Leapfrog innovation for a composite upper stage: opportunities of thermoplastic CFRPs

5th Colloquium on Production Technology

DLR

Workshare DLR BT / WF

ArianeGroup

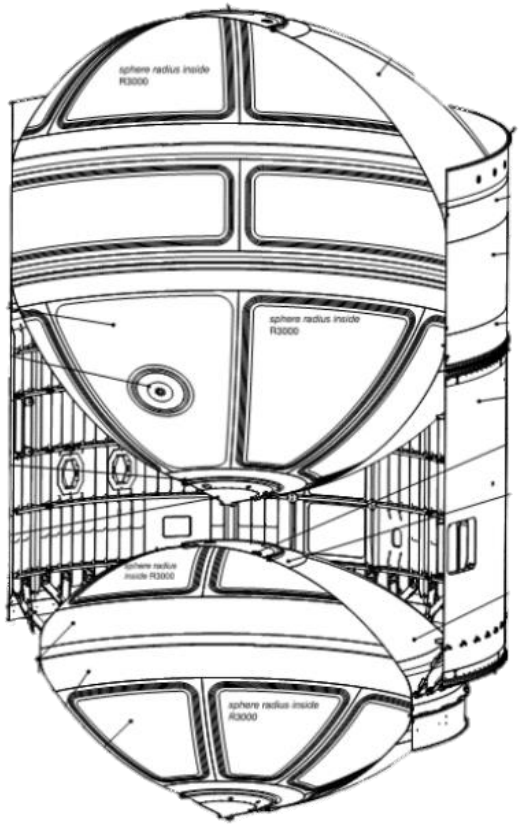
- Launcher System Study
- Upper Stage System Study
- Upper Stage Technologies
- Pre development LOX tank

MT Aerospace

- Pre development LH2 tank
- Material screening CF-Thermoset
- Inter tank structure
- Sandwich Common Bulkhead

DLR BT / WF

- Material screening CF-Thermoplastics for LH2 tank
- Process development in-situ TPC AFP



Source: AGG / Merino [2017]

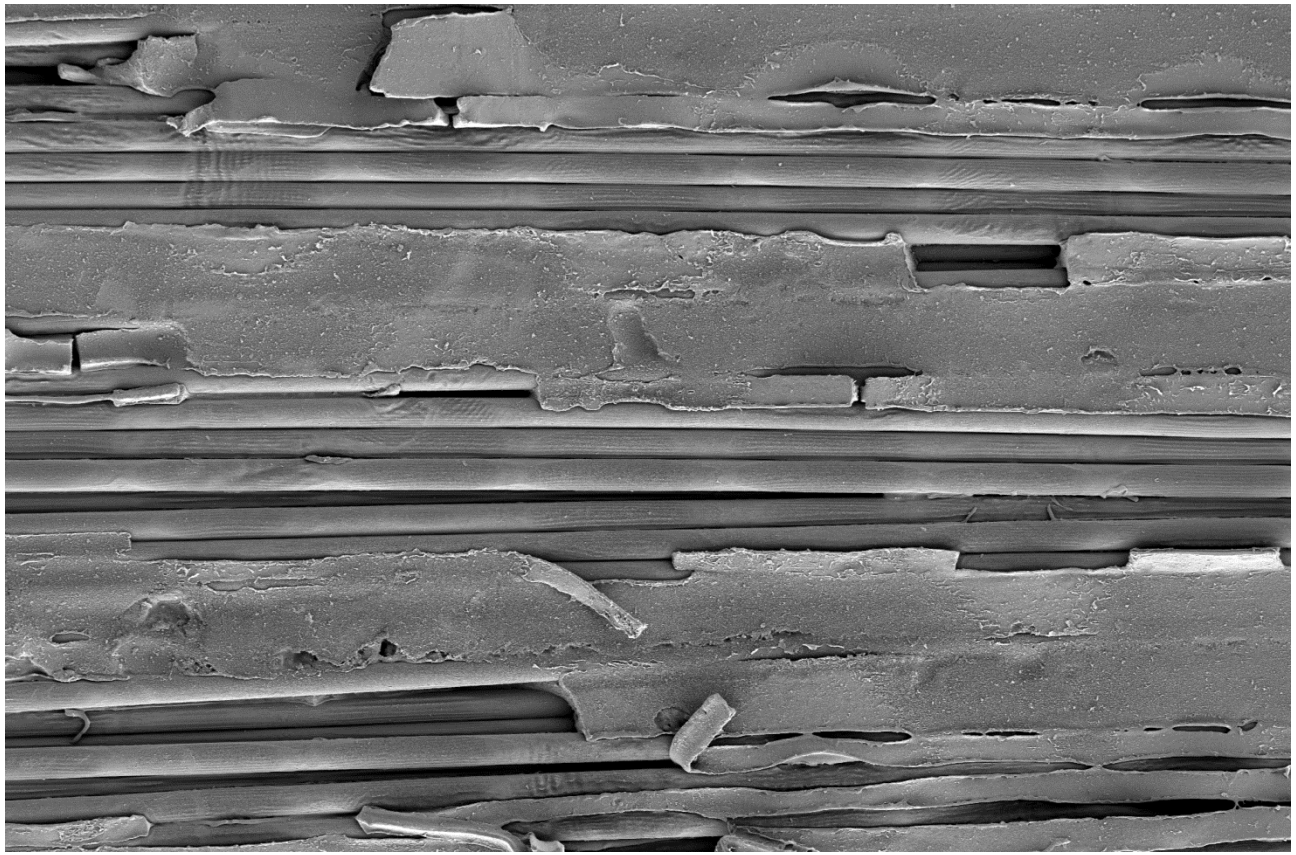
Executive Summary

- Thermoplastic CFRPs offer wide variety of opportunities in material, design, process and scalability
- DLR BT / WF cover whole process chain from material to part
  - Material screening
  - Quality Assurance
  - Process development
  - Simulation AFP process
  - Core capability: scalability / full scale production
- We are ready for a rapid ramp up and industrialization

