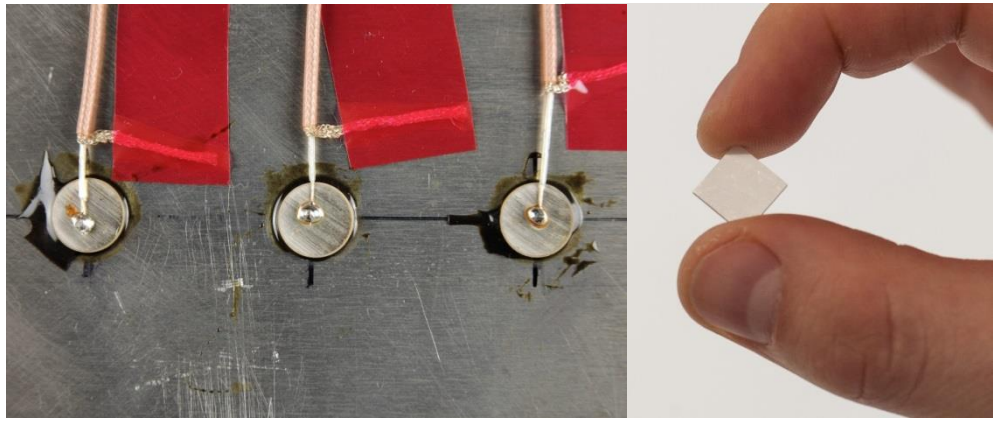


Ultrasonic Sensors (Flowfront and Cure Monitoring)

- 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 ↑40x
  - Low cost (Price ↓20x)



