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Fraunhofer Institute for Microstructure of Materials and Systems IMWS

Investigation of Interfacial Shear Strength of Hybrid Fibre-Reinforced Polyamide Composite Structures Made by Fused Granular Fabrication and Automated Tape Laying

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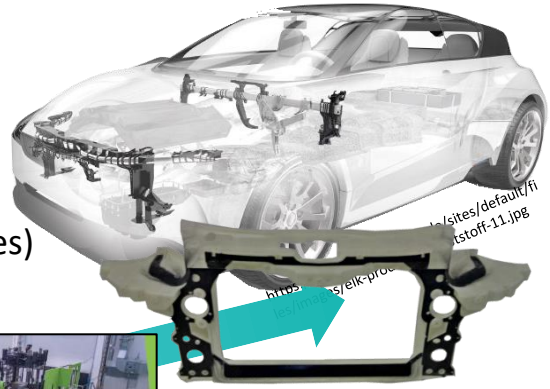
14–16 May 2024 | Messe Erfurt

Polymer Applications @Fraunhofer IMWS

Focus: Thermoplastic lightweight design - material, process and component development

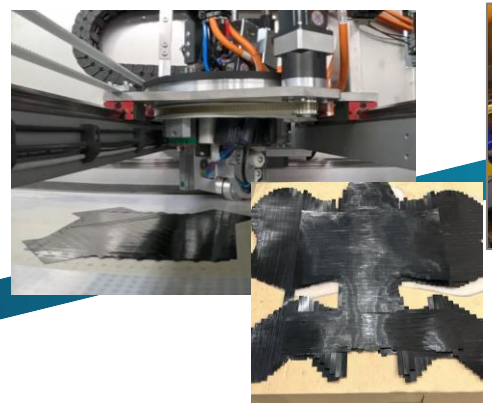
- **Cost-effective materials and semi-finished products** (material and process efficiency)
- **Cost-effective component manufacturing processes** (material efficiency, automation, cycle time)
- **Virtual material, process and component development** (reliability and lightweight design, shortening of development times)
- **TPC-compatible quality control** (reproducibility, in-line monitoring)
- **Recyclability and sustainability** (thermoplastic and bio-based, Design4Recycling)



Hybrid TPC structural component

Hot forming and functionalization in the hybrid injection molding process

Heating and laminate positioning



Tape sheet semi-finished products or tailored tape fabrics

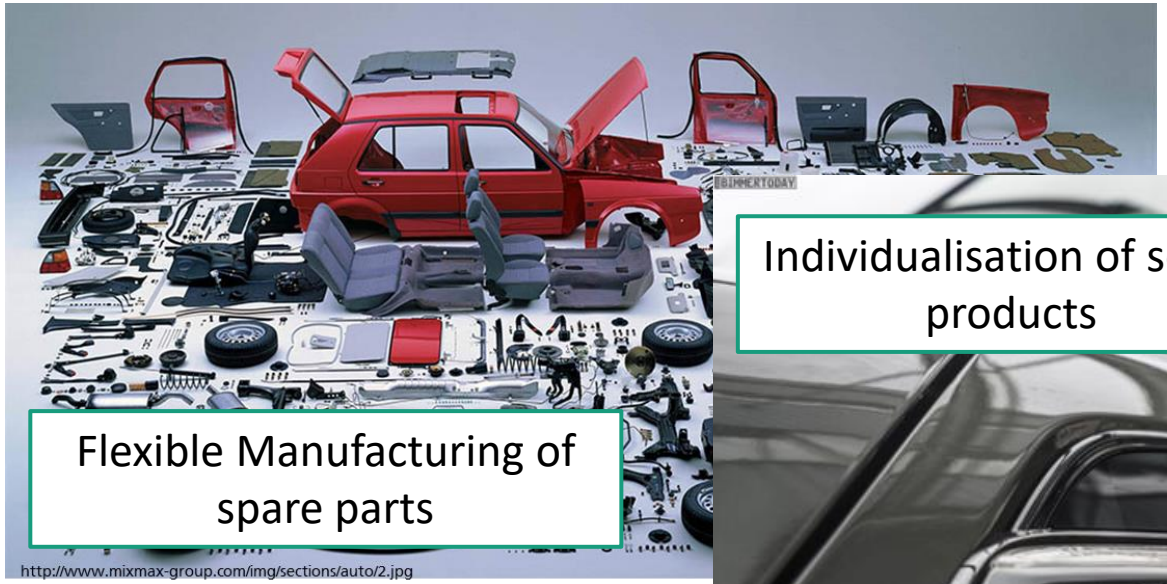
Manufacture of TPC tapes and compounds

LCA

Recycling

Motivation

Industrial AM applications in the future



http://www.mixmax-group.com/img/sections/auto/2.jpg

Flexible Manufacturing of spare parts

Source: eos, ottobock

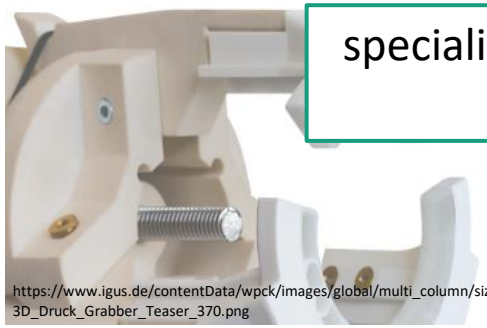
Individualized Medical products

Individualisation of series products

http://cdn.bimmertoday.de/wp-content/uploads/2016/07/3D-Druck-BMW-Produktion-2016-11.jpg

http://www.hamburg-aviation.de/fileadmin/user_upload/140416_K...

Flexible repair techniques



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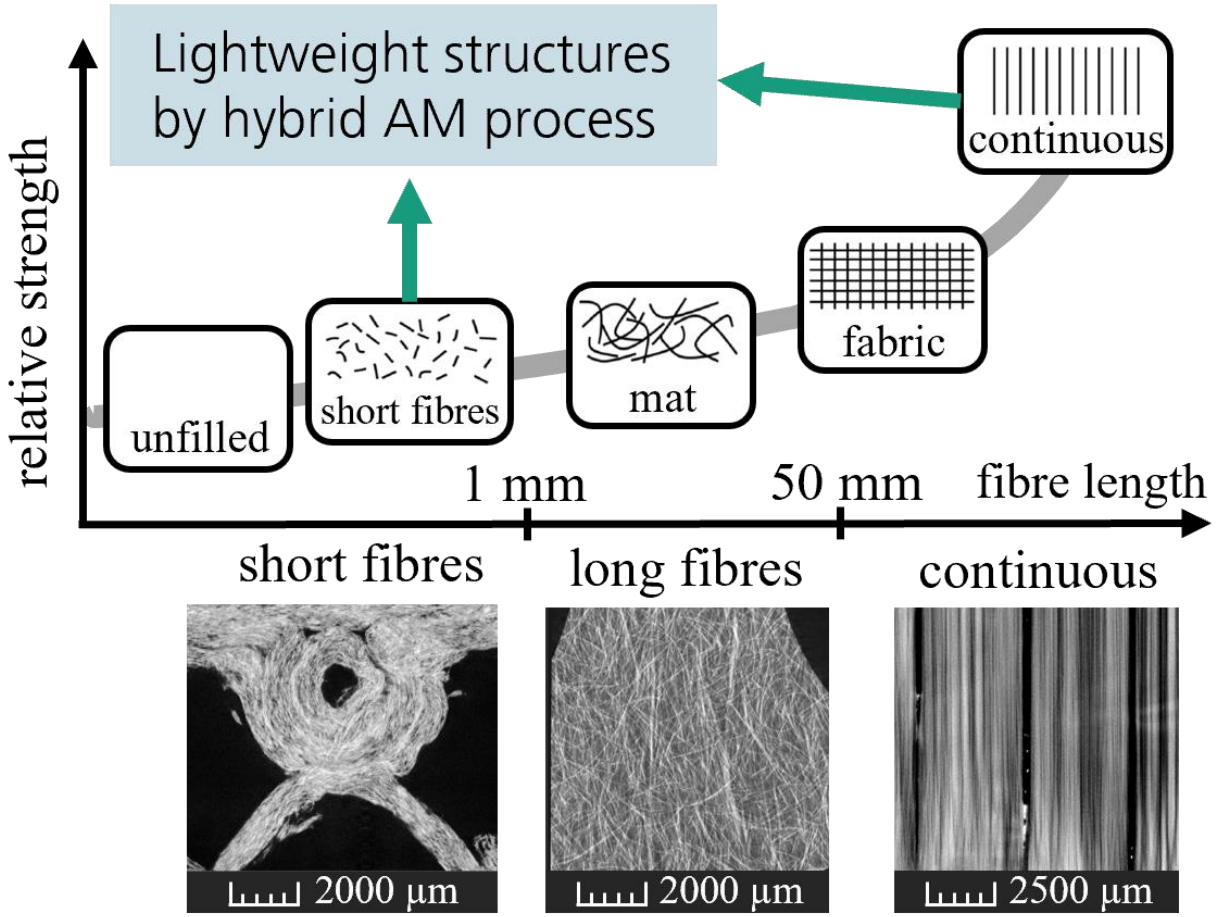
specialized machine parts

