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CLEAN JOINING TECHNOLOGIES FOR FUTURE MULTI-MATERIAL DESIGNED PARTS USING PULSED LASER

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ABSTRACT

Change from metallic materials to fiber-reinforced plastics (FRP) is progressing steadily, for its resource saving capacities. Along goes the adaption of production processes. One approach to produce high loadable lightweight structures is the FuPro-Design. Hollow thermoplastic composites (TPC) profiles are combined with TPC sheets, metallic parts and functionalized using the injection molding process. However, there is a R&D need in combining the diverse requirements of complex components in an environmentally compatible way.

The Multi Material Design for Recycling (MM4R) project aims at the eco-balance: reducing variety of materials, improving separability and avoiding contamination. Besides the weight reduction compared to aluminum, the objective is the avoidance of additional adhesive promoter materials. Here, the pulsed laser technology is the chosen approach.

This work offers insight into the possibilities of pulsed laser processing of compound lightweight materials. Selective processing of the temperature-sensitive FRP becomes possible since non-contact processing prevents any mechanical stress and thermal damage can be prohibited. The joining mechanism bases on a surface structuring resp. the exposure of the fiber reinforcement on the surface of the composite with the effect of achieving high joining strength when the structure is further processed. With no adhesion promoters, laser processing is a clean technology for surface pretreatment for joining processes like injection molding / over molding, 3D printing, bonding or metallization.

The presented studies show the advantages of the laser technology in two applications. TPC sheets were pretreated using laser radiation in order to improve the pull-off strength of over-moulded rib-parts. Laser pre-treatment could significantly improve the bonding strength of over molded solid TPC-sheets, showing an improvement of 713 % compared to the untreated samples and 128 % compared to hot over molding. Secondly, the laser pre-treatment was performed before hot pressing TPC and FRP sheet, which were evaluated in single-lab sheer tests.

AGENDA

- Motivation
- State of the Art
- Materials & Processes
- Treatment Results
- Looking Forward

MOTIVATION | MM4R approach

- Reduction of material variety; replacement of metallic functional structures (weight, environmental impact, energy invest)
- Avoidance of contamination (with additional adhesive promoters)
- Improvement of separability and recyclability

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- Economic attractiveness
- Compleyxity of components and demands

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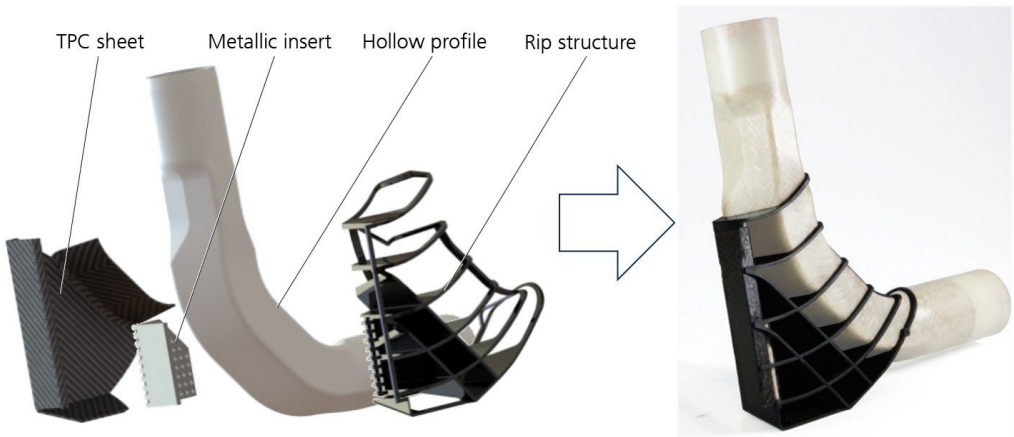
- Recycling-ready multi-material design for lightweight structures
- Enhancement of adhesion strength to join to foreign material via
  - Hot pressing (to metal / TPC)
  - Injection molding