Conventional sensors versus tool mounted piezo elements

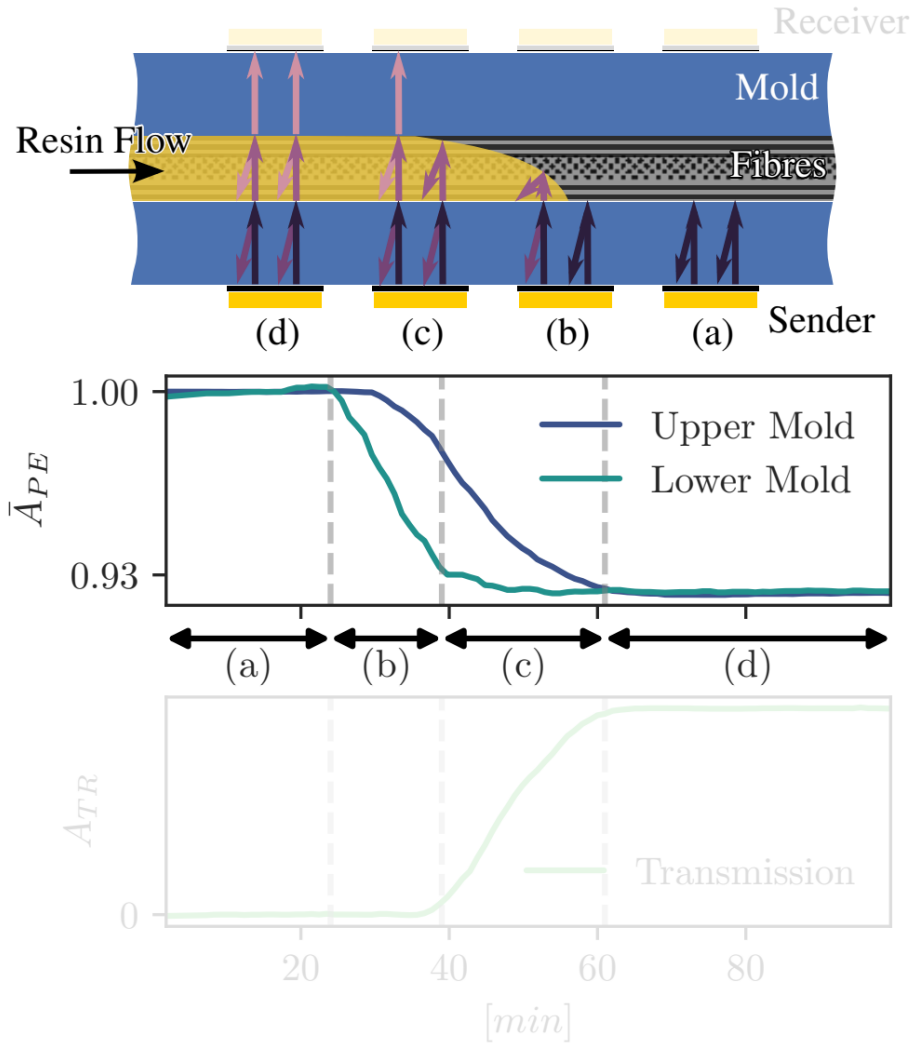


Low cost ultrasonic process monitoring sensors

Ultrasonic Sensors (Flowfront and Cure Monitoring)

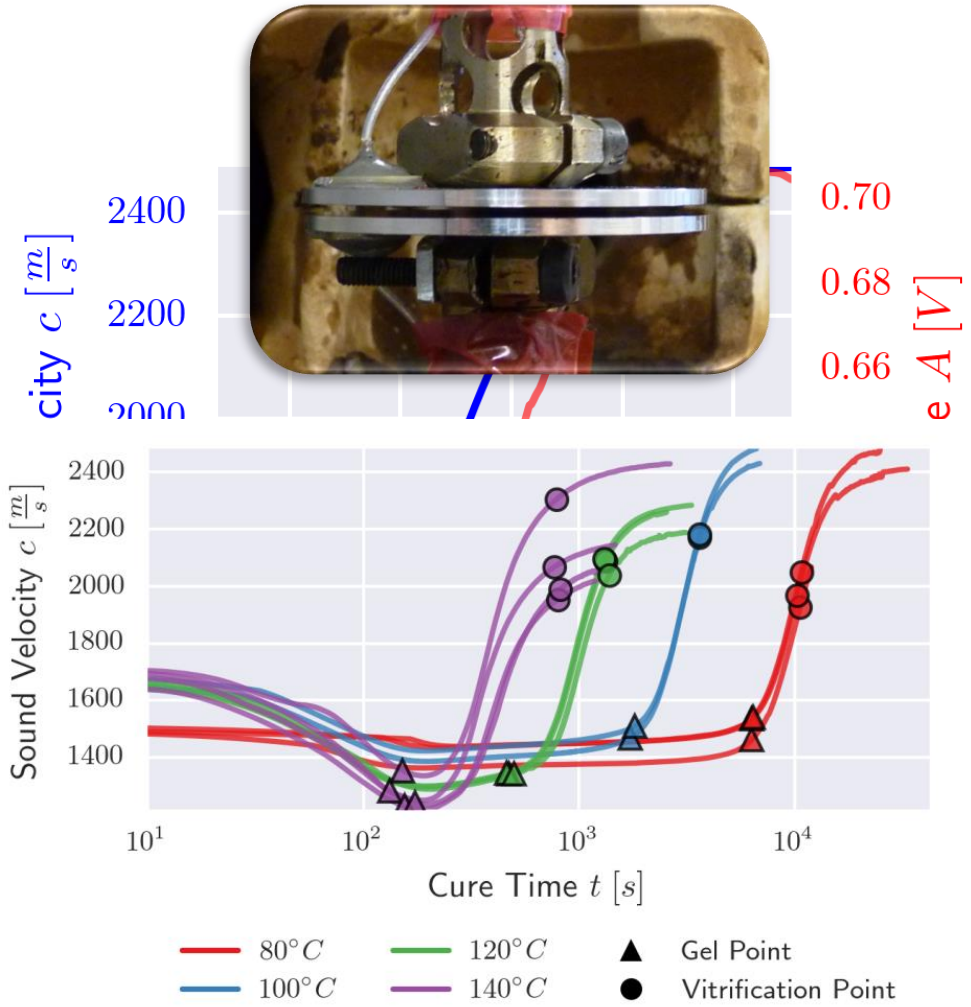
- *Pulse-Echo:*
  - Before resin arrival →Total reflection at mould-cavity-interface
  - On resin arrival → Reflection amplitude drops until sensor cross section is completely wetted, then constant

- *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)