Motivation

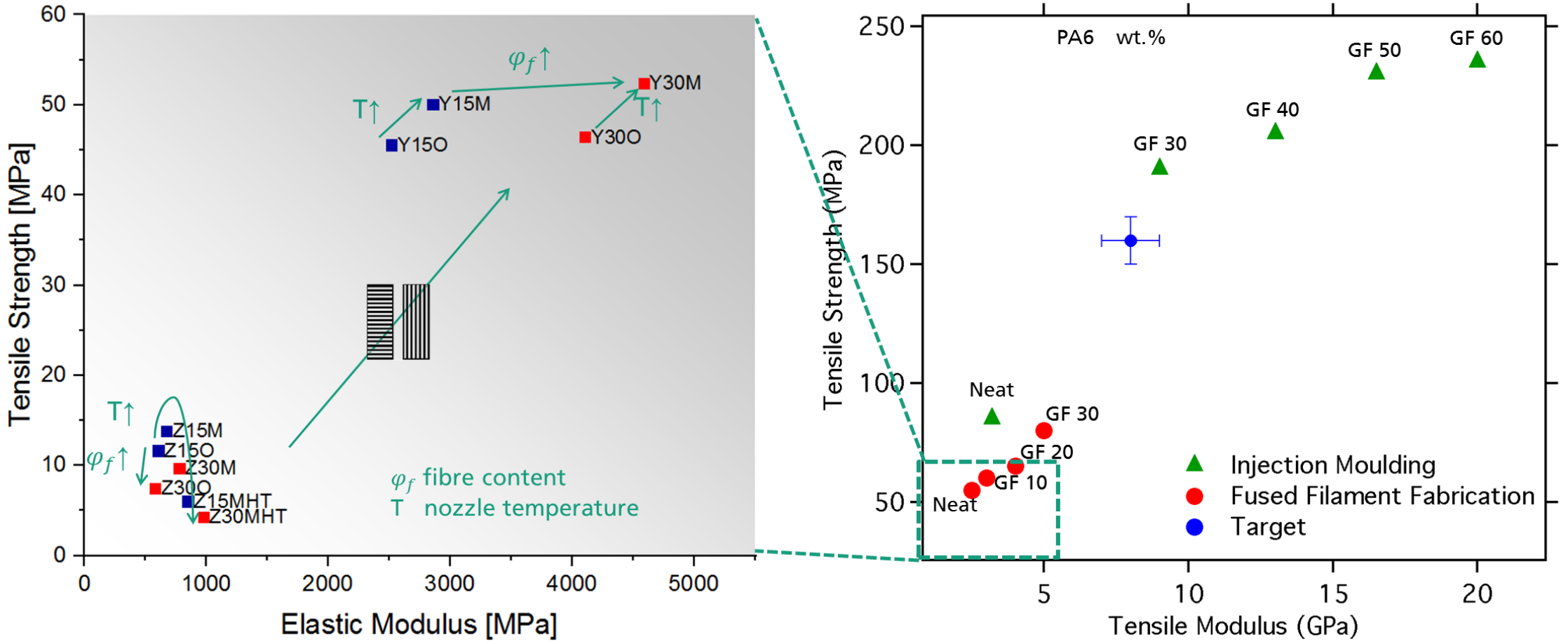
Thermoplastic Composites

- **High economic efficiency**
  - short cycle time, complex geometries, functional integration
- **High mechanical properties**
  - continuous fibres, no fibre undulation, anisotropic
- **High material efficiency**
  - near-net-shape, load-path-compatible, anisotropic, hybrid structure



Motivation

Process Influence and Mechanical Properties of PA6-GF



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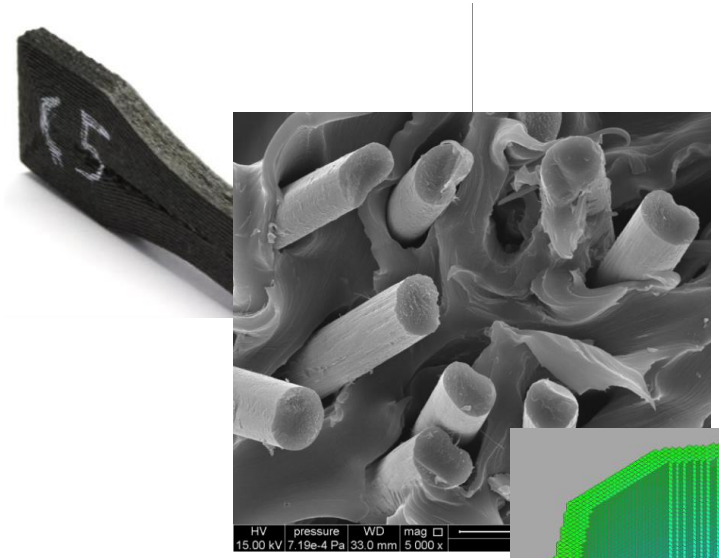
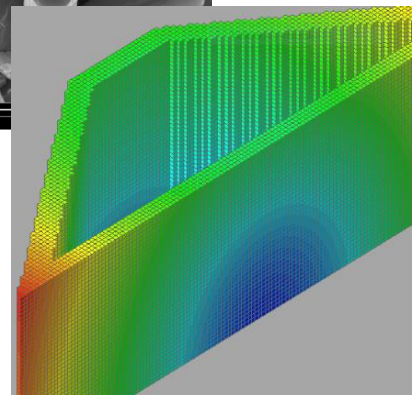
Motivation

So what do we need to do?

Adaption of process and material

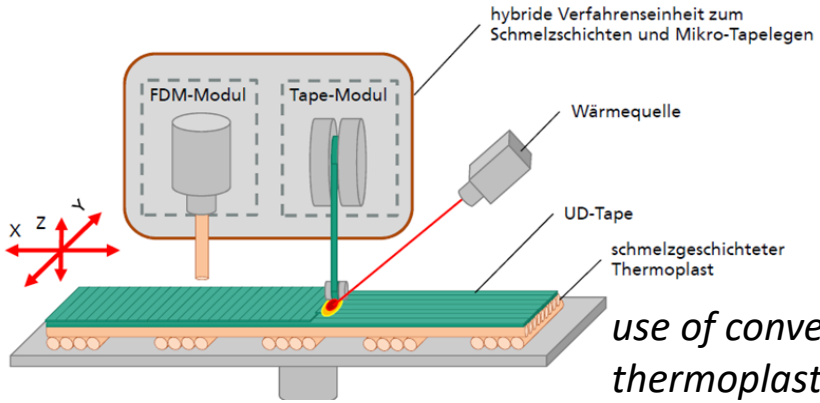
e.g. fibre reinforcement





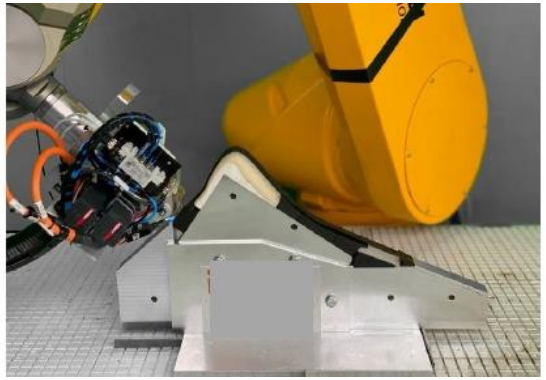
Simulation of the thermomechanical behaviour

