DLR Activities in the Field of Thermoplastic Fiber Placement and Additive Manufacturing

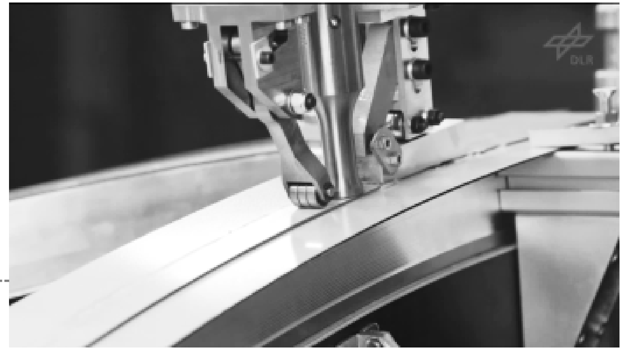
Sebastian Nowotny

Ashley Chadwick, Georg Doll, Olivia Hellbach, Simon Hümbert, Lukas Raps, Ines Schiel, Manuel Simone

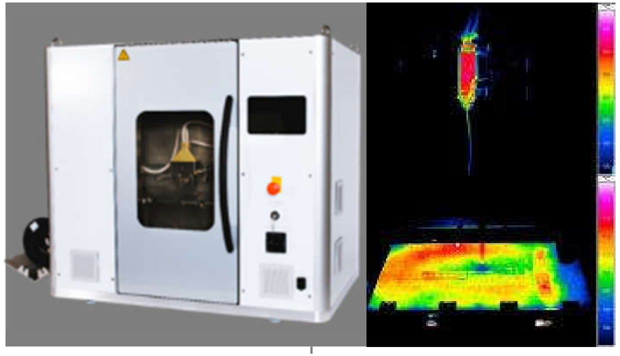
DLR

Automated Manufacturing of Thermoplastic Structures

- Rapid Press-forming
- Continuous Welding
- Automated Fibre Placement
- 3D-printing



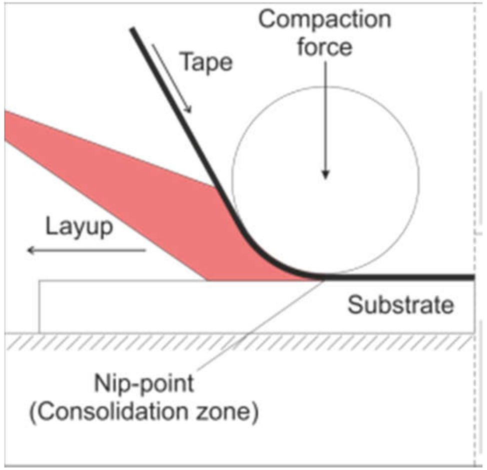
[1]



Automated Tape Placement for Thermoplastic Composites

Tape Placement cell at DLR Stuttgart

Incoming tapes, laying at a heated tooling



Principle of tape placement [2]

- AFPT GmbH head
- ½" – 2" tapes
- 3 x ½" simultaneously
- 6 kW laser
- Cooled compaction roller

- Using highly automated process
- IR-Laser is welding several tape to a laminate
- Preforming and consolidation at one step
- Planar, cylindrical, and complex structures

Automated Fibre Placement – Two-step or In-situ

Two-step

Layup

↓

Vacuum bagging

↓

Autoclave finishing

↓

Final product

⇨ Improved homogeneity and mechanical strength

In-situ

Layup

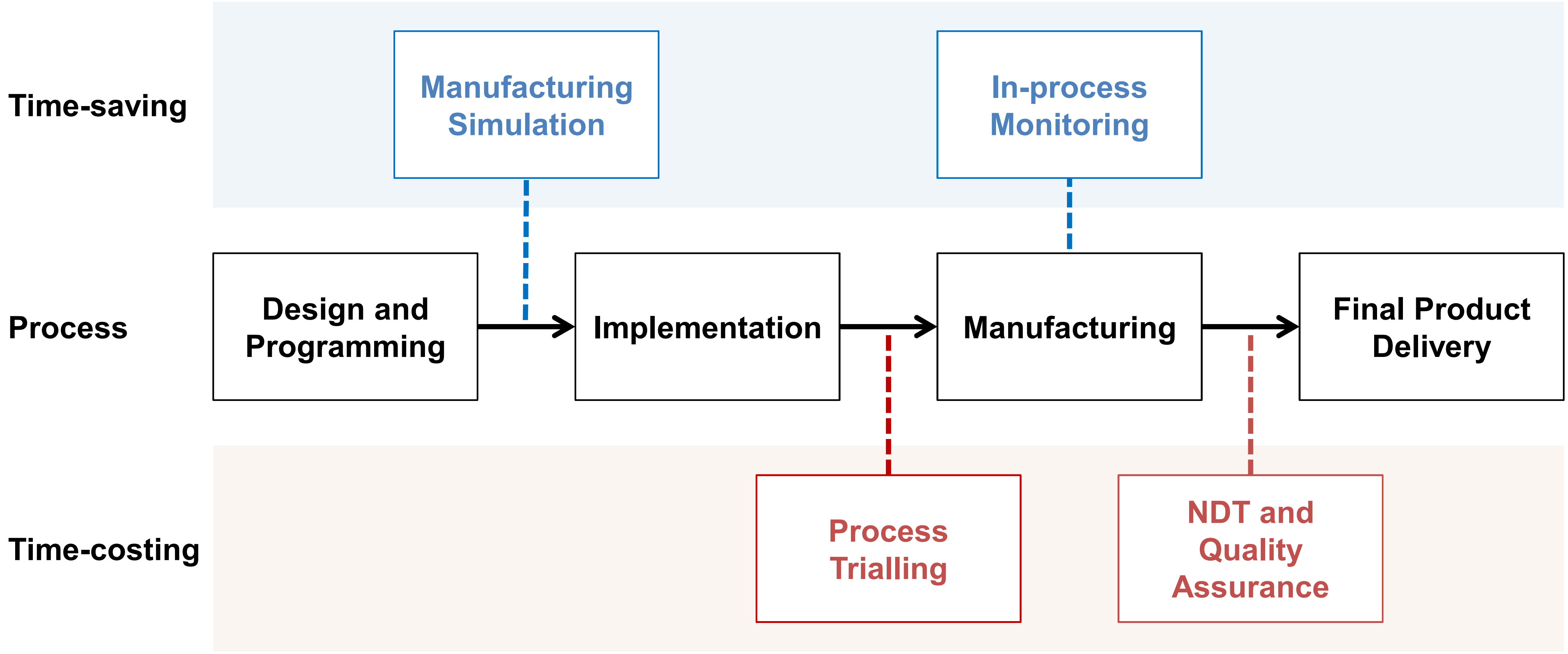
↓

Final product

⇨ Potential for significantly reduced unit cost and production time

[3]