Material

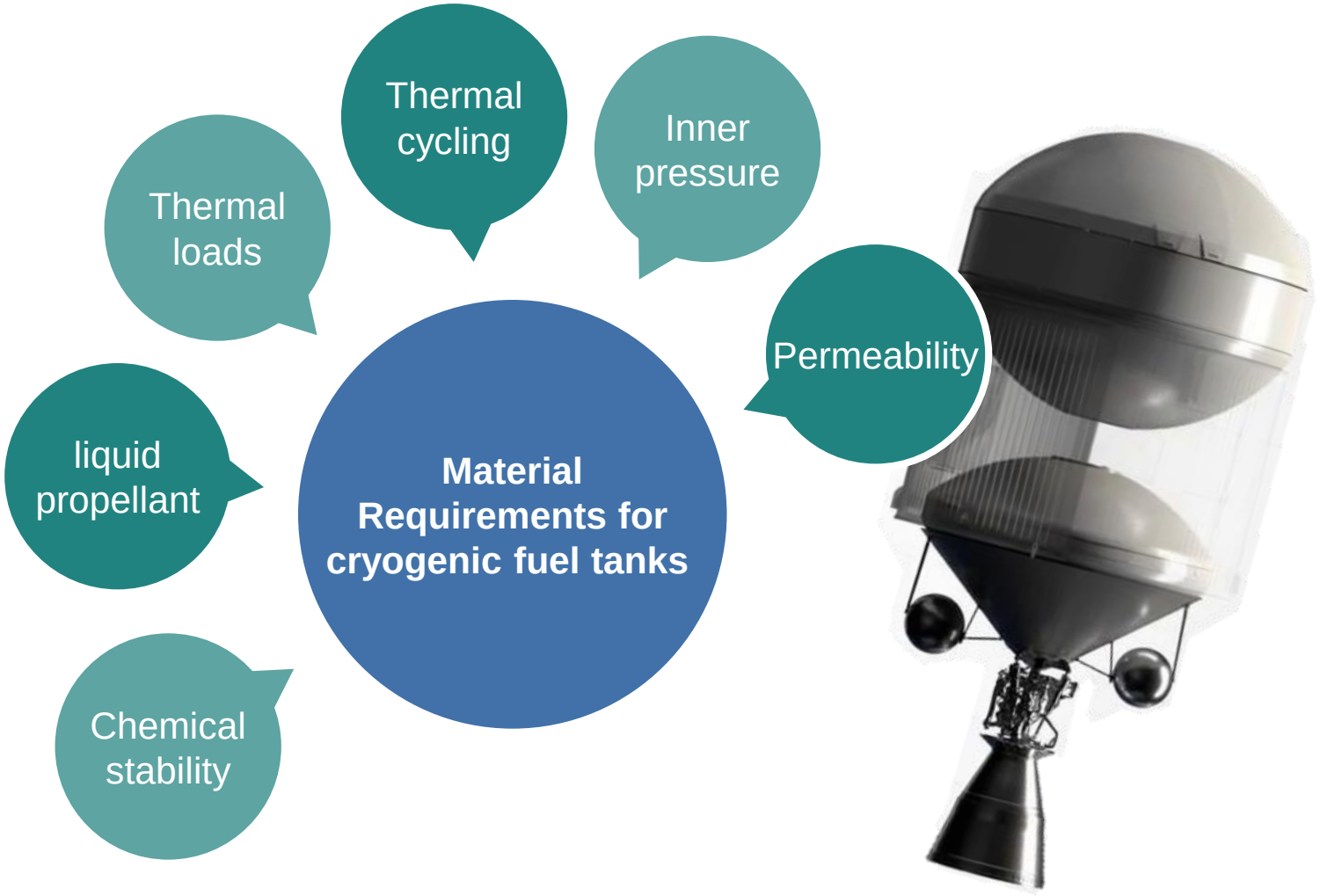
Opportunities thermoplastic CFRPs

- General material properties
  - Ductility in cryogenic temperatures
  - Dimensional stability
  - Low moisture absorption
  - Unlimited shelf life
- Welding Technologies
- CF/PEEK
  - Studies for propellant tanks exist[1]
  - First applications in cryogenics
- New materials (e.g. LM PAEK)



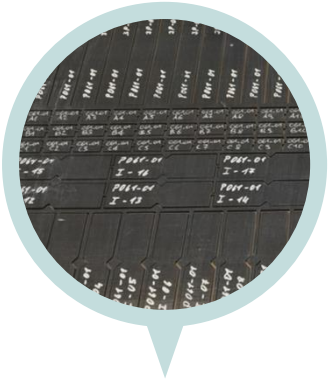
[1]e.g. Flanagan et al [2017]

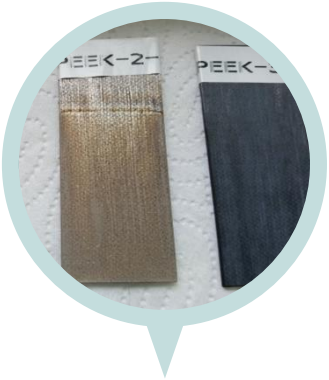
Challenges for materials in cryogenic fuel tanks



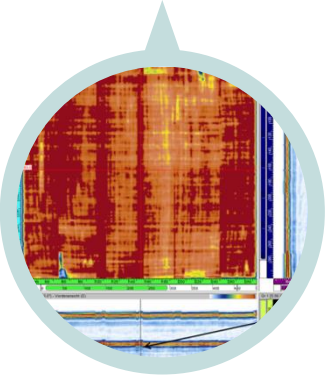
Source: AGG

Screening Thermoplastic CFRPs at DLR BT / WF





Material search → Production of test specimen → Quality Assurance → Coating concepts → Material testing → **Material properties**



Materialtest in Thermoplastic CFRP screening

	Room temperature (20 °C)	Liquid nitrogen (-196 °C)	Liquid hydrogen (-252 °C)
Permeability	Unloaded and thermally clycled	Unloaded and thermally clycled	
Tension test	unloaded		unloaded
3 point bending test	unloaded		unloaded
Short bending test	unloaded		unloaded

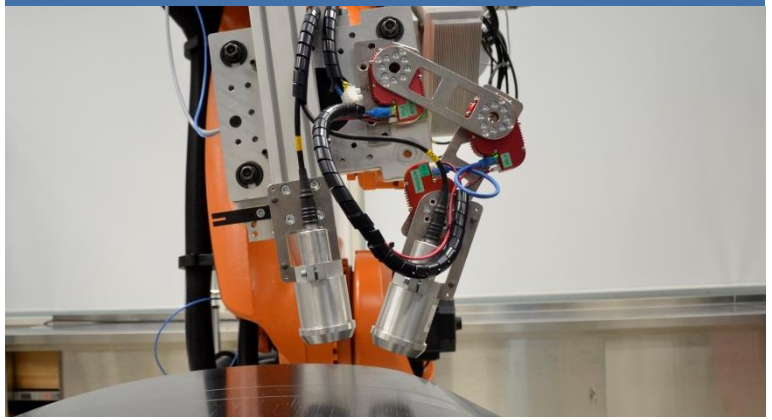
Materials Characterization and QA along the process chain

Inspection tape

- Microscopy (Optical, SEM, TEM)
- Differential Scanning Calorimetry
- Thermogravimetry
- Rheometry