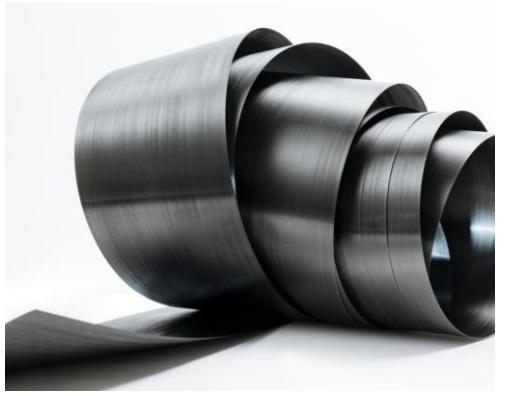
Customized hybrid technologies



use of conventional thermoplastic semi-finished products

e.g. robot-supported, trajectory-based processes



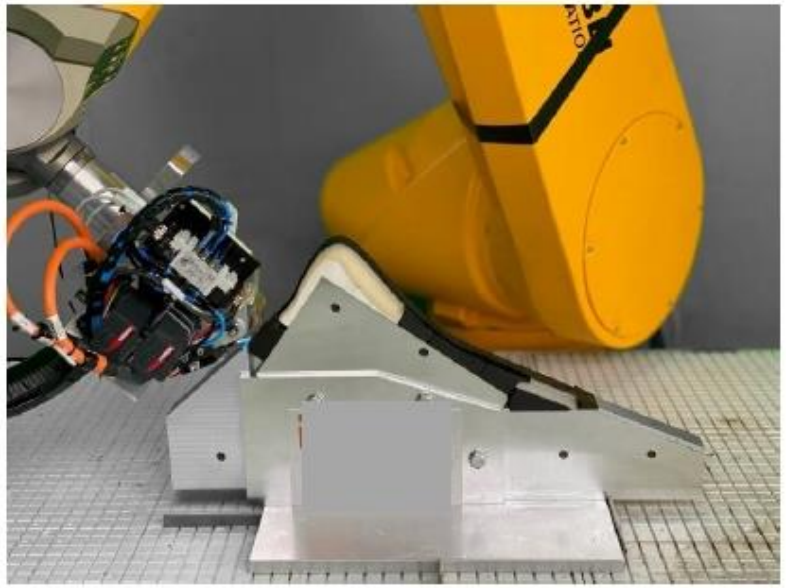


Possible Solutions

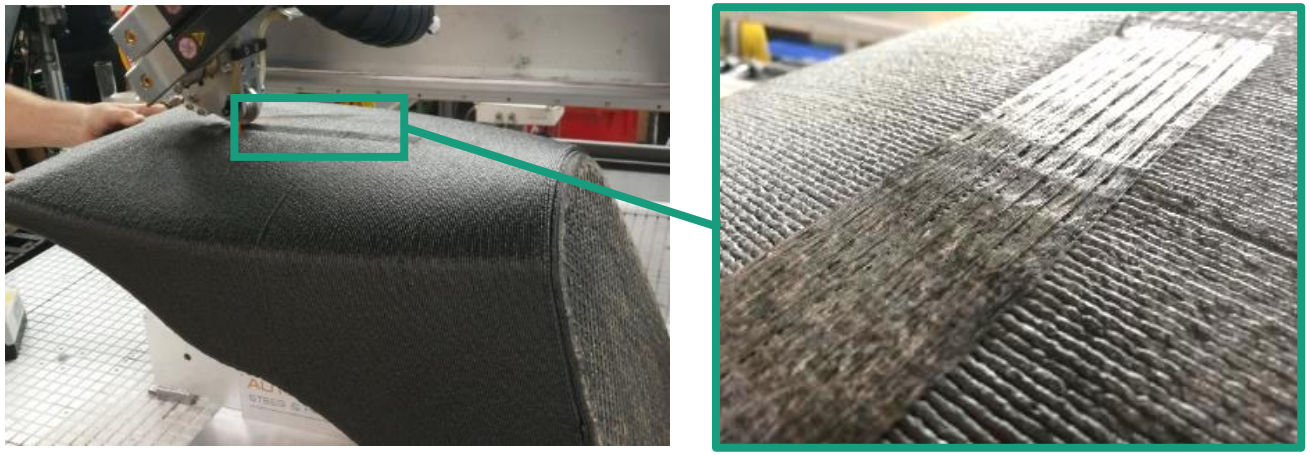
Fused Granulate Fabrication (FGF) + 3D Micro-tape laying

Research Goals

- Increased structural performance of additively manufactured structures through continuous fibre reinforcement
- Efficient technology for continuous 3D fibre reinforcement
- Durable interface between the fibre reinforcement and the additively manufactured base structure
- Design and manufacture of demonstrator structures



Lower leg orthosis



Lightweight seat structure

Materials and Methods

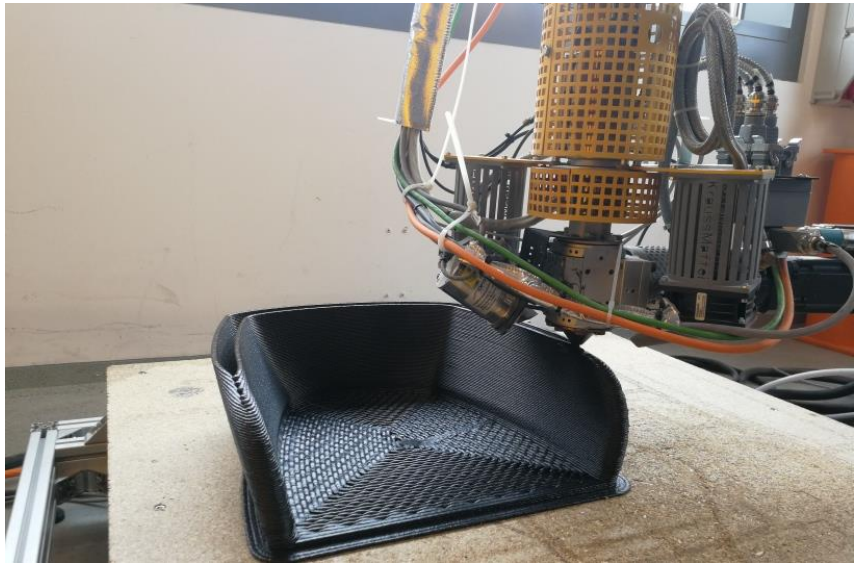
Materials

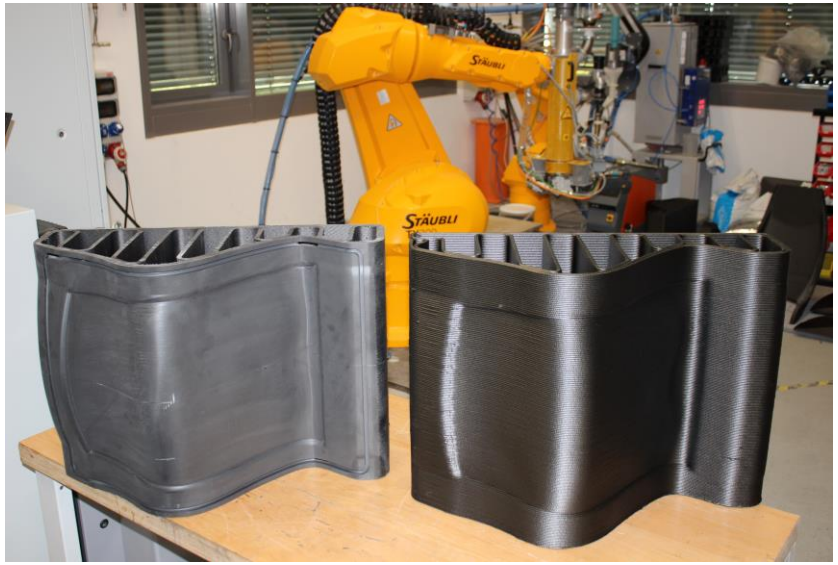
Composite Material	PA6/CF40	PA6/GF60-UD
Grade	AKROMID® B3 ICF 40 black	Celstran® CFR-TP PA6-GF60
Supplier	AKRO-PLASTIC GmbH	Celanese
Reinforcement	carbon fibre	glass fibre
Fibre Weight Content [%]	40	60
Density [g/cm³]	1.31	1.69
Flexural Modulus [GPa]	25 (dry) 17 (conditioned)	32.1 (dry)
Flexural Strength [MPa]	320 (dry) 215 (conditioned)	752 (dry)
Melting Temperature [°C]	220	220

Materials and Methods

Fused-Granulate-Fabrication (FGF)