Automated Fibre Placement and the Time to Defect Detection

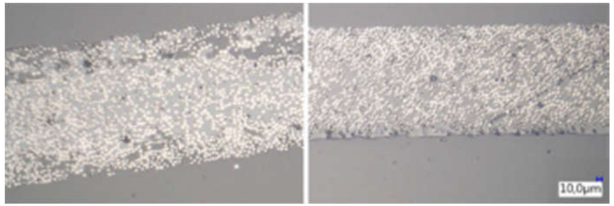


Process development and optimisation
Process Chain – Form bulk material to laminates

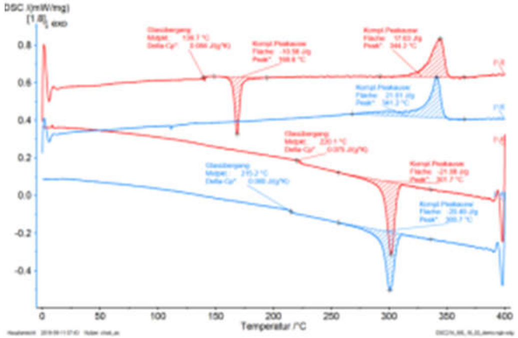
- Analyse different tape materials
  - Pores and inhomogeneity
  - Thermal behaviour for process borders

- Develop DoE methods incl. fast and cost efficient test methods

- Manufacturing laminate and generate laminate values



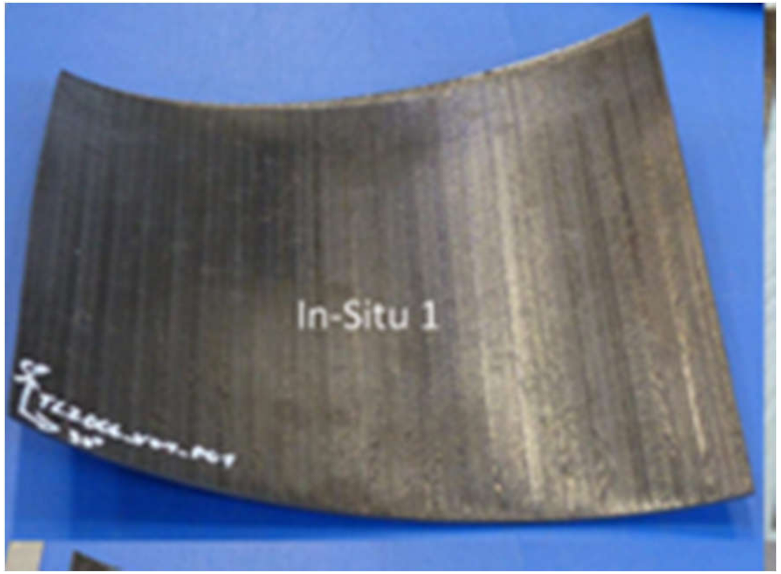
Thermal and optical inspection of the bulk material



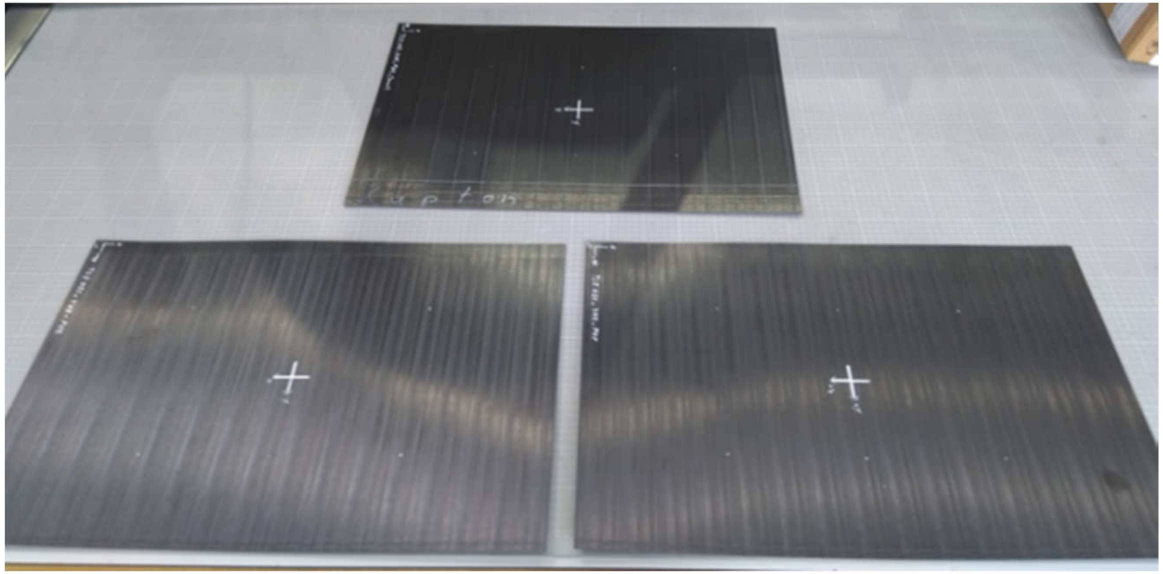
DoE specimen for fast process optimization [2]

Challenging for high temperature thermoplastics
- deformation due to layer by layer heat introduction -

- Additive manufacturing is defined by heat introduction layer by layer
- Inhomogeneous temperature distribution inside laminate provokes stresses and deformations
- Knowledge in material behaviour is supported by process simulation