Generic FuPro Structure
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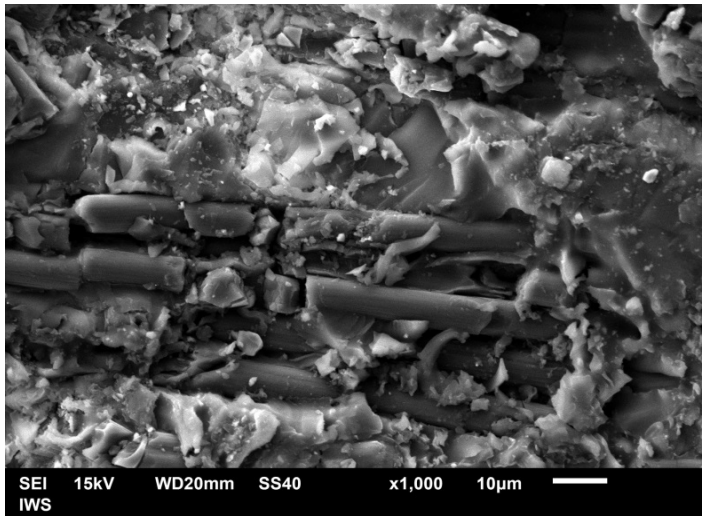
STATE OF THE ART

- No pre-treatment for injection molding
- Occasional surface pre-treatment on FRP is mechanical blasting
  - Fibers get impaired and stick out of the surface
  - Broken fibers and matrix fragments on the surface lead to shadowing effects during coating process
  - High rejects and low reliability of joining zone are the consequences
- Current challenges:
  - Higher bonding strengths required for more opportunities in material choice
  - Defined material removal
  - No damage of surface-near and load bearing fibers during surface pre-treatment
  - Defined and locally limited joining areas

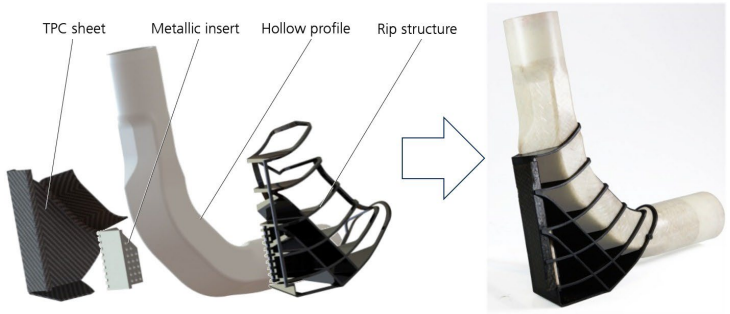


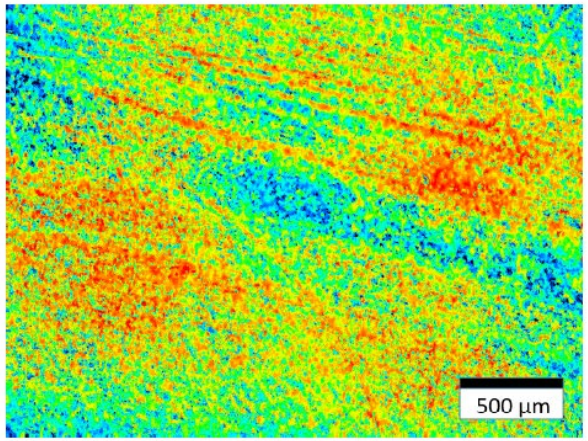
SEM image of corundum blasted CFRP at 0.7 bar

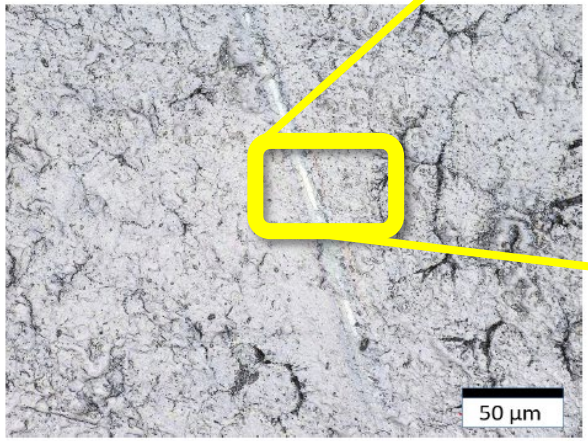
FRP suitable surface pre-treatment method required