Inline Quality Assurance

- Air coupled ultrasonic testing
- Thermography
- Placement accuracy

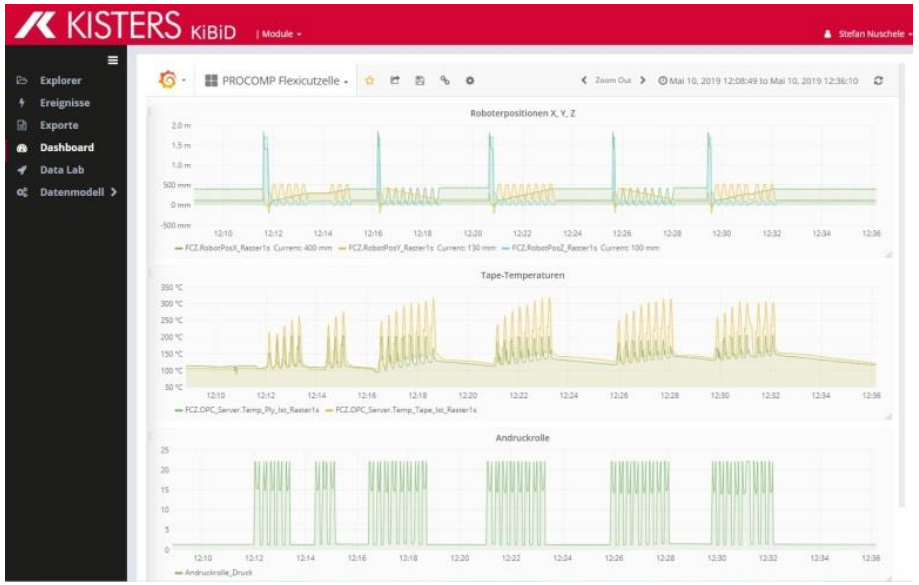


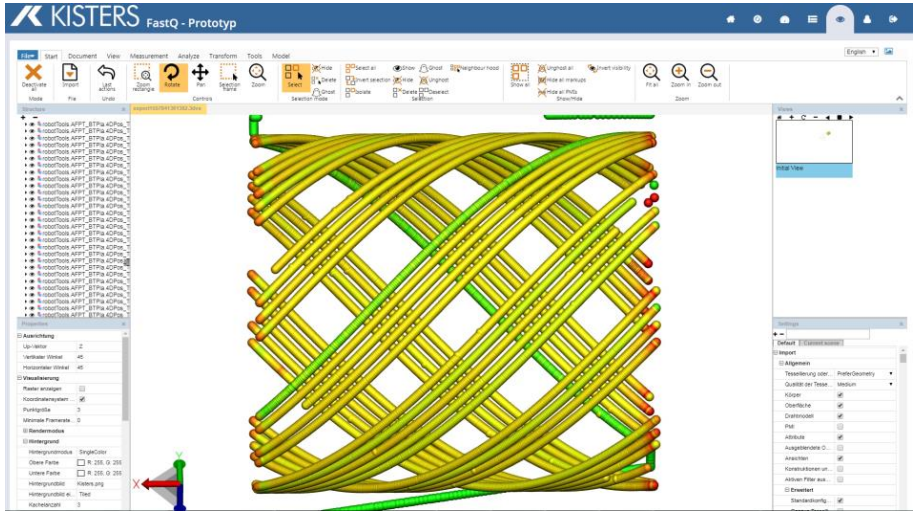
NDT & mechanical testing

- CT
- WC/AC testing
- Mechanical Testing (e.g. Drum Peel, ILSS, SL)

Data acquisition and quality feedback

- All Data stored on our databases and available for:
  - Processing and failure analysis
  - Data-based Quality Assurance
  - Loop back in Design and Simulations