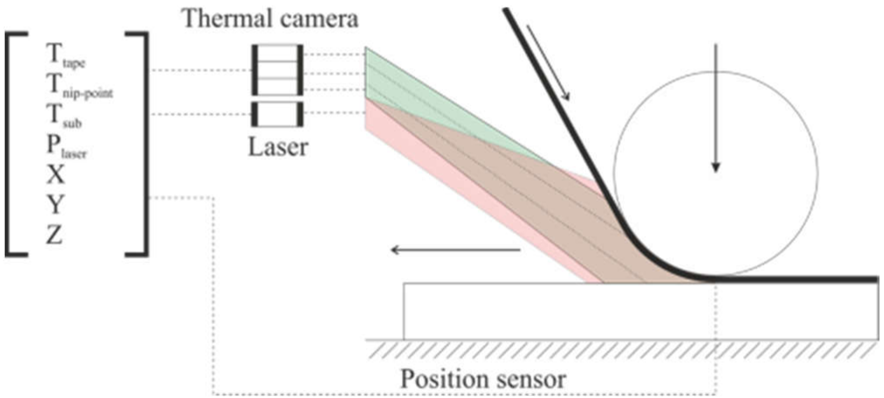


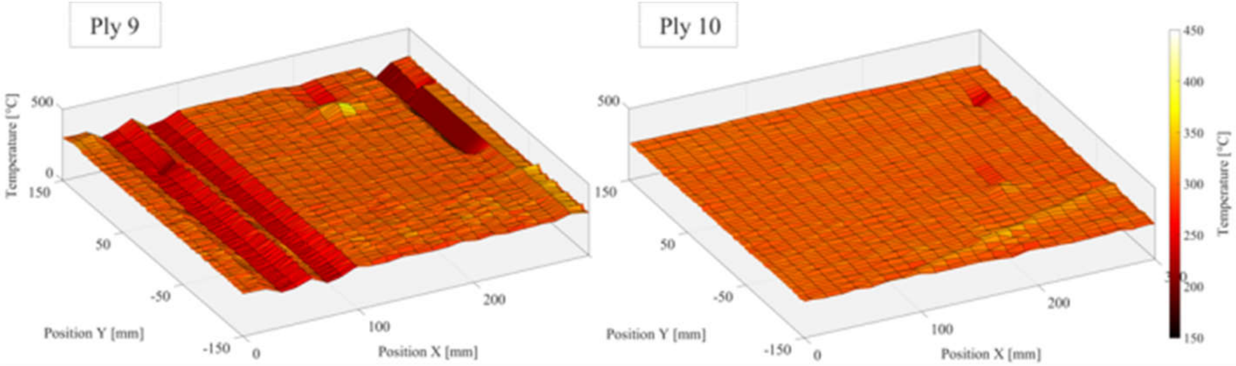
Initial parameters without optimisation, Insitu AFP, PEEK sample 300x300mm



Optimised process parameters, Insitu AFP, PEEK sample 650 x 345 mm

Quality evaluation via online process monitoring and evaluation





Use of in-process monitoring to detect defects in thermoplastic AFP-produced parts [4]

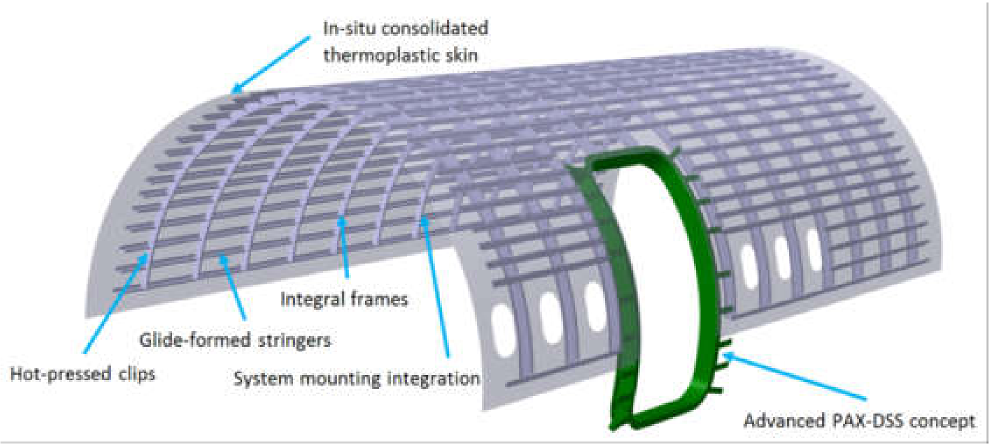
- Laser is controlled via thermal camera
- Data is recorded from ever single position of the part
- Compare the data to defined process window

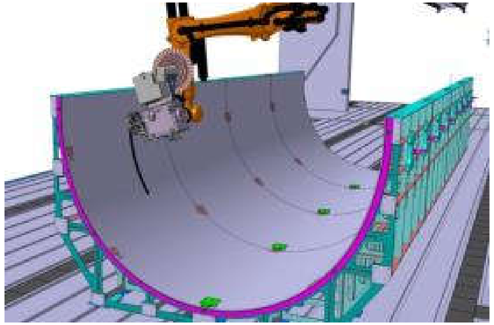
⇨
- Reduce effort for NDT
- Find scrap parts as soon as possible during the process chain

Application of Automated Tape Placement for Thermoplastic Composites

CleanSky2 Thermoplastic Fuselage Demonstrator

- Augsburg
  - Full Scale Manufacturing (8 m x 3,8 m)
- Stuttgart
  - Maximum performance at a scaled demonstrator





CleanSky 2 Project MFFD [5]

Highlight Project - ATEK

In-situ-manufactured primary structure for two-stage sounding rocket

Part of DLR MAPHEUS programme
- Material physics experiments at zero gravity
- Annual launch (beginning 2009) from MORABA facility in Kiruna, Sweden

Current generation vehicles:
- Two-stage VSB-30
- Maximum altitude = 260 km

[3]

Launch – June 2019

- Launched on 13 June 2019 (04:21)
    - Maximum altitude = 239 km
- Significant charring of thermal protection system but structural integrity maintained
- Successful landing and recovery
    - 67 km from launch site
- Video:

https://www.youtube.com/watch?v=JlcReUwZXFU



Combining 3D-Printing with In-situ TP-AFP

- In-situ AFP for large, thin shells
- 3D-Printing for small and complex structures

- 2 areas have to be investigated:
  - 3D-printing on AFP laminates
  - Tapelaying on partially open 3D-printed structures

3D-Printing Setup and Materials

FFF-Printer for High-Temperature Thermoplastics:

- Nozzel Temperature up to 450° C
- Print-bed termperature up to 270° C
- Build-chamber temperature up to 260° C