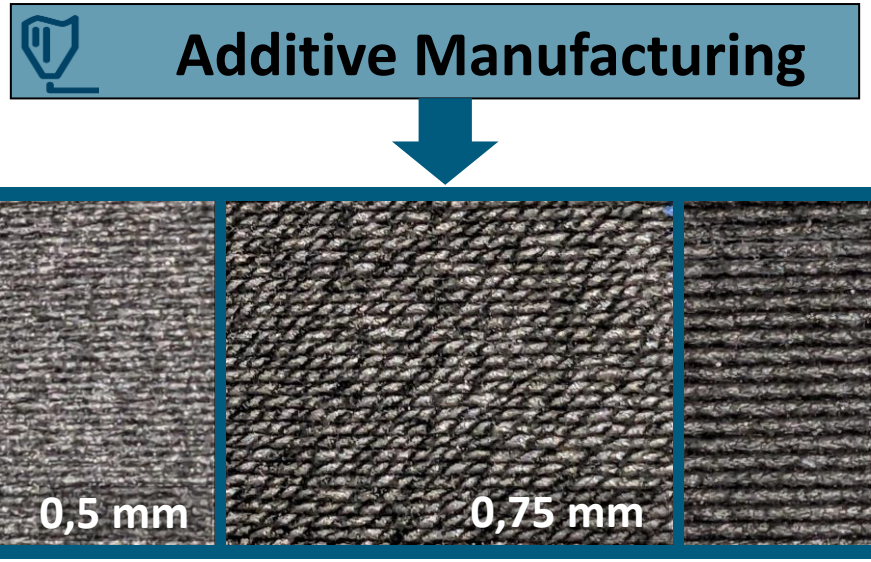
- Extrusion-based 3D printing process in which plastic granulate is melted and deposited layer by layer (5kg/h)
- Stäubli TX200 and Stäubli RX160 industrial robots
- Build volume of up to 3000 x 5000 x 2000 mm