Design

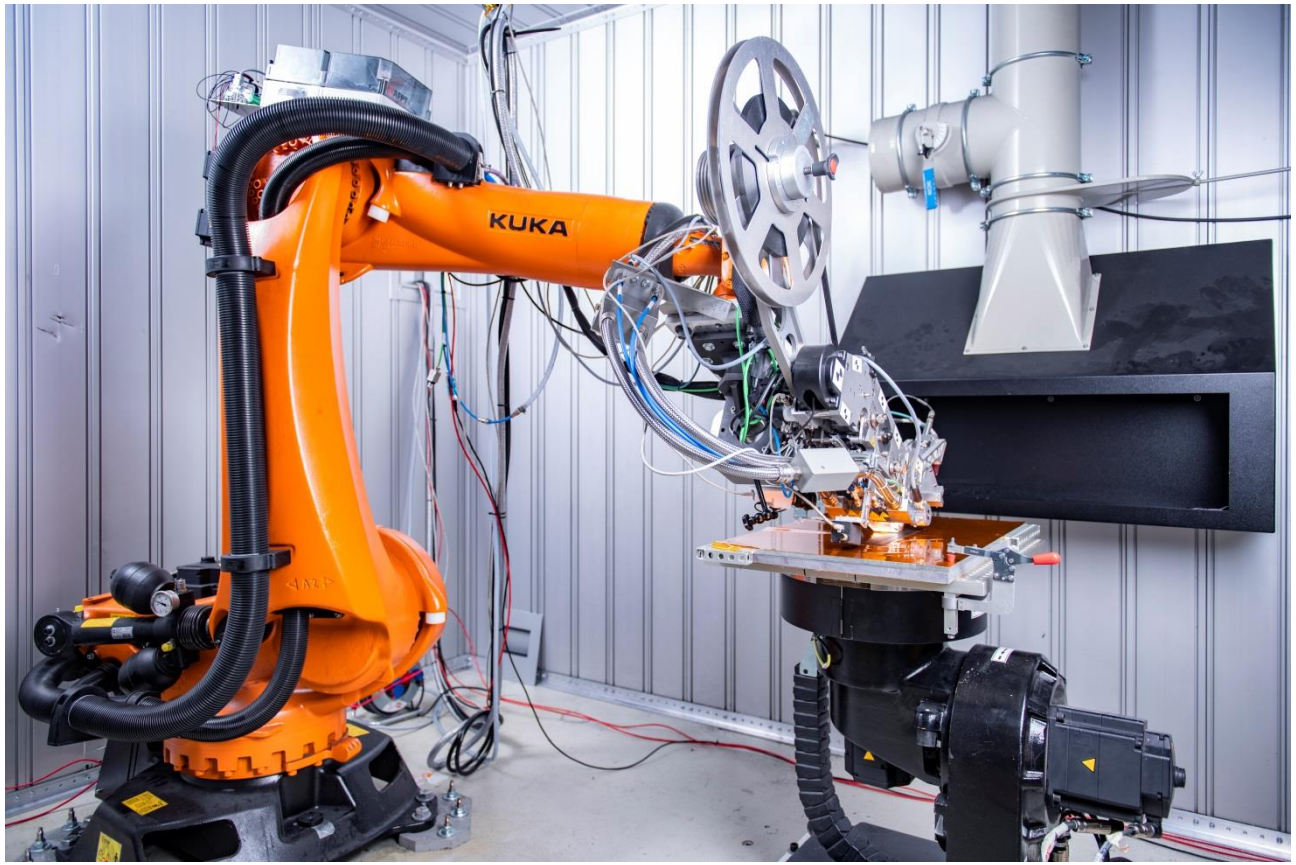
Opportunities in Design

- Welding technologies enable:
  - Modularization and dustless assembly
  - Pre-equipment fuel tank
  - Reduce bolted interfaces
- Direct Sensor integration possible
- Reinforcement of
  - autoclave / hot press parts
  - Cut outs
- Process mix
- Over molding und 3D printing

Process

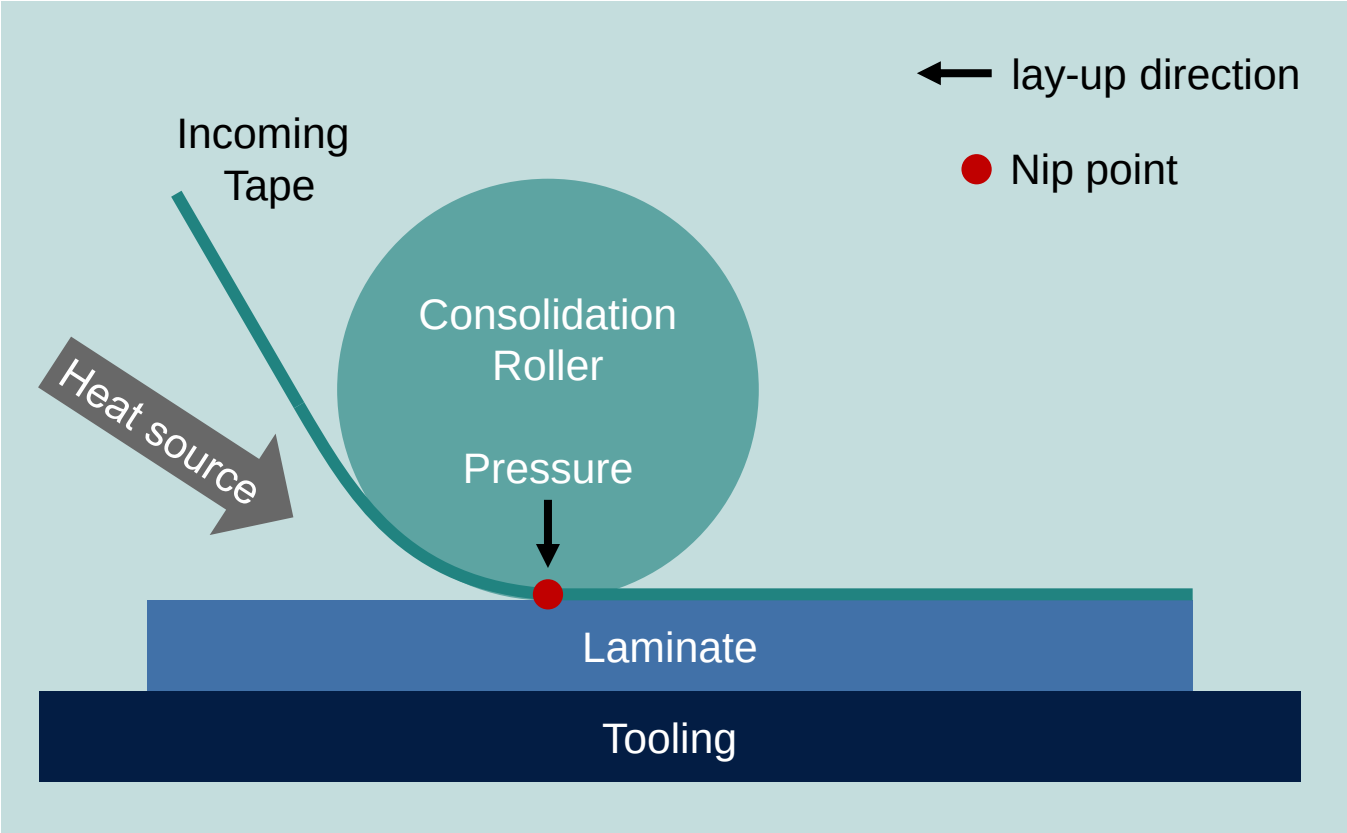
Opportunities TPC AFP Process

- Lean additive manufacturing process
  - Fully Automated Fiber Placement machine
  - Out of autoclave
  - In-situ consolidation
- Inline Quality Assurance
- Layup on liner



The in-situ TPC AFP

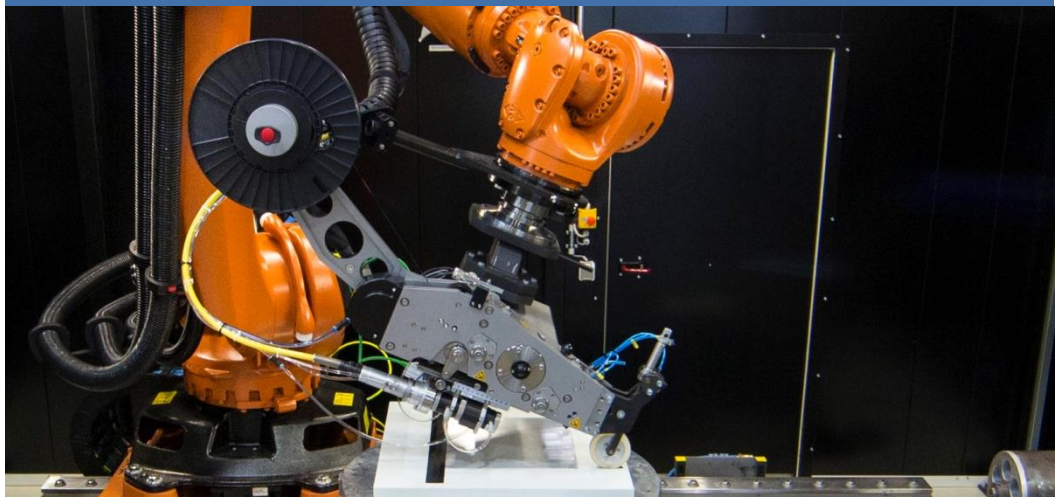
- Tape transportation
- Heating income tape (laser/flashlamp)
- Consolidation via roller
- Intimate contact and Van-der-Waals Forces between polymer chains
- Crystal formation and growth while cool down
- Part is build up layer by layer
- No additional processes steps needed