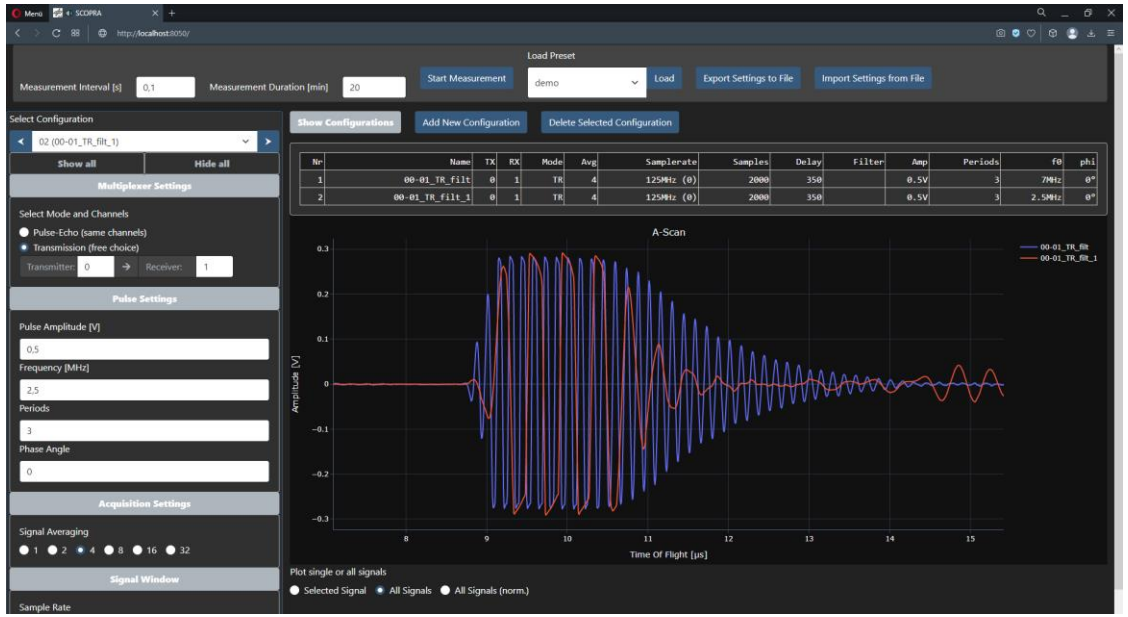
- Sound velocity ↑ Degree of Cure ↑
- Sound velocity linked to mechanical properties (elastic modulus and density)
- Gellation and vitrification

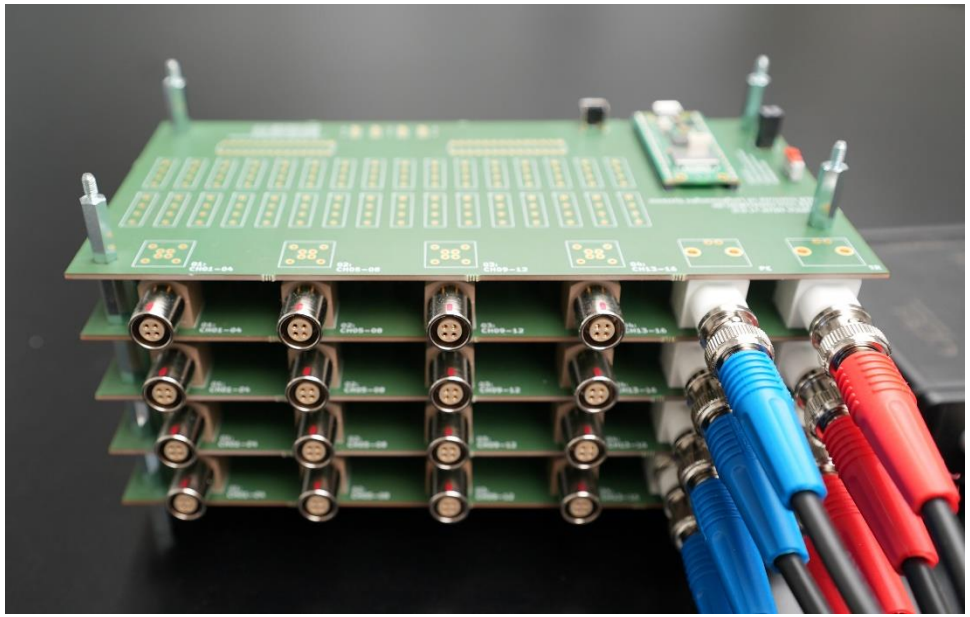


Ultrasonic Sensors (Flowfront and Cure Monitoring)