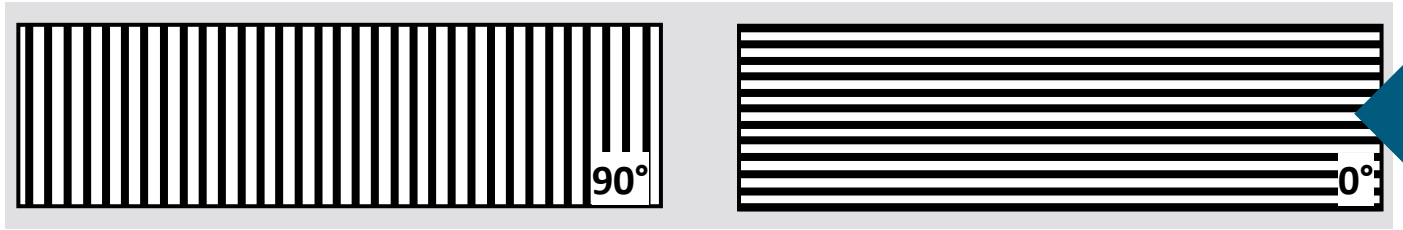


Materials and Methods

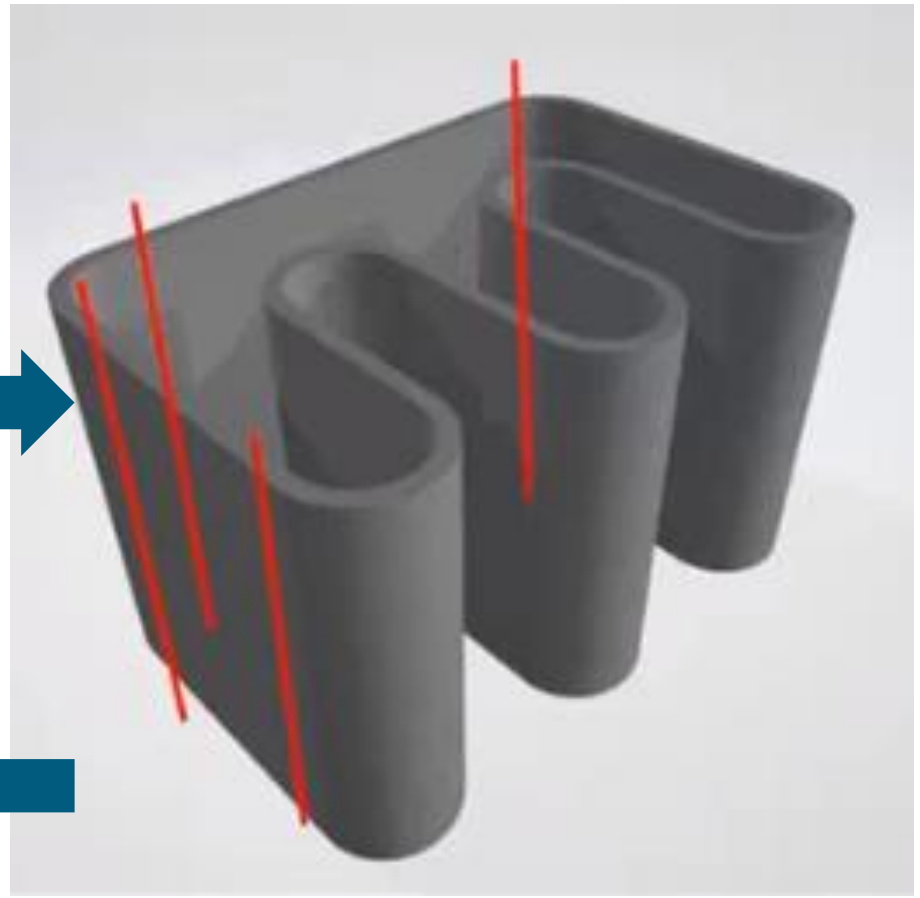
Specimen Preparation



Different Layer Heights



Specimen with different layer orientations



Print model with plates to be cut out

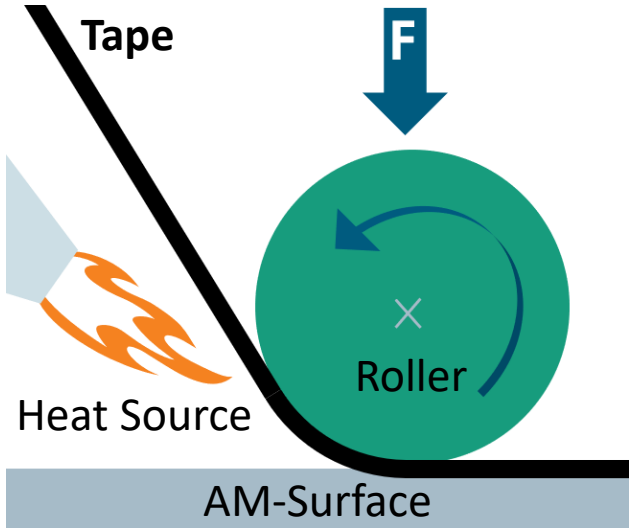
Source: Fraunhofer IWU

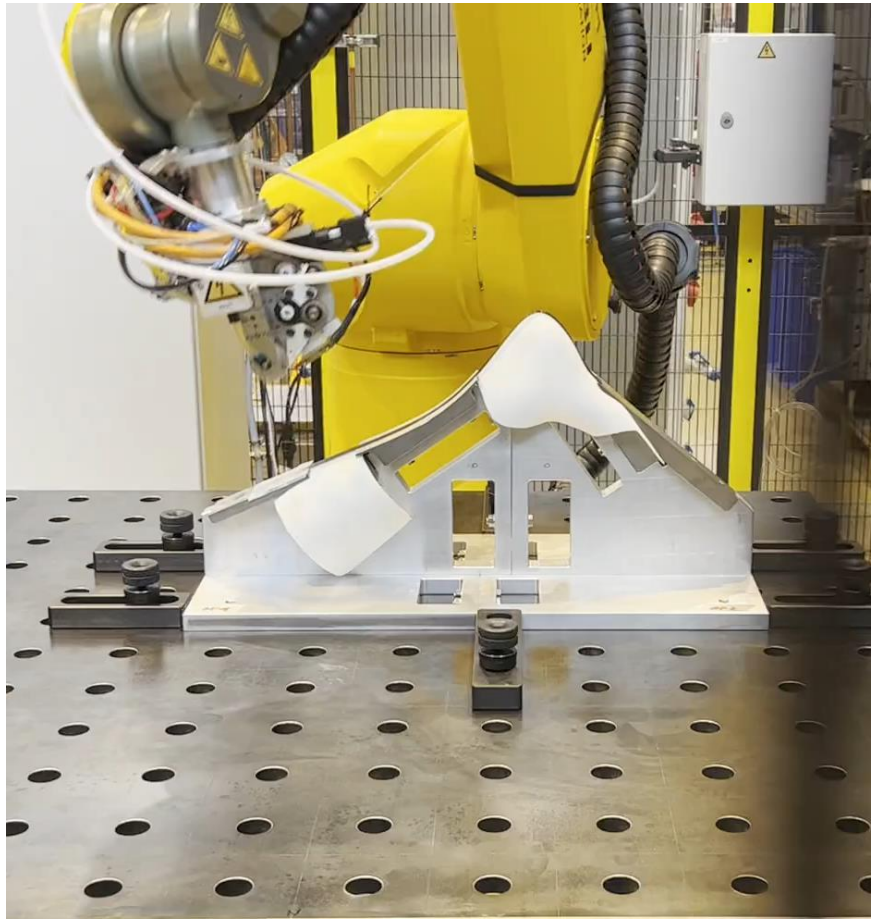
Materials and Methods

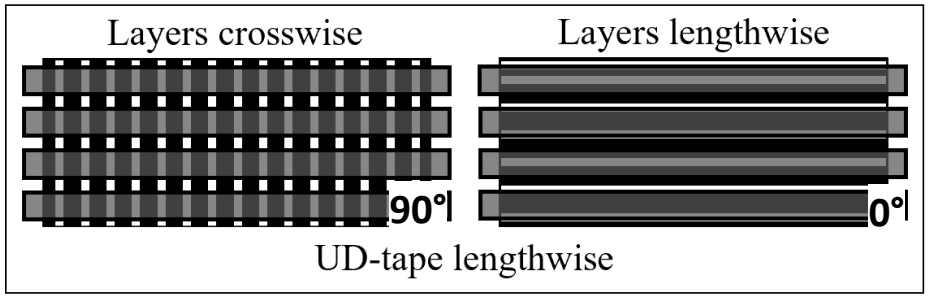
3D Micro-Tape Laying

Automatic Tape Laying Unit « F3-Compositor »

- Tape Laying Head equipped on an **industrial robot**
- Tape with molten matrix is consolidated the AM Surface
  - **In-situ process**
  - Constant force
- Open flame heating mechanism
- Laying Speed up to 1000 mm/s