AFP Layup Heads at DLR BT/ZLP

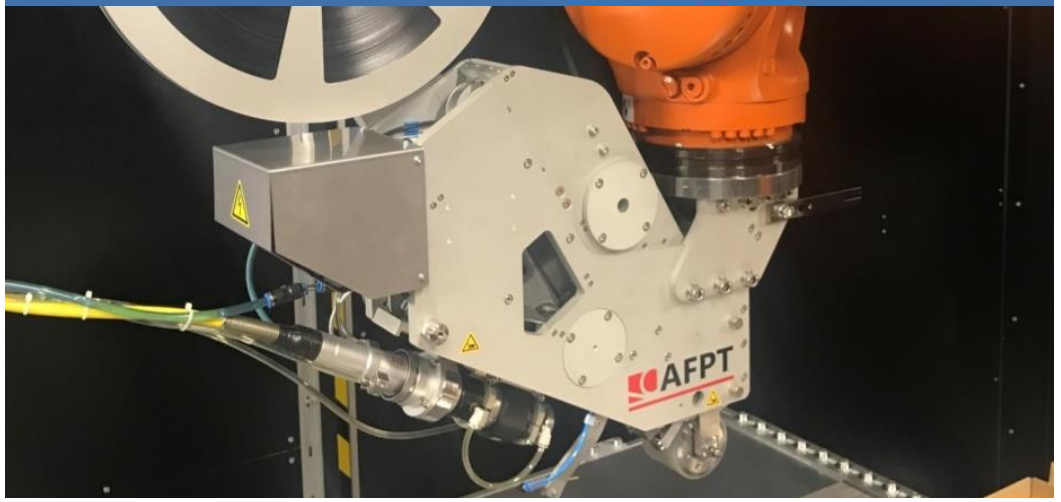
Single Tow Winding Head (STWH)

- Thermoplastic Tapes
  - 1x 6-25 mm
- Compact design
- Flexible consolidation roller



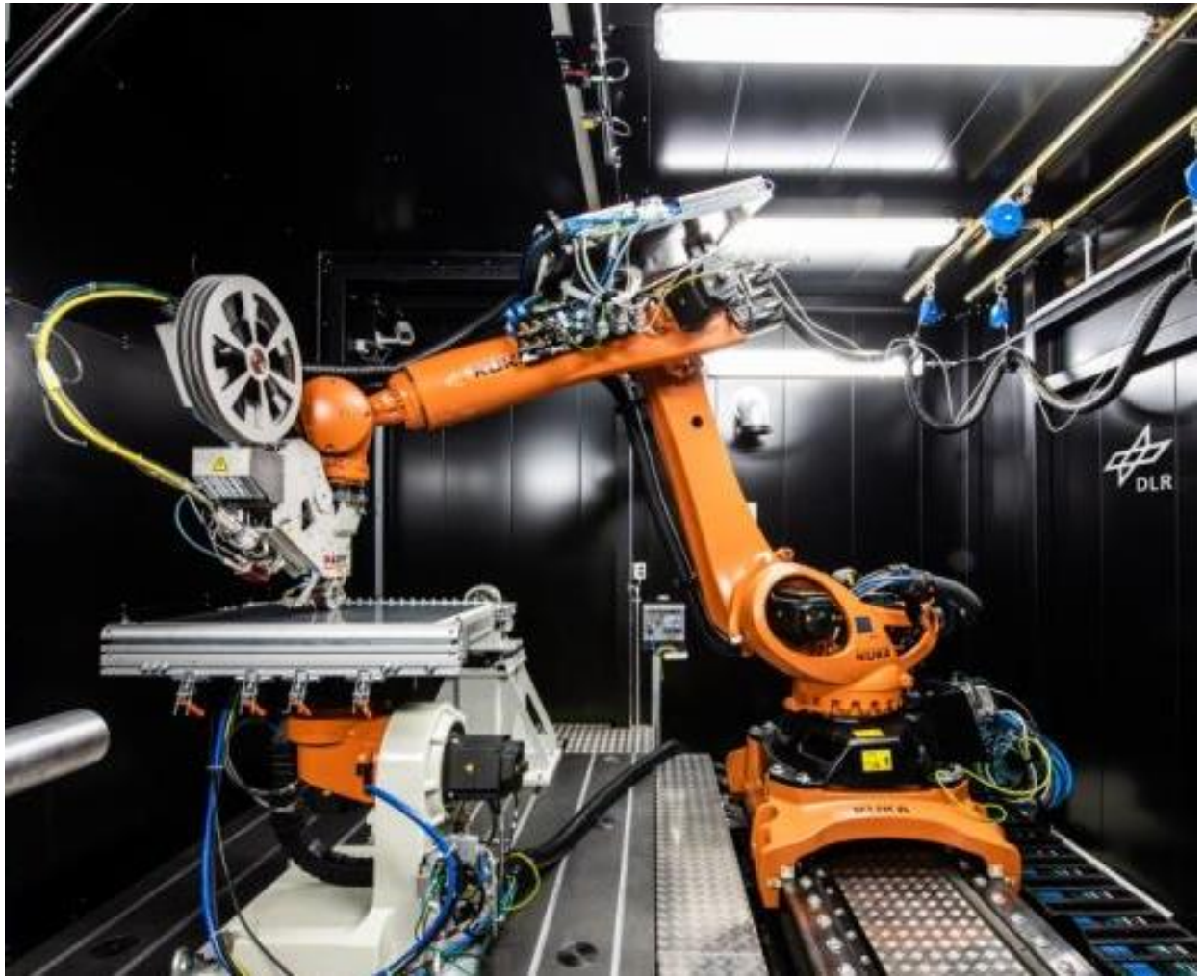
Multi Tape-Laying Head (MTLH)

- Thermoplastic Tapes
  - 1-3 x 12-13mm, 1 x 1”, 1 x 2”
- Improved design and position control
- Cooled consolidation roller