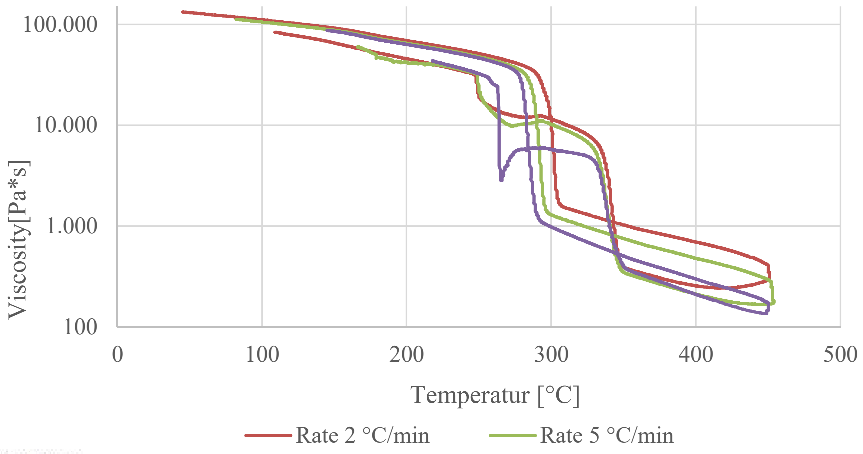
High Temperature Materials:

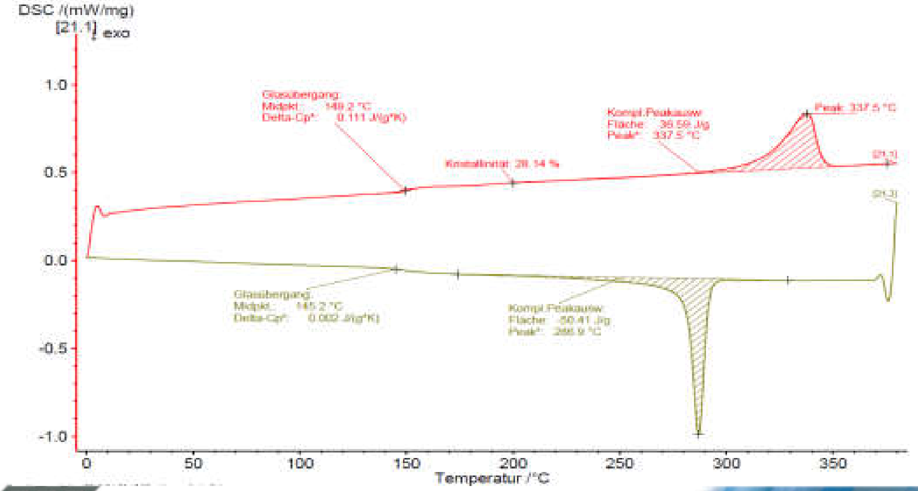
- PEEK (up to 30% CF)
- PEI (up to 15% CF)
- PPSU

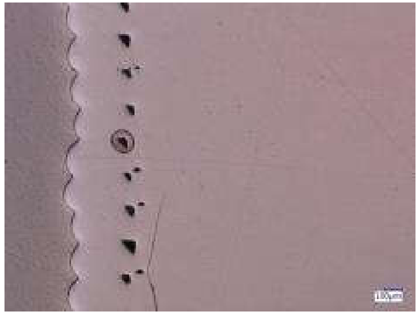
Engineering Materials:

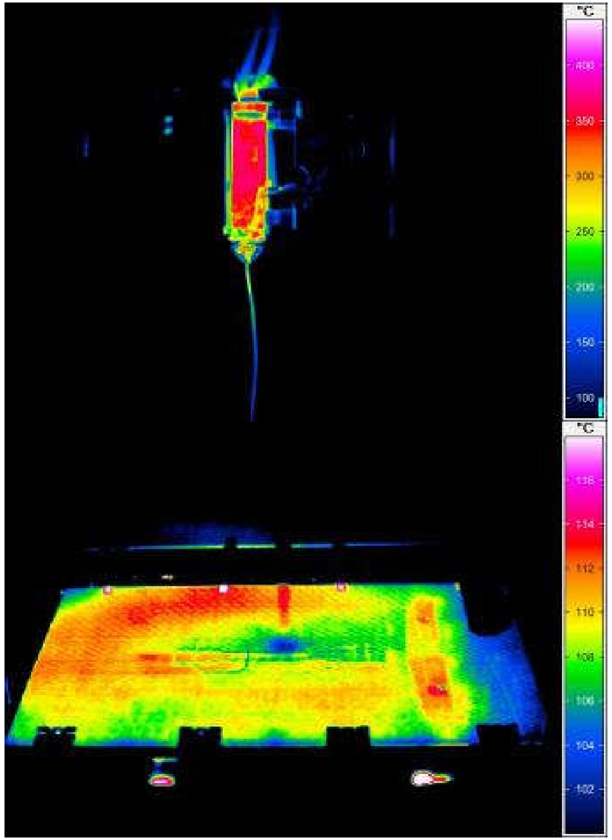
- PA (up to 30% CF)
- PC-ABS
- ABS

Process Evaluation



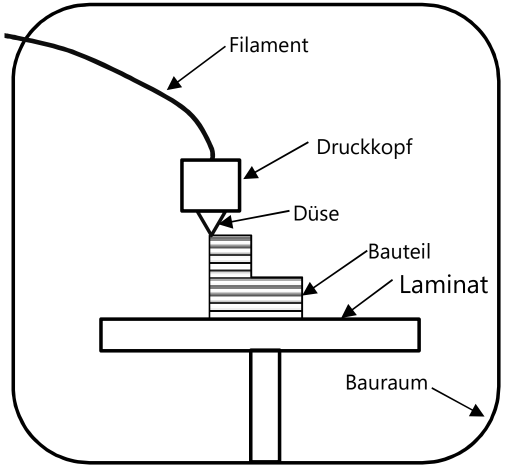




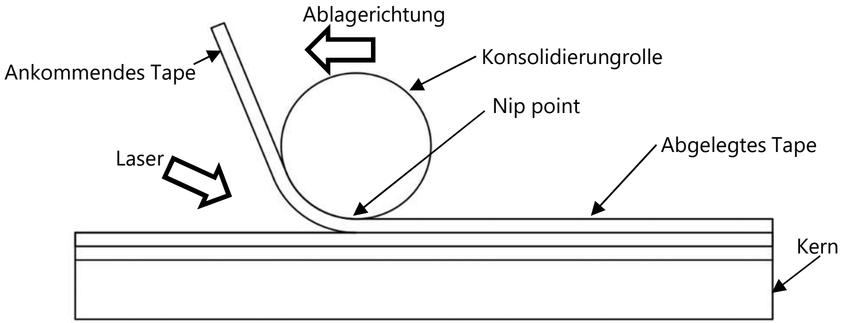


Additive Manufacturing of a Sandwich Structure

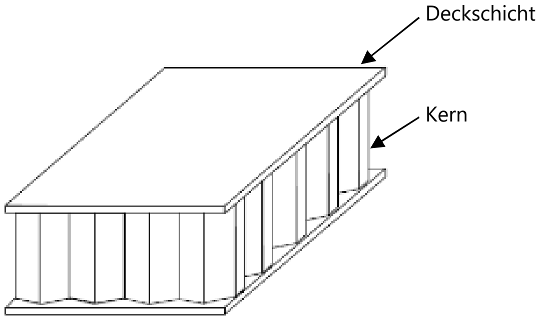
3D-Printing of a Core on top of an existing Laminate



AFP-Process

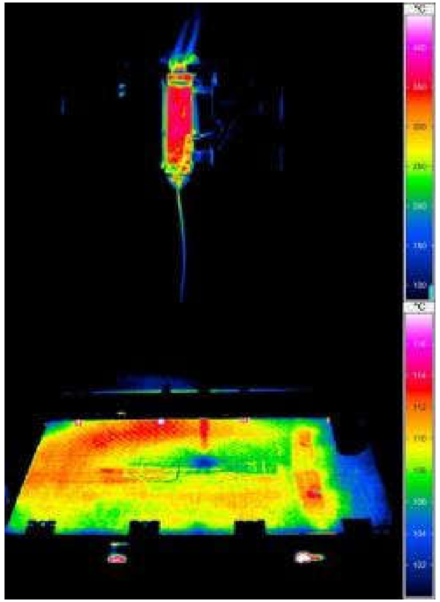


Sandwich Structure



Bildquelle: SEEMANN, Ralf: *A Virtual Testing Approach for Honeycomb Sandwich Panel Joints in Aircraft Interior*. Berlin, Heidelberg : Springer Berlin Heidelberg, 2020

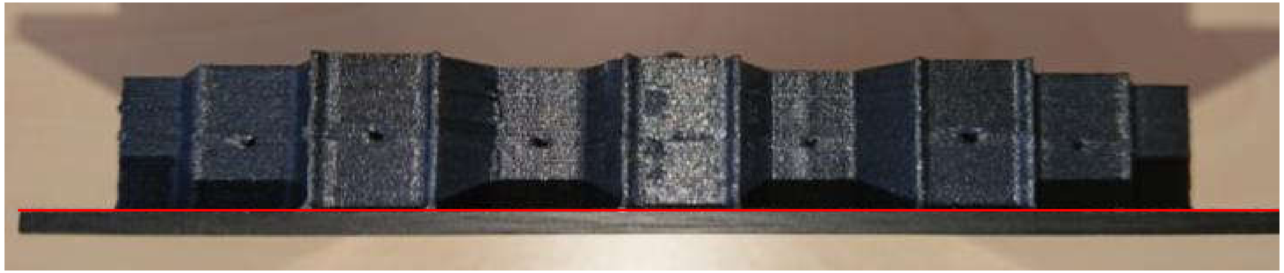
3D-Printing with PEEK / LM-PAEK on existing structures



High temperature gradient

High residual stresses

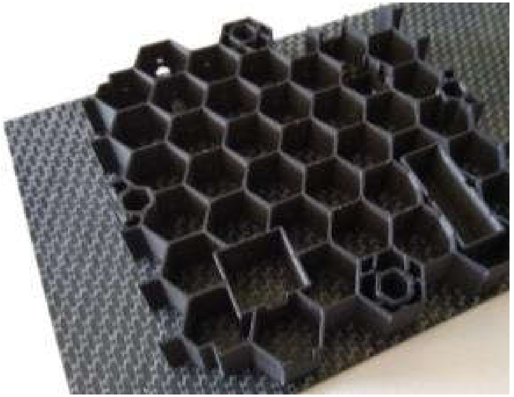
High CTE



Low CTE

Uneven / rough surface

Large structures



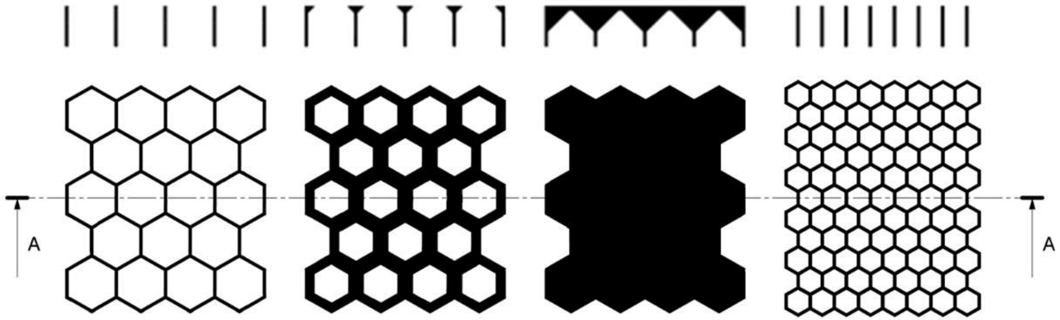
Mechanical Evaluation

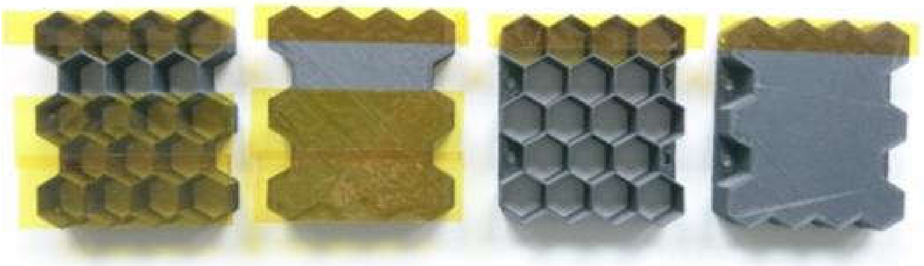
$$\text{Degree of Surface Cover} = \frac{\text{Surface of Top of Printed Material}}{\text{total Surface}}$$