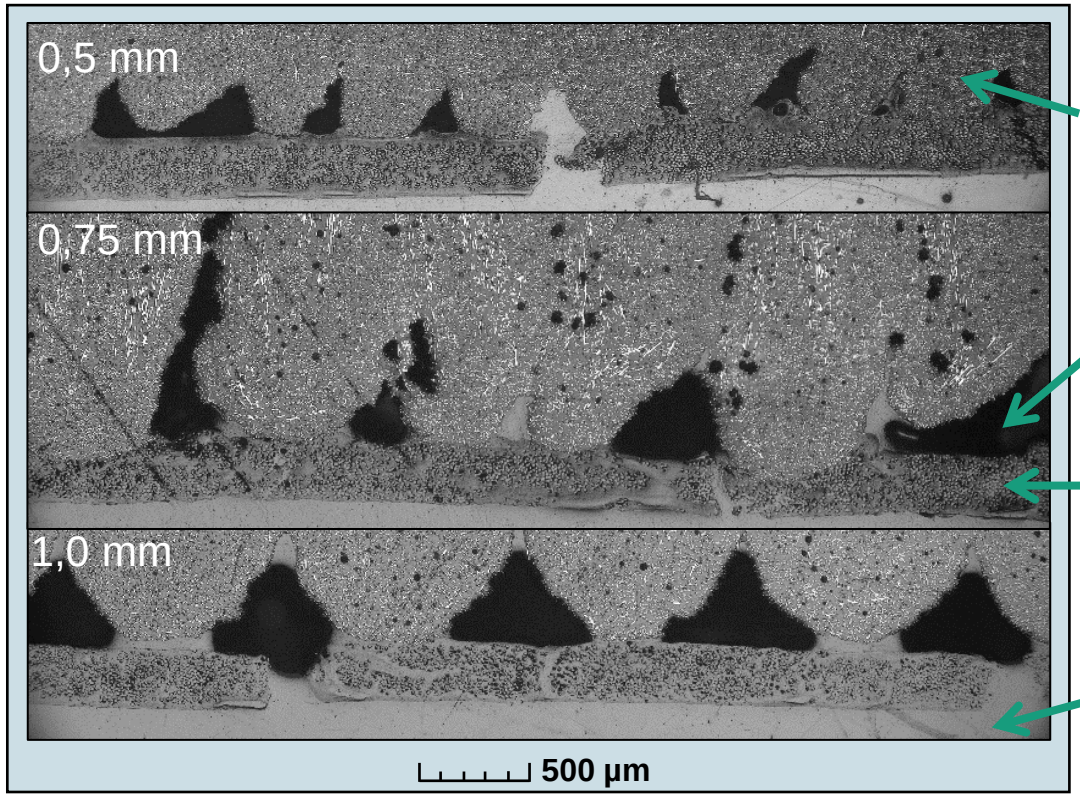




Results

Morphology

Micrographs

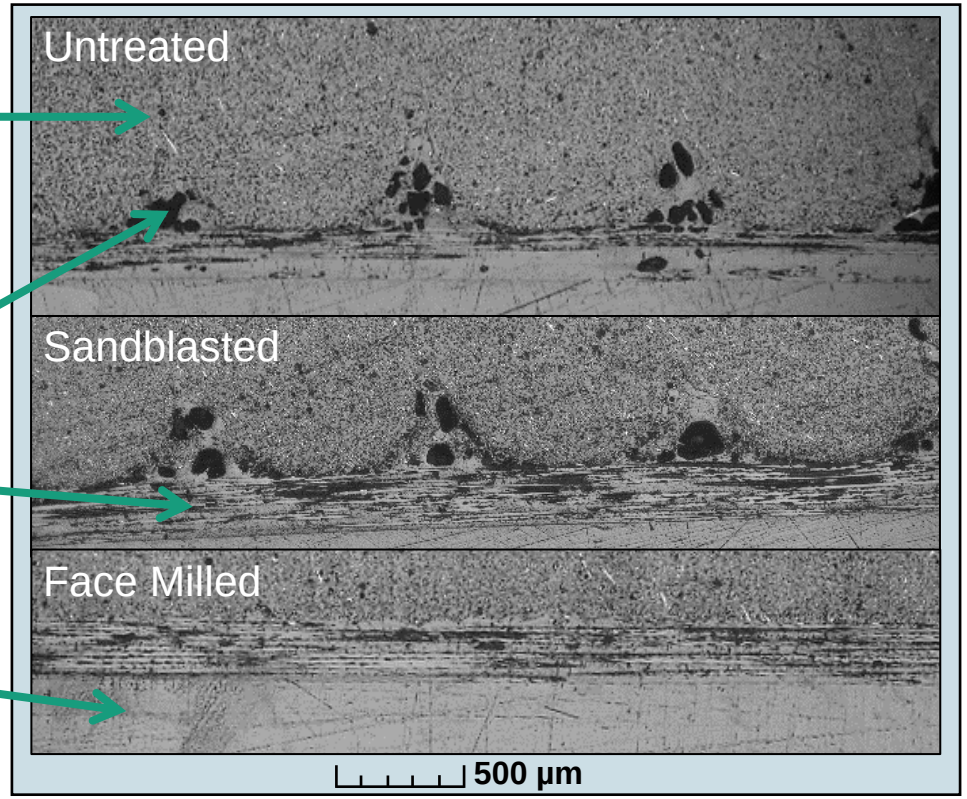


Base Structure with carbon fibres

Air / Pores

UD-Tape with Glas fibres

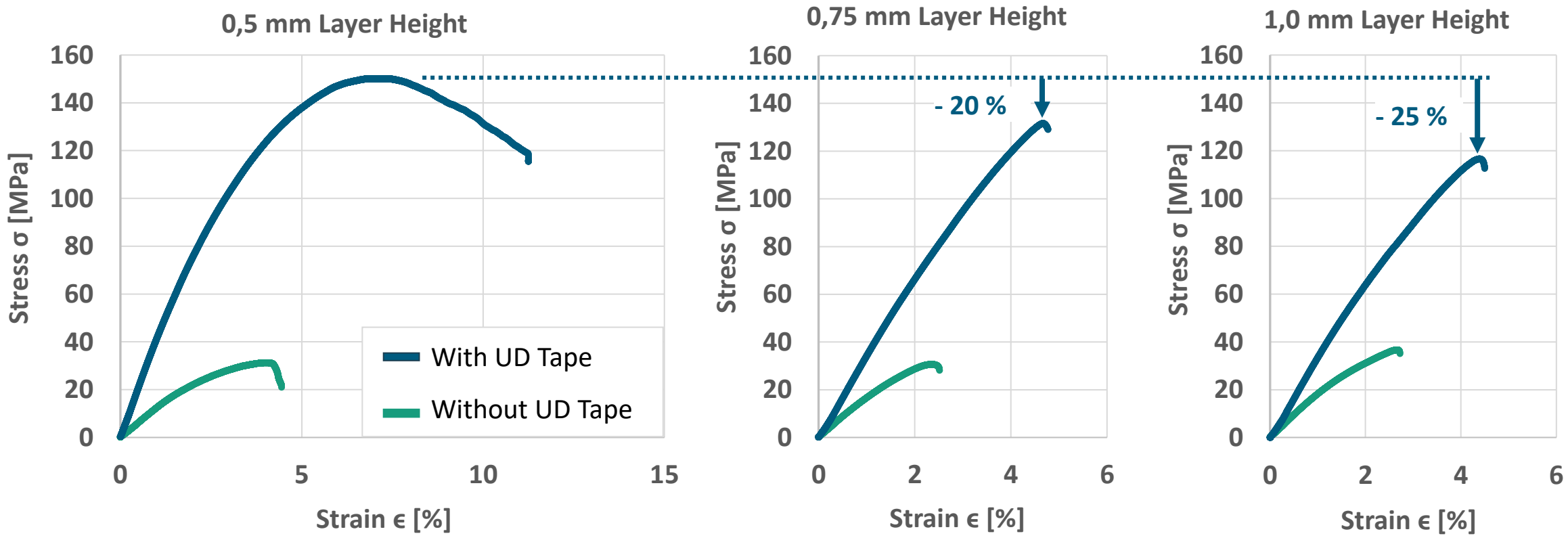
Epoxy



Results

Mechanical Analysis

3 Point Bending Tests 90° specimen / UD Tape layers crosswise / untreated surface

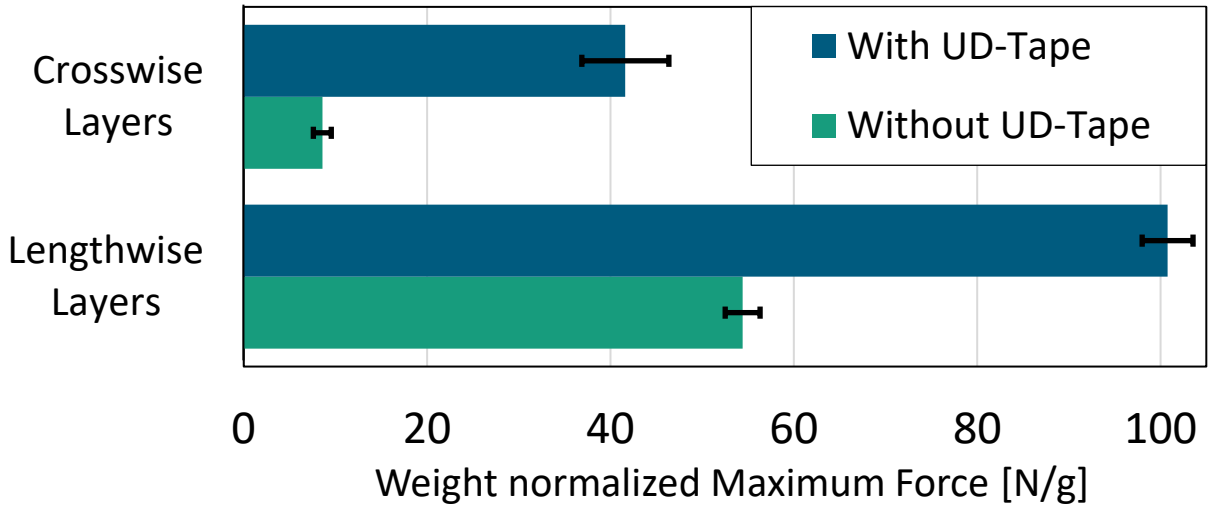


Results

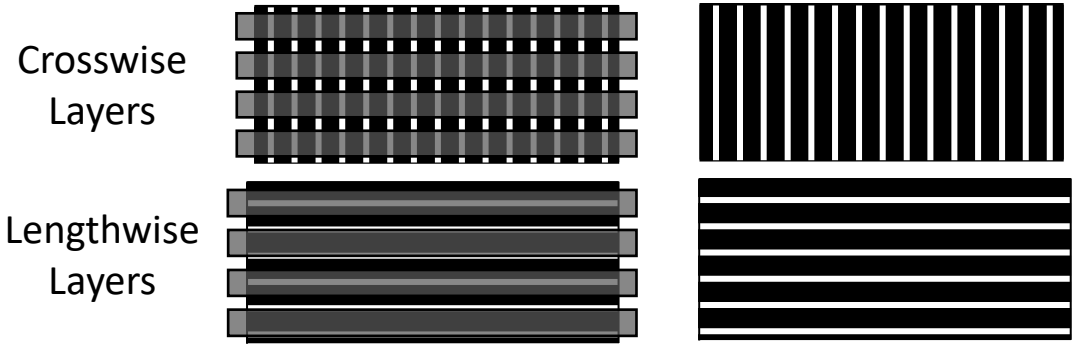
Mechanical Analysis

3 Point Bending Tests, weight normalised

- Fundamental increase
  - Independent of layer orientation
- Tape laying on crosswise layers almost equalises anisotropy



Associated Test Specimen:

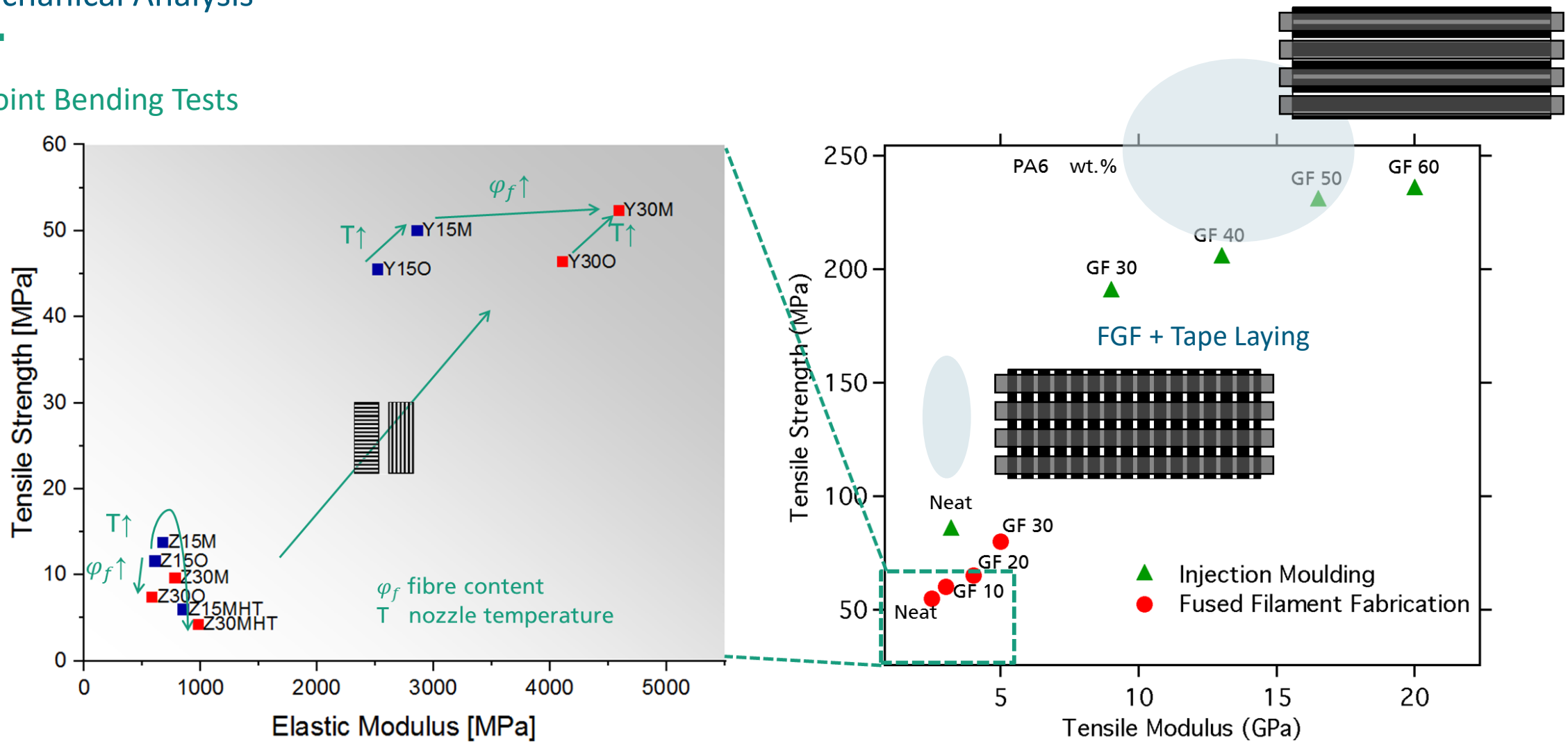


0,5mm Layer Height

Results

Mechanical Analysis

3 Point Bending Tests



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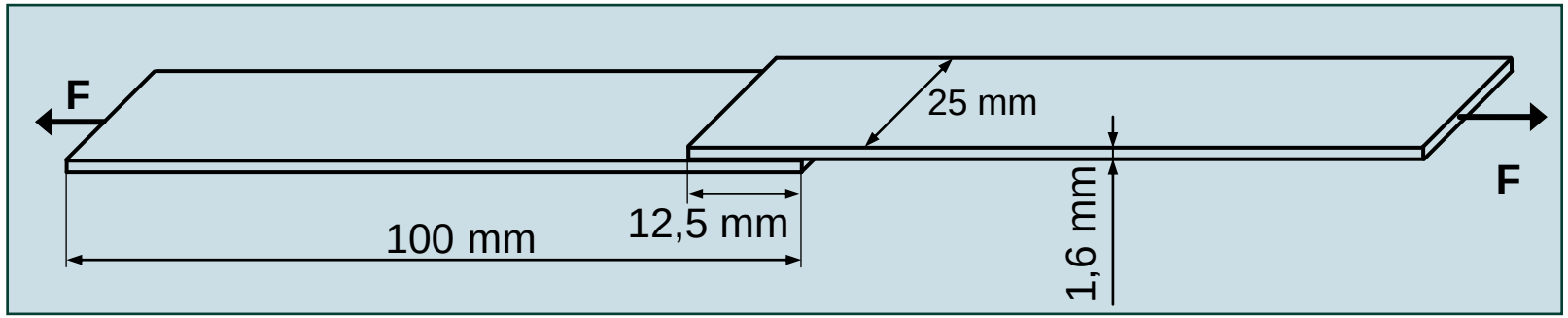
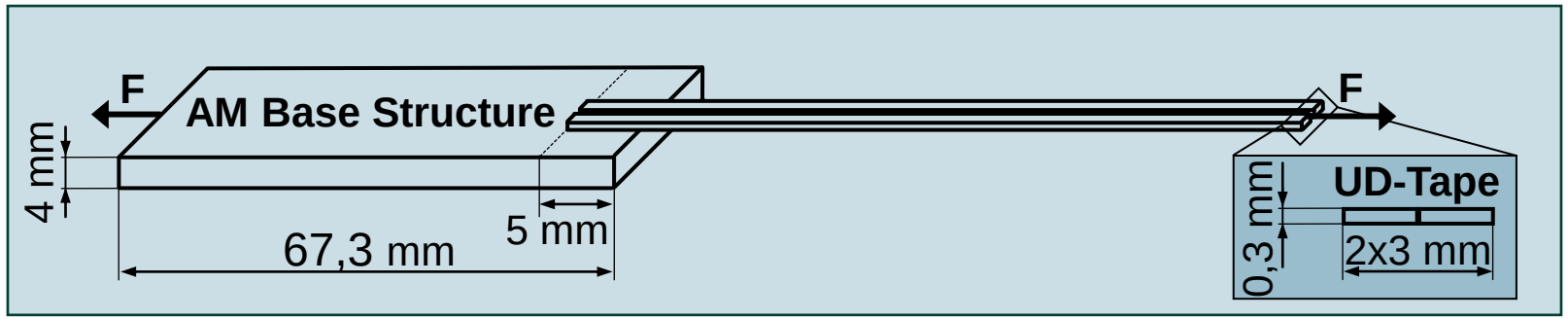
Materials and Methods