- DLR development, software and part of hardware self developped

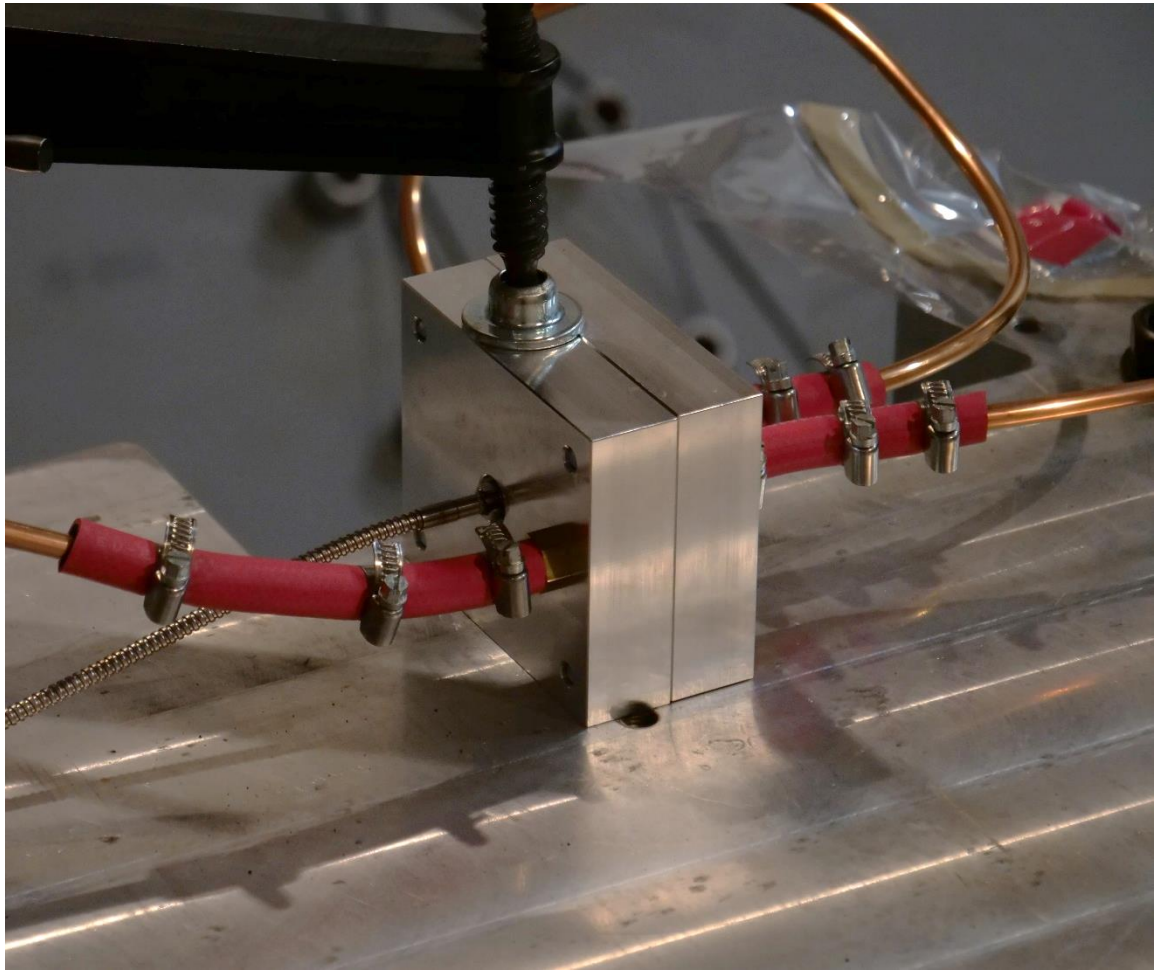
→ enables data access and integration into digital twin