Degree of Surface Cover	**8%**	**50%**	**100%**	**16%**
Mass	3,47 g	5,04 g	15,36 g	6,58 g
Relative Mass	1	1,45	4,43	1,9
Relative Mass per Surface	1	0,23	0,35	0,95

Schnittebenen-ansicht A-A

Draufsicht





Shear Test 8%

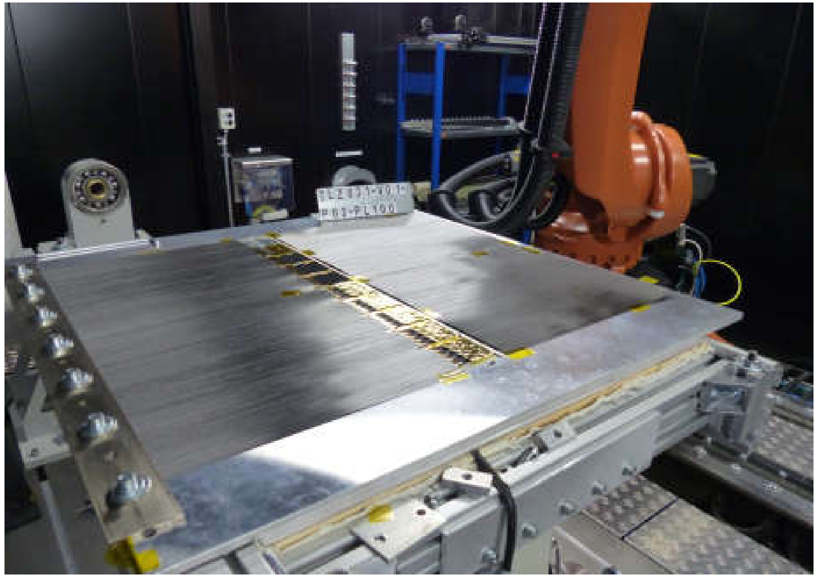
Shear Test 100%

Peel Test 8%

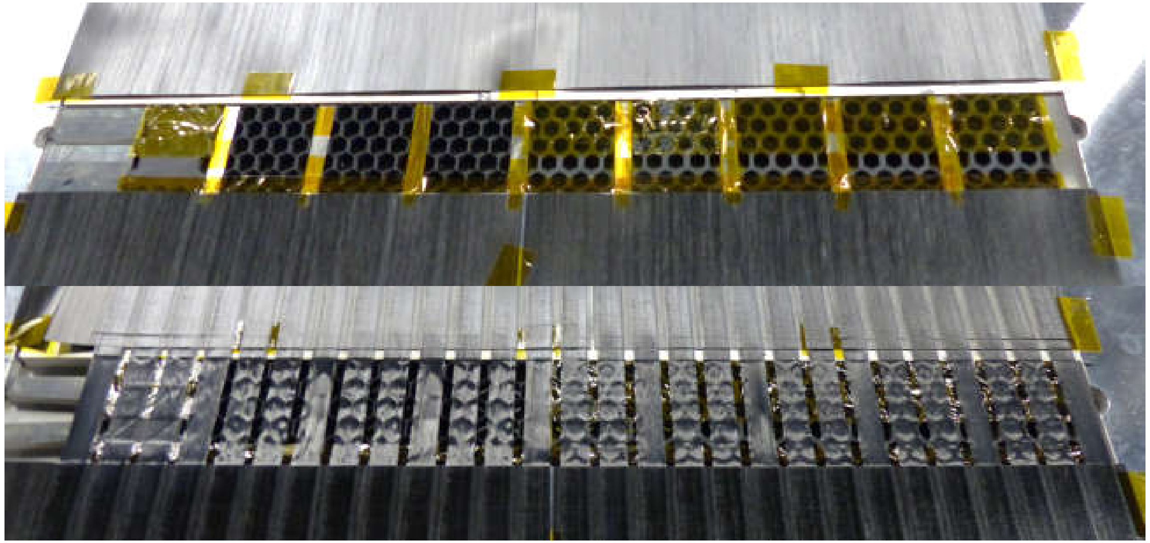