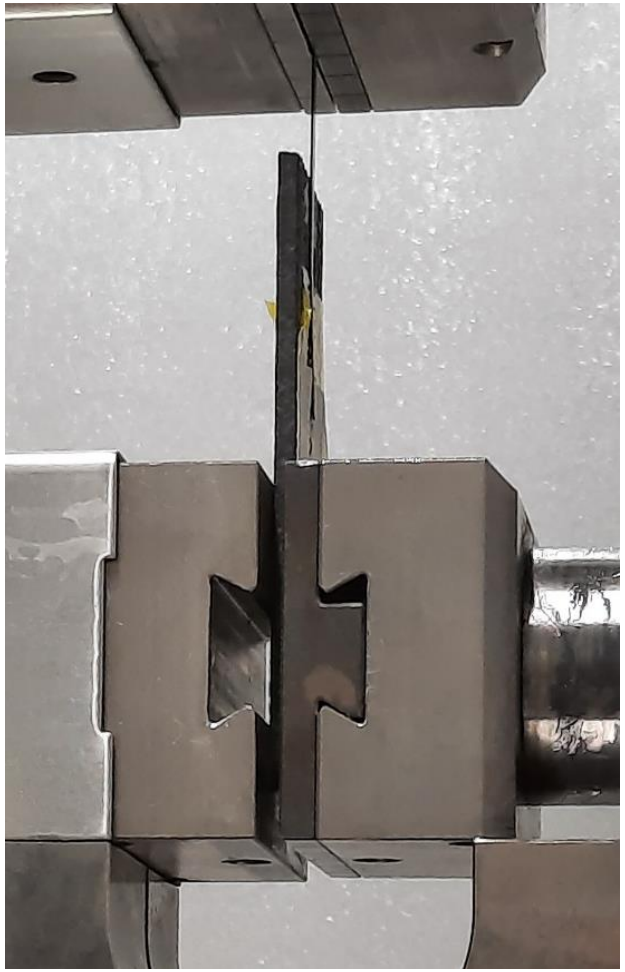
Modified Lap Shear Test

Adapted from DIN 1465



Modified for AM



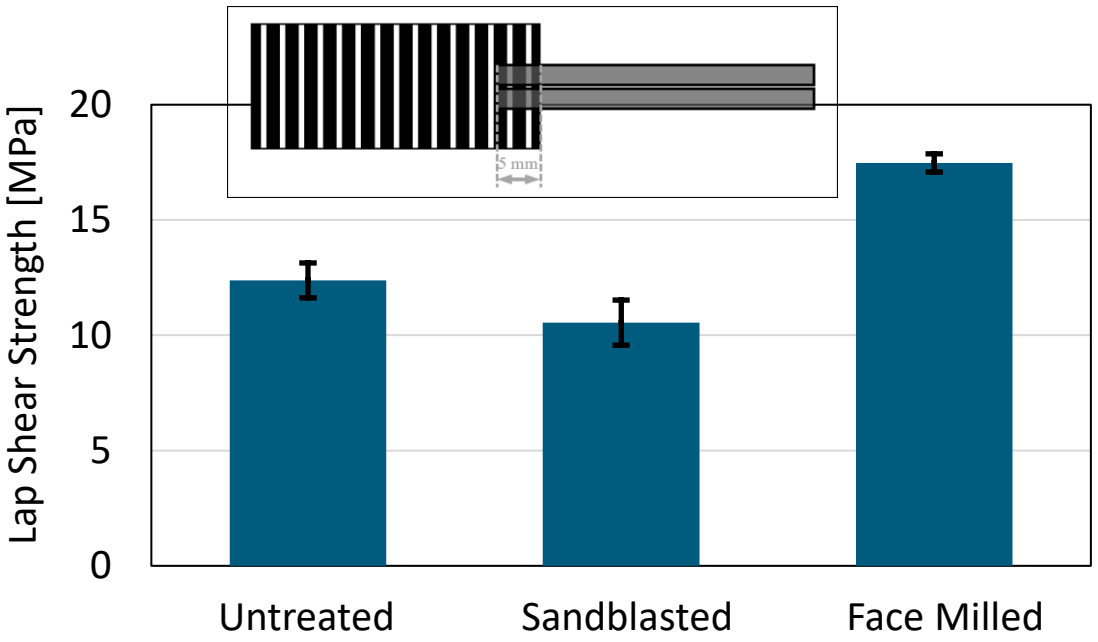


Results

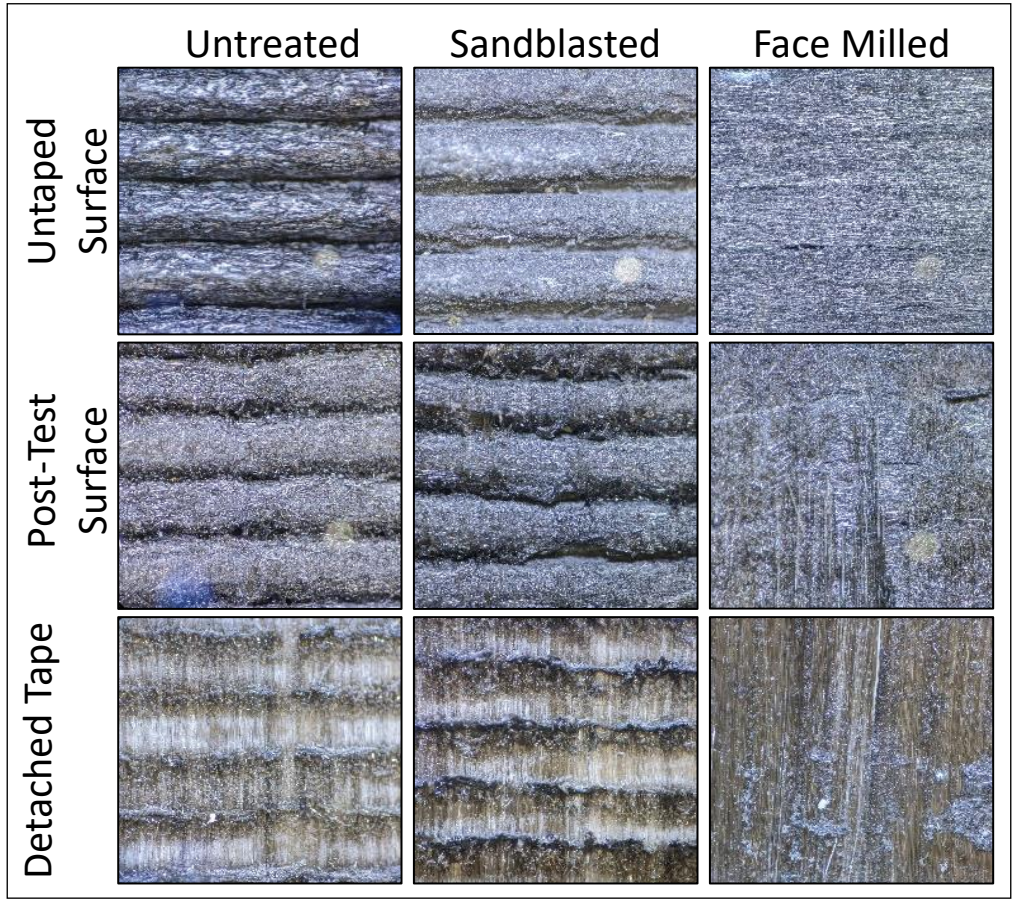
Mechanical Analysis and Morphology

Modified Lap Shear Test / 90° specimen

- Sandblasting = negative Effect
- Face Milling = 44% Improvement



Microscopic Analysis



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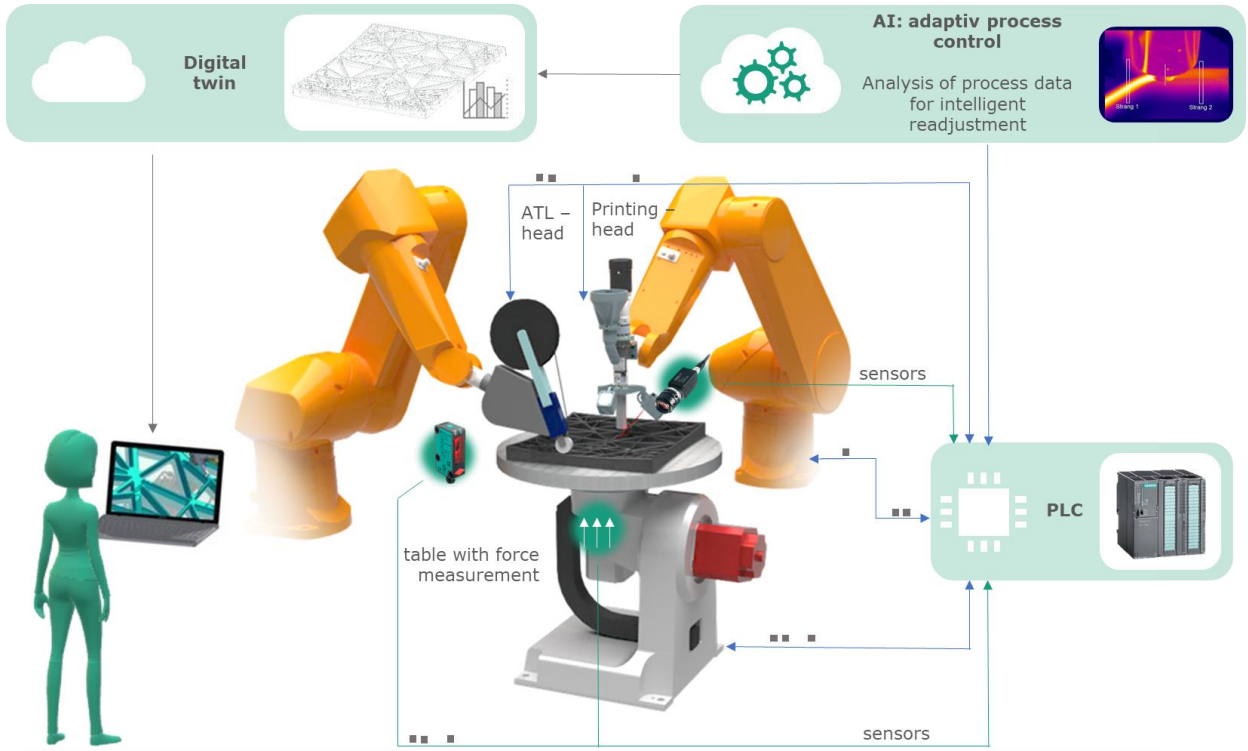
Conclusion and Outlook

Hybrid Fibre-Reinforced Polyamide Composite Structures

- **Fibre reinforcement** (short fibres, continuous fibres) and the use of conventional semi-finished products (e.g. UD tapes) enable an increase in structural performance
- Process concept of **3D micro-tape laying** successfully tested
  - Tape laying on crosswise layers almost equalises anisotropy
  - The bond between UD-tape and AM plates is crucial for the reinforcing effect
  - Ridged surface significantly reduces contact area between UD-tape and FGF base structure
  - Face milling significantly increases lap shear strength

But there is still a lot to do:

- Increased understanding of materials and processes through the application of **established materials engineering** and **materials mechanics methods** as well as **quality assurance** methods for processes and parts



AddiQ: Teilprojekt im Rubin-Netzwerk

Qualitätssicherung in der Additiven Fertigung

AddiQ Qualitätssicherung in der Additiven Fertigung

RUBIN Regionale unternehmerische Bündnisse für Innovation

VISIT BOOTH of GMBU @RapidTech

Ziel des Netzwerks:

- Innovations- und Wettbewerbsfähigkeit insbesondere kleiner und mittlerer Unternehmen (KMU) stärken
- Hochschulen und Forschungseinrichtungen dabei unterstützen, sich noch stärker für die Verwertung ihrer Forschungsergebnisse und daraus entstehende Innovationen zu engagieren

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MODELL TECHNIK · NEL Leuchtet ein! · PSM · DVS SLV HALLE · SONOTEC ULTRASONIC SOLUTIONS · < studio.201 > software-developer · Technische Hochschule Brandenburg University of Applied Sciences

Acknowledgements

Many thanks to the entire project team!

Cornelius Rackwitz[1] · Simon Scholz[1] · Moritz Vyhnal[1] · Patrick Hirsch[1] · Ralf Schlimper [1] · Matthias Zscheyge[1] · Ondrej Kotera[2] · Michaela Stipkova[2] · Sebastian Scholz[2]

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And many thanks to the funding organizations:

Bundesministerium für Bildung und Forschung

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