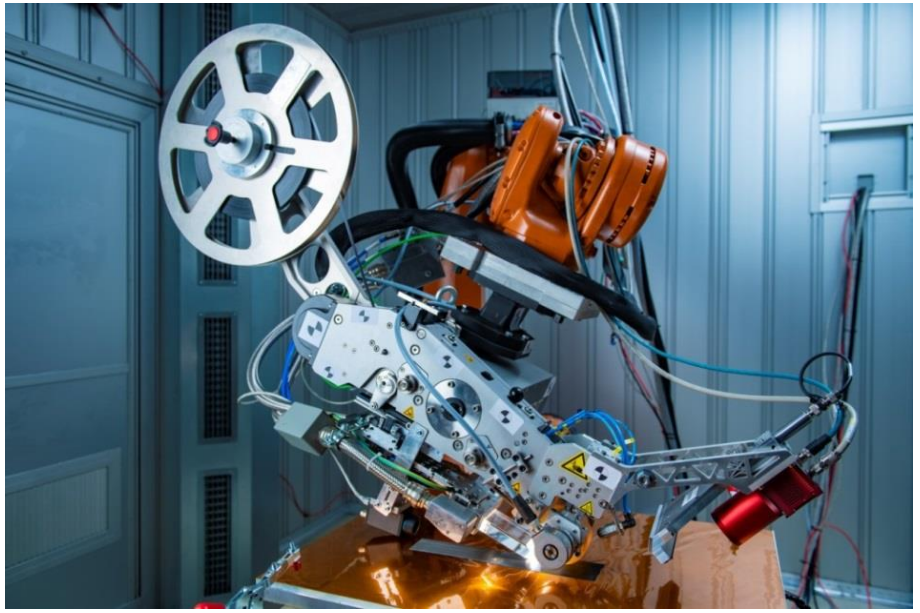
Laser assisted thermoplastic AFP

- Processing of thermoplastic tapes (PPS, PAEK such as PEEK, PEKK)
- Tape heating via laser (6 kW)
- Laser in-situ: 1-15 m/min
- Laser with post consolidation: 40 m/min
- Max. component dimensions:
  3500 mm x 1800 mm
- Suitable for cylindrical and 3D-curved shapes



Flashlamp assisted thermoplastic AFP

- Processing of thermoplastic tapes (PPS, PAEK such as PEEK, PEKK)
- Tape heating via flashlamp (6-20 kW)
- Flashlamp (at 6 kW): 2,4 m/min
- Flashlamp with post consolidation (at 6 kW): 6 m/min
- Suitable for cylindrical and 3D-curved shapes
- No laser safety housing needed

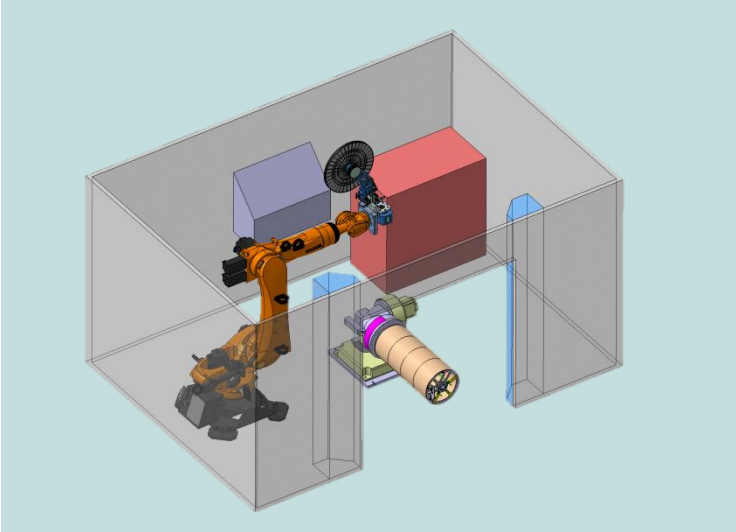


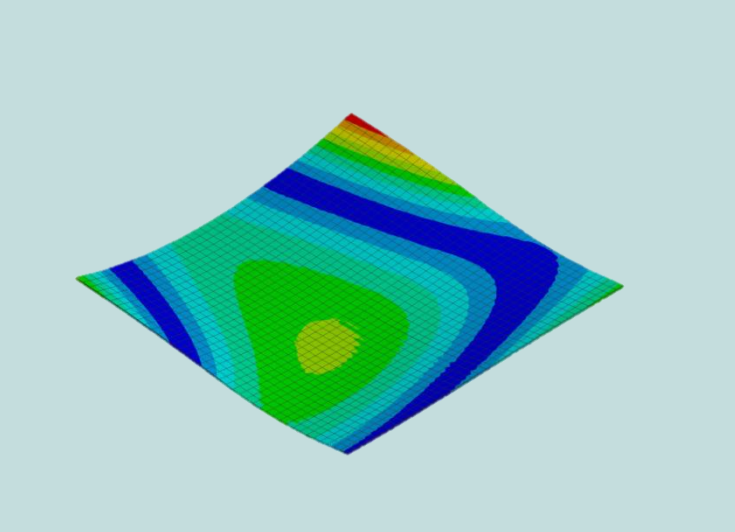
Establishing, Optimization and Benchmarking of Processing Parameters

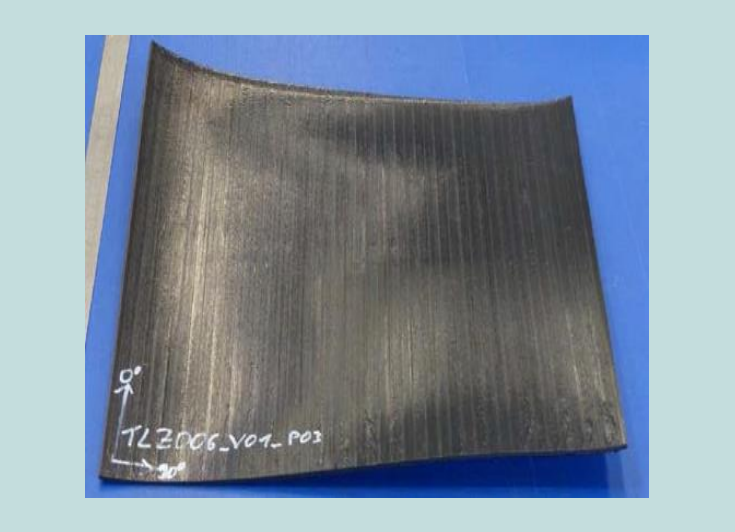
- Joint Design of Experiment across sites to systematically handle this highly transient process
- Equal experimental setup and testing (single-lap specimen designed at DLR-BT)
- Optimization in terms of mechanical performance and producibility

Simulation-based process

- Robot simulations to verify manufacturability
- Offline laminate design and path planning
- Heat distribution simulation to predict process parameters
- Goal: establish simulation based closed-loop control