Peel Test 100%

Manufacturing of Specimen

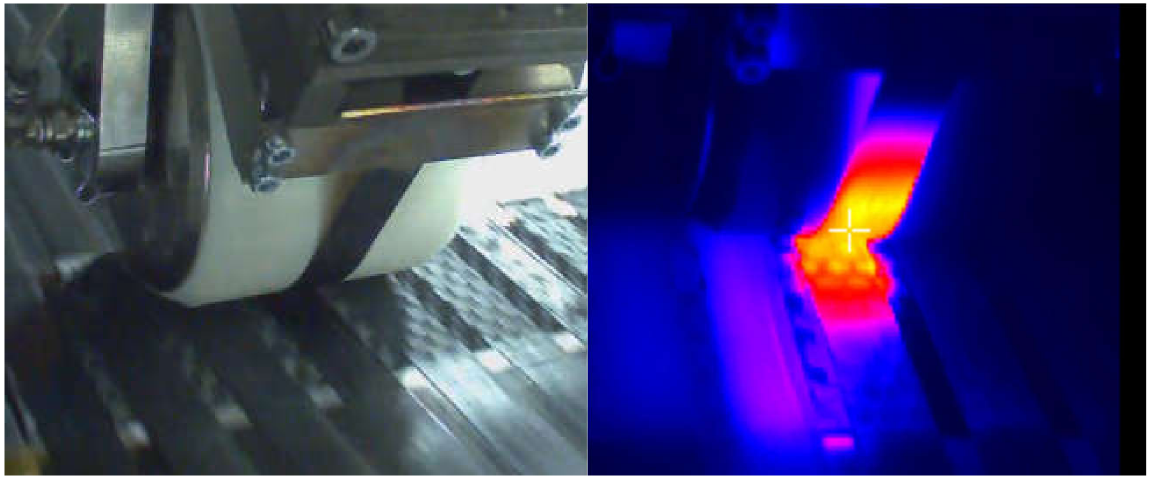
Manufacturing of Cores with 3D-Printing



Preparation of Cores for Tapelaying

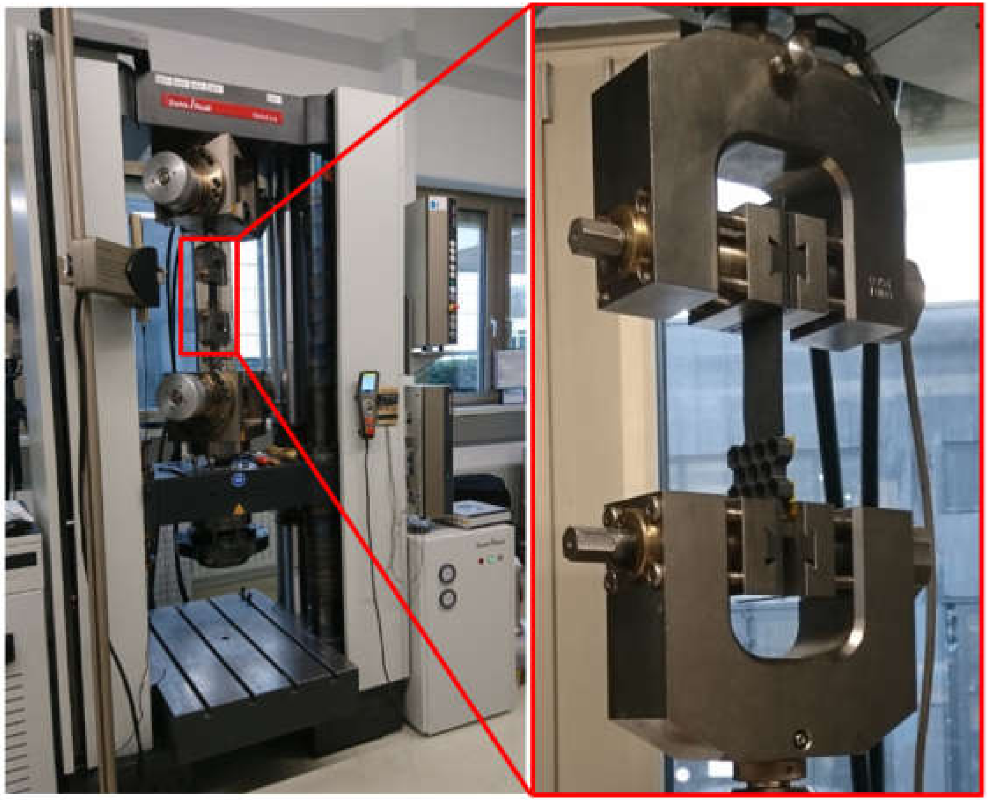


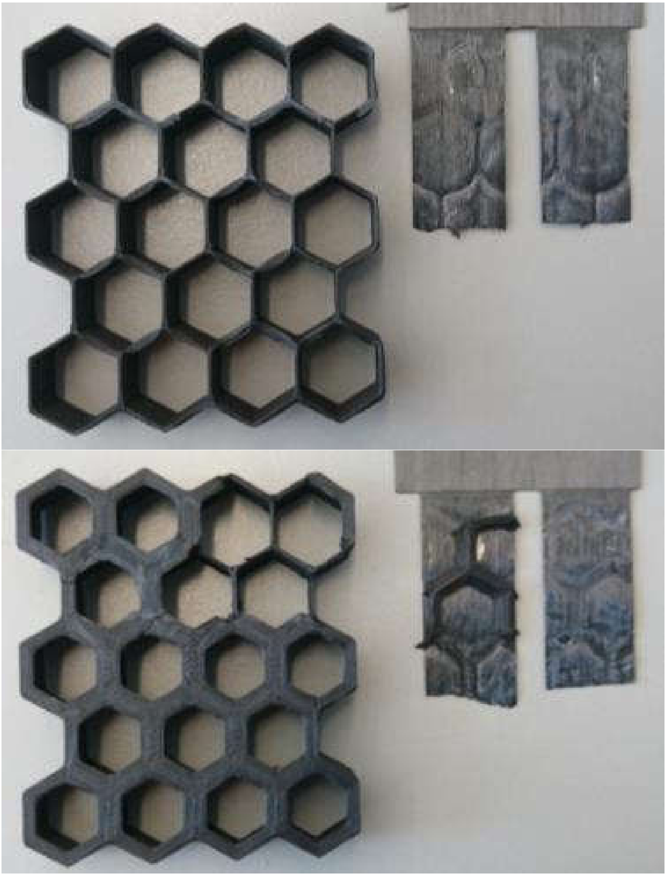
Cores place inside Tapelaying Mould before & after Tapelaying