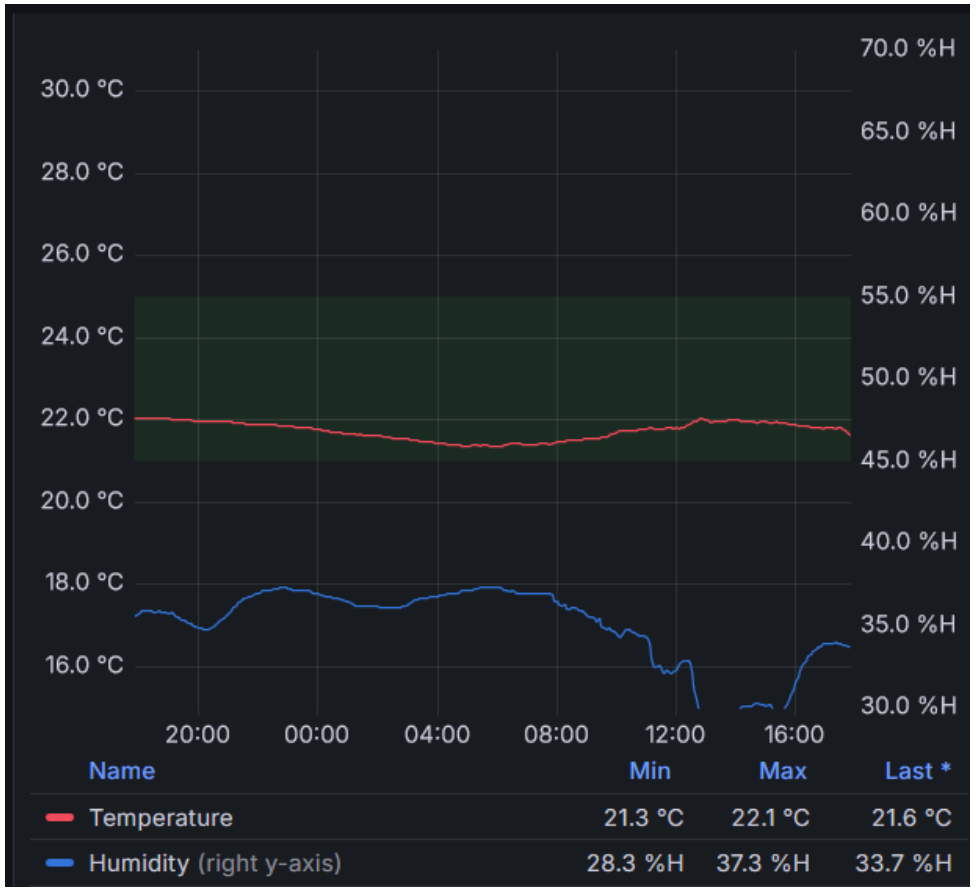
Pressure sensors

- 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



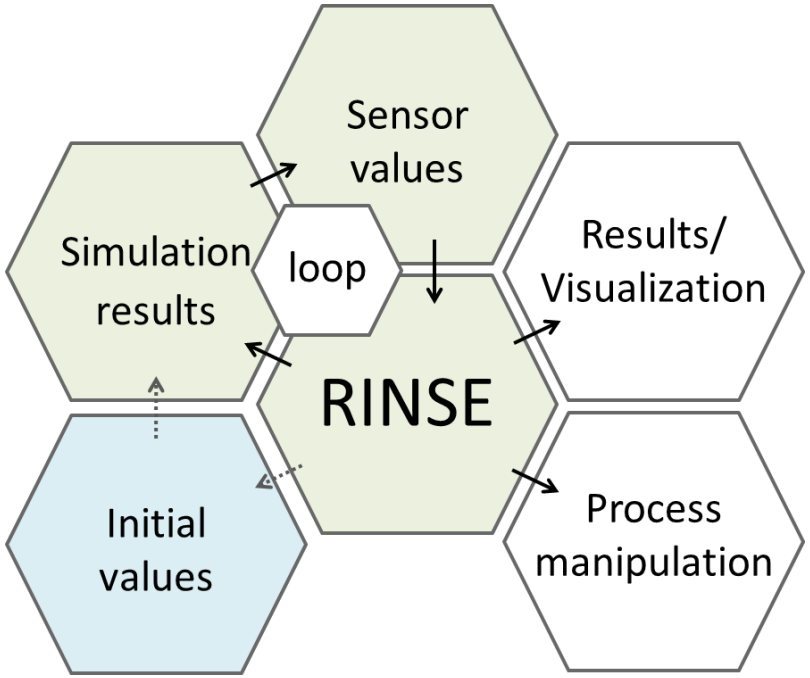
Ambient condition sensors

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

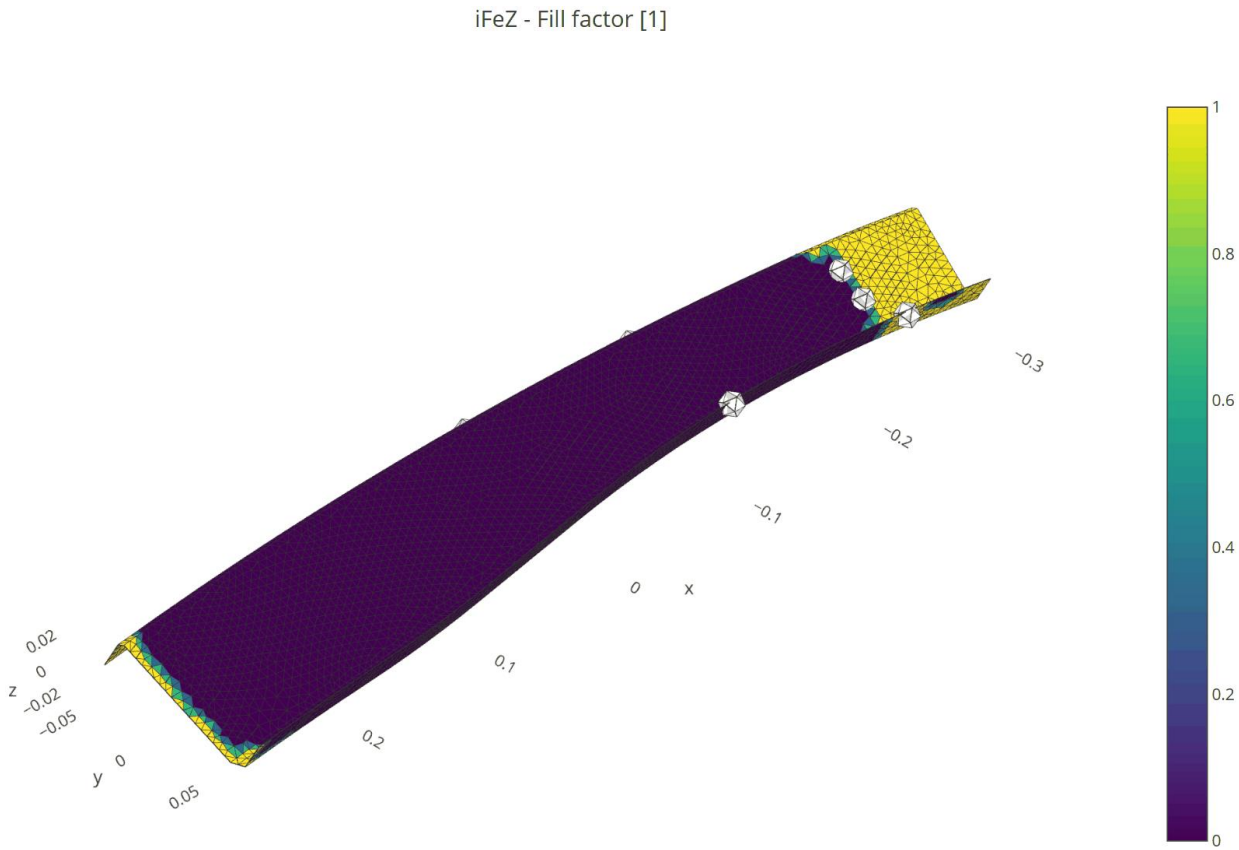