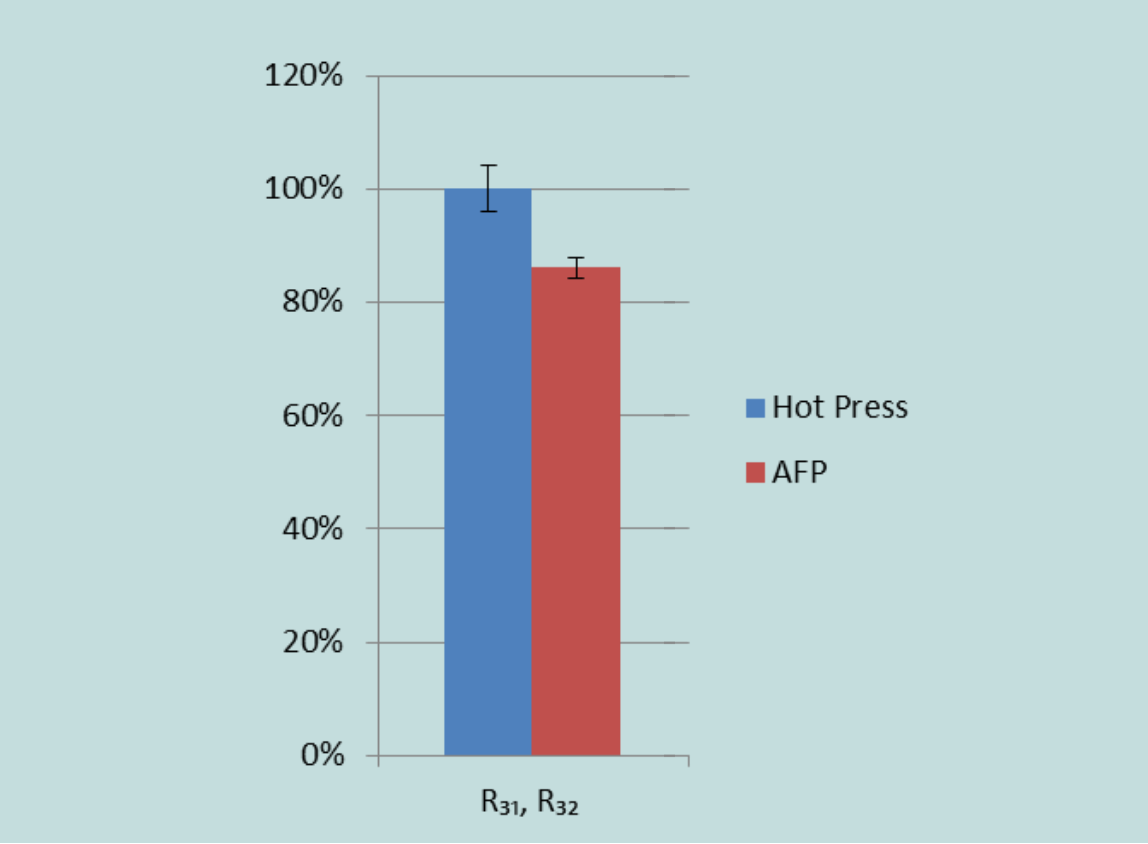




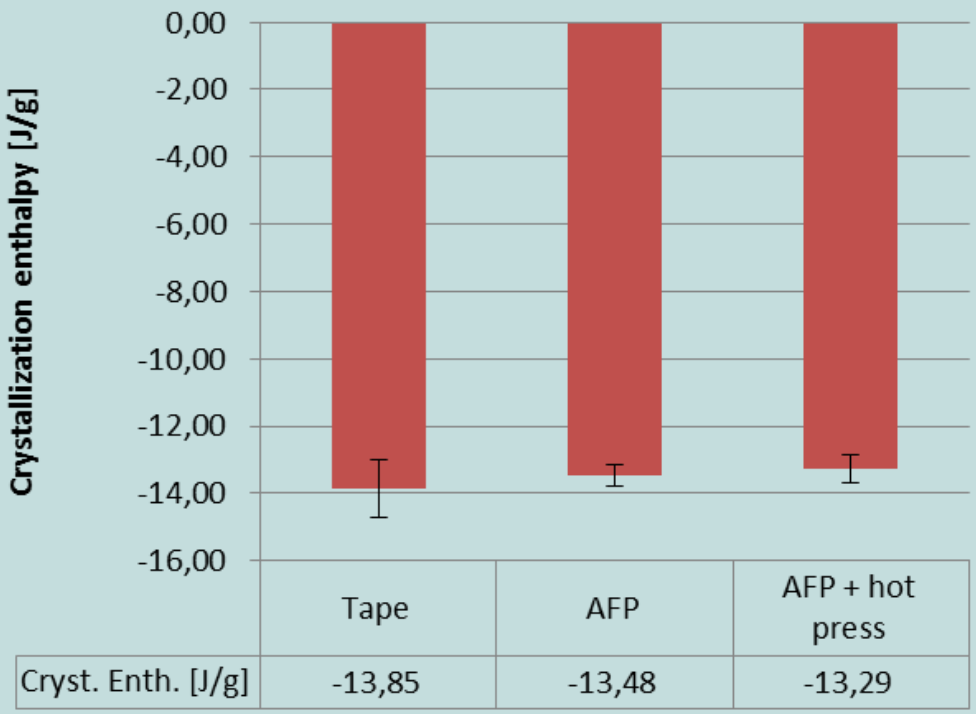


Properties of In-Situ TP-AFP Consolidation

ILSS DIN ISO 14130 Short beam bending CF-PEEK



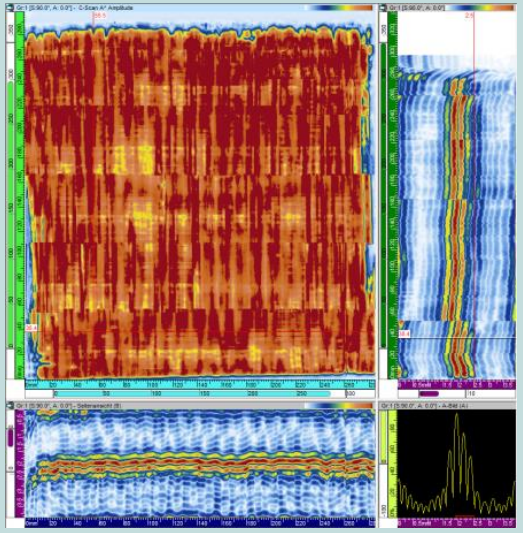
Crystallization enthalpy



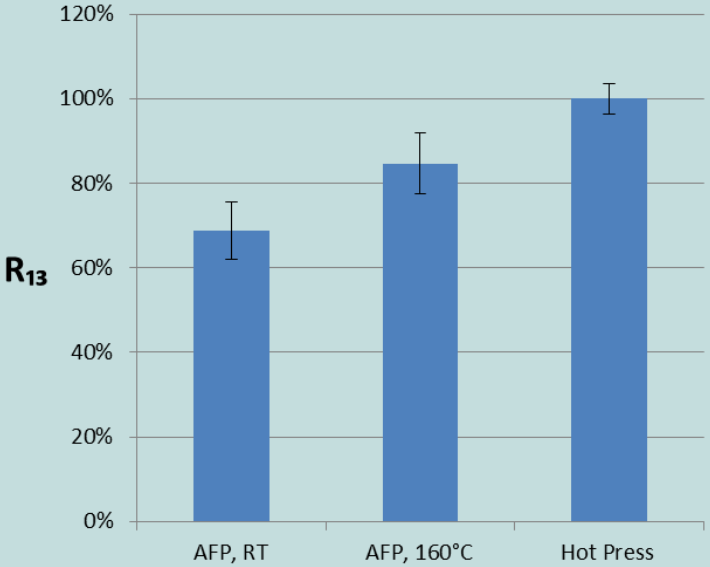
	Tape	AFP	AFP + hot press
Cryst. Enth. [J/g]	-13,85	-13,48	-13,29

Status of CF-PPS Tape Laminates with In-situ Tape-laying

- Good C-Scan with ultrasound