Optical & Infrared Images during AFP-Process

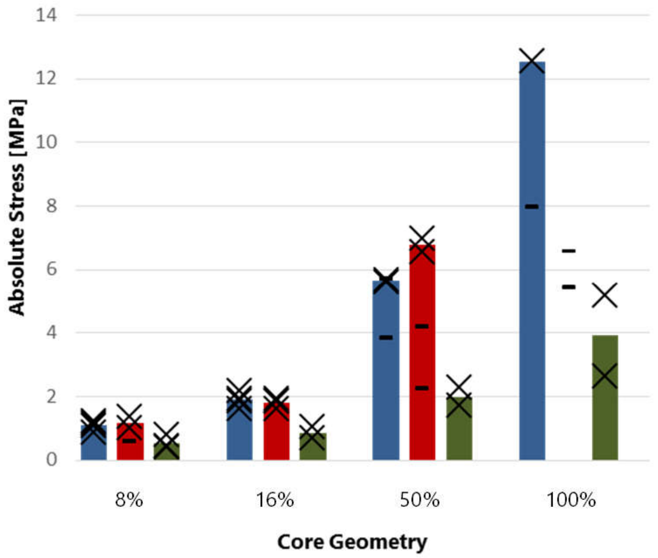
Test Setup for Tensile Shear Test



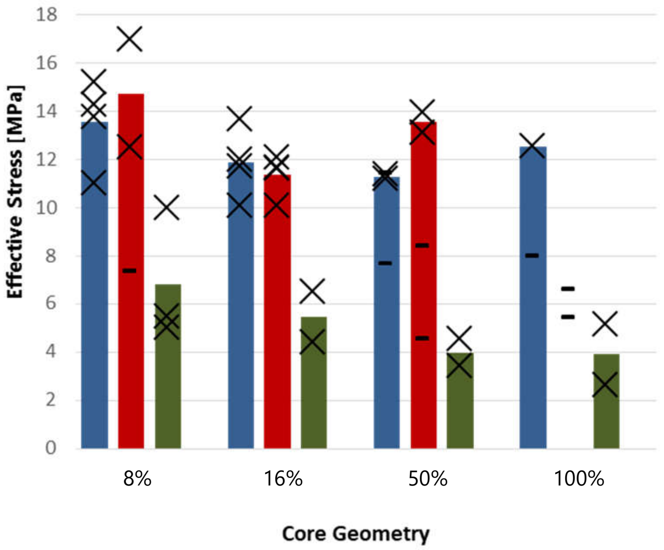


Results: Tensile Shear Test – Strength

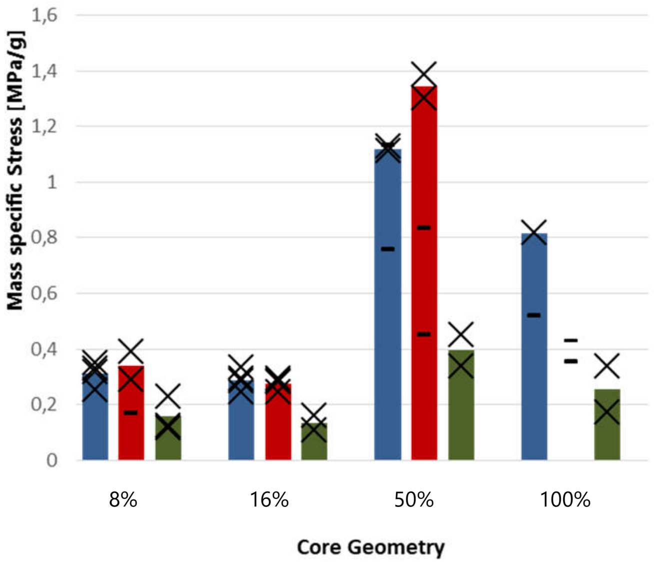
$$\tau_{abs} = \frac{F}{A_{abs}}$$



$$\tau_{eff} = \frac{F}{A_{eff}}$$



$$\tau_m = \frac{\tau_{abs}}{m}$$

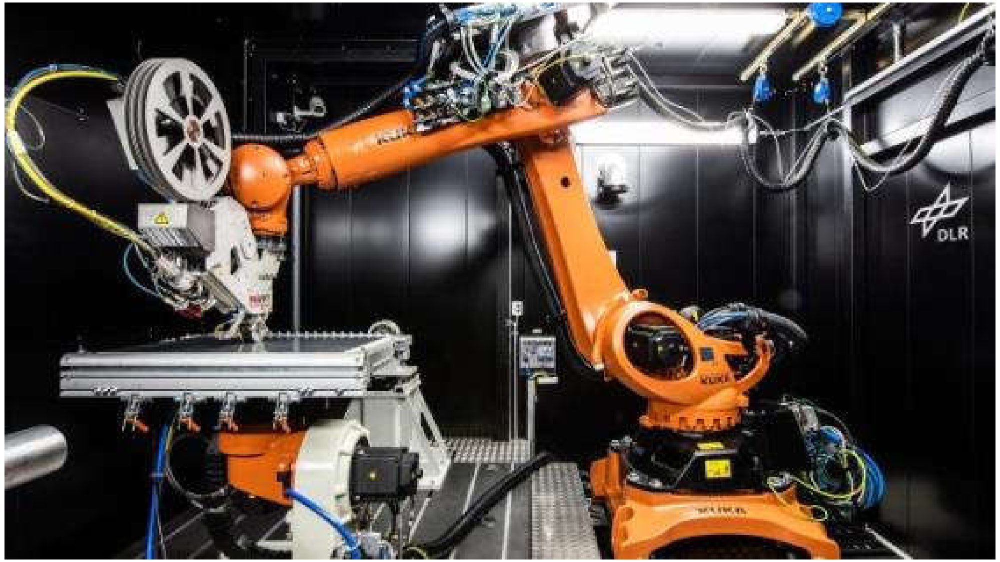


Joining Method:
- AFP at 410 °C
- AFP at 460 °C
- Thermoset Bonding

Summary

Technology development for high temperature Thermoplastic including

- Tape Placement
- 3D-Printing
- Welding
- Press forming



Technology validations with state of the art tools and scientific background

Focus at aerospace applications like skins and joints for fuselages and Space Applications

DLR Mission:

- Transfer the know how to wide community,
- Transfer from R&D into serial technology

Contact

Institute of Structures and Design

Department for Component Design and Manufacturing Technologies

Pfaffenwaldring 38 – 40
70569 Stuttgart

Head of Department	Mr. Sebastian Nowotny Sebastian.Nowotny@dlr.de
Head of Composite Technology Group	Mr. Georg Doll Georg.Doll@dlr.de
Manufacturing Simulation	Mr. Daniel Fricke Daniel.Fricke@dlr.de
3D-Printing	Mr. Simon Hümbert Simon.Hümbert@dlr.de
Automated Fibre Placement	Ms. Ines Schiel Ines.Schiel@dlr.de Mr. Lukas Raps Lukas.Raps@dlr.de

References

[1] DLR Institute of Structures and Design, 'Robot-based Continuous Ultrasonic Welding,' *5th Colloquium on Production Technology – special page*, May 2019, https://event.dlr.de/en/10jahre-zlp/robotergestuetztes-kontinuierliches-ultraschallschweissen/

[2] Dreher, P, Chadwick, AR and Nowotny, S, 2019, 'Optimization of in-situ thermoplastic automated fiber placement process parameters through DoE', Proceedings of the SAMPE Europe conference, Nantes, France

[3] Chadwick, AR, Dreher, P, Petkov, I and Nowotny, S, 2019, 'A fibre-reinforced thermoplastic primary structure for sounding rocket applications', Proceedings of the SAMPE Europe conference, Nantes, France

[4] Chadwick, AR, and Willmeroth, M, 2019, 'Use of in-process monitoring and ultrasound to detect defects in thermoplastic AFP-produced parts', Proceedings of the 22nd ICCM conference, Melbourne, Australia

[5] CleanSky 2 Projekt 'Multifunctional Fuselage Demonstrator'

https://www.dlr.de/zlp/en/desktopdefault.aspx/tabid-15354/24923_read-62324/#/gallery/33698