https://shepard-grafana.nimbus.dlr.de

Flow simulation coupled with sensor data



RINSE: „**R**esin **I**mpreg**n**ation **S**yst**e**m“

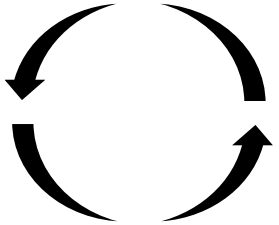


Pointwise sensor data → 3D representation

CureSim

- Thermal and cure simulation in pure Python

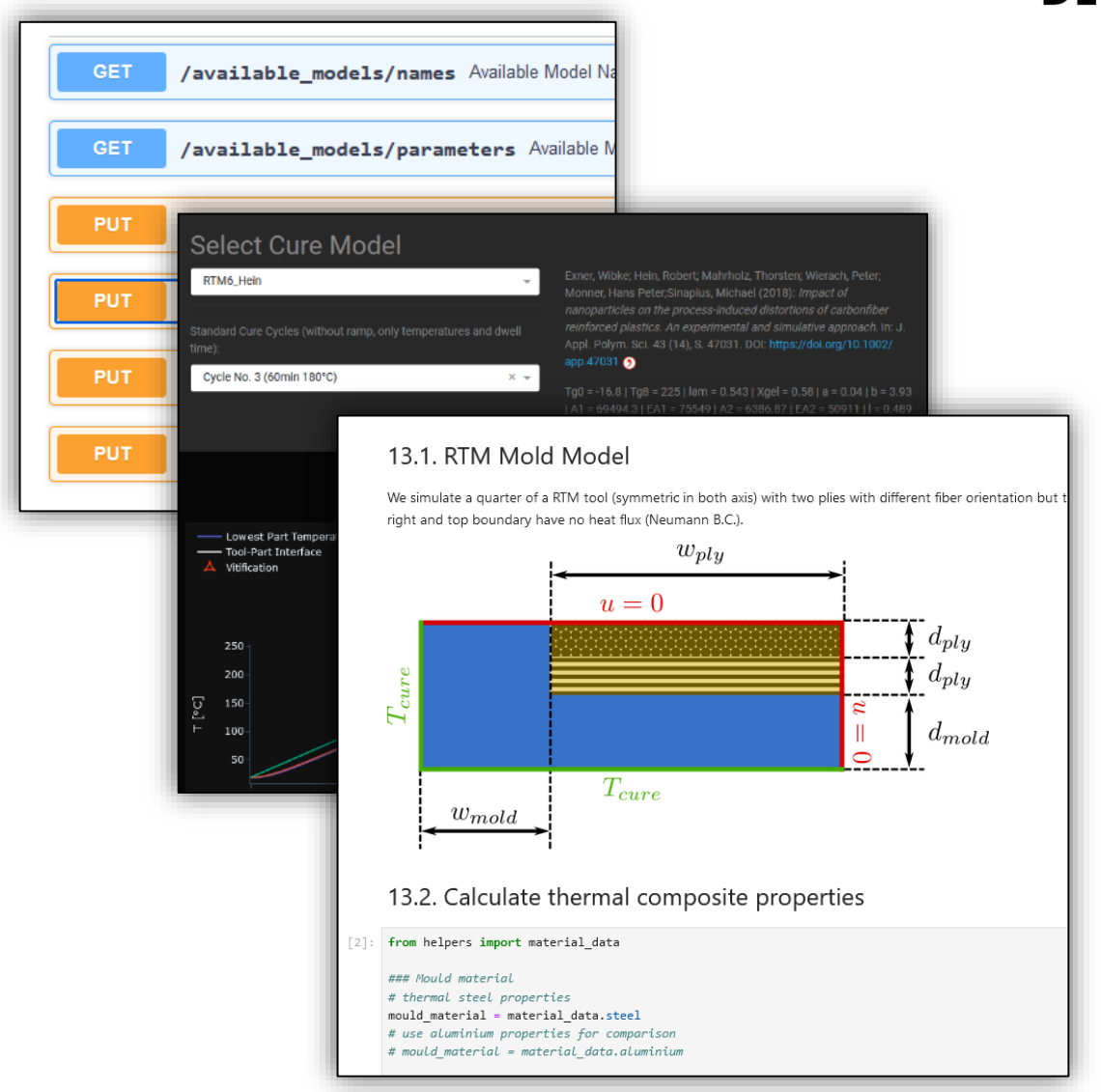
$$\frac{\mathrm{d}X}{\mathrm{d}t} = k_1(1-X)^l + k_2 X^m (1-X)^n$$



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

CureSim

- 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)



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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