- Approximately 84% of Hot-press laminates (produced at higher pressure)

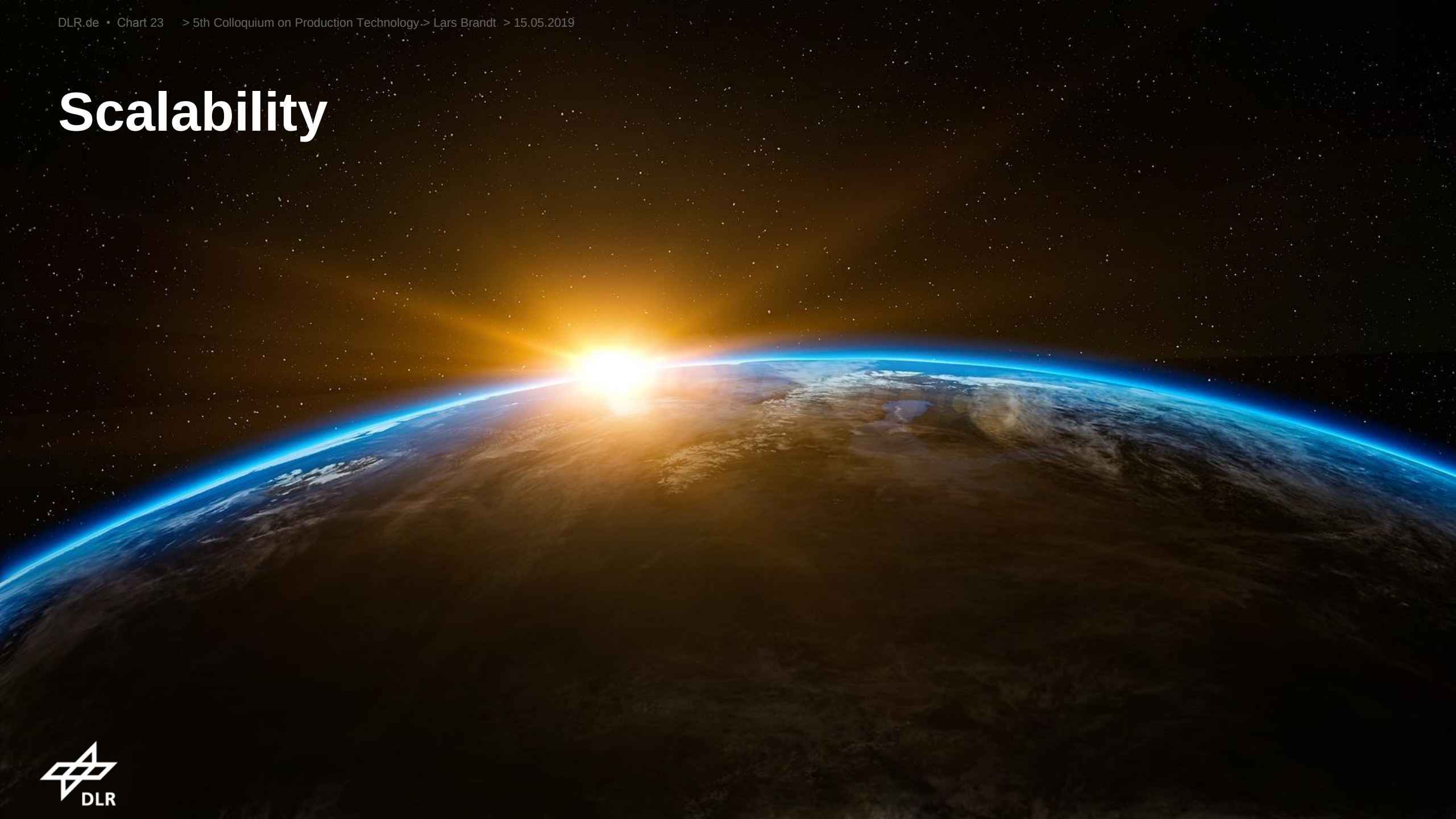


US-C-Scan of Insitu CF-PPS laminate

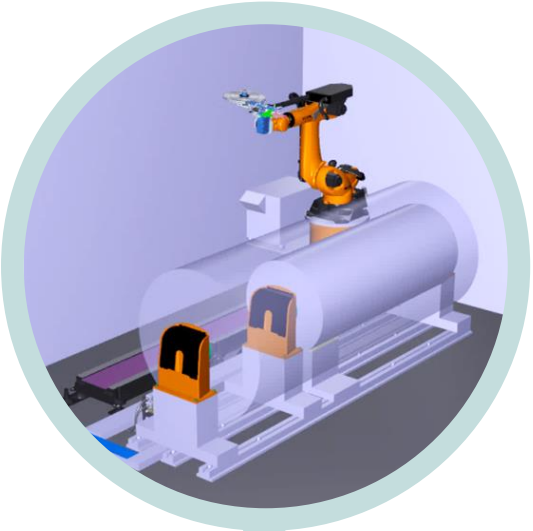


Influence of Tool-Temperature

Scalability



Opportunities Full-scale capability and ramp up



Today **October 2019** **Full scale?**

Questions? Contact me!

Lars Brandt

Center for Lightweight Production Technology

Am Technologiezentrum 4

86159 Augsburg

Lars.Brandt@dlr.de

+49821 319874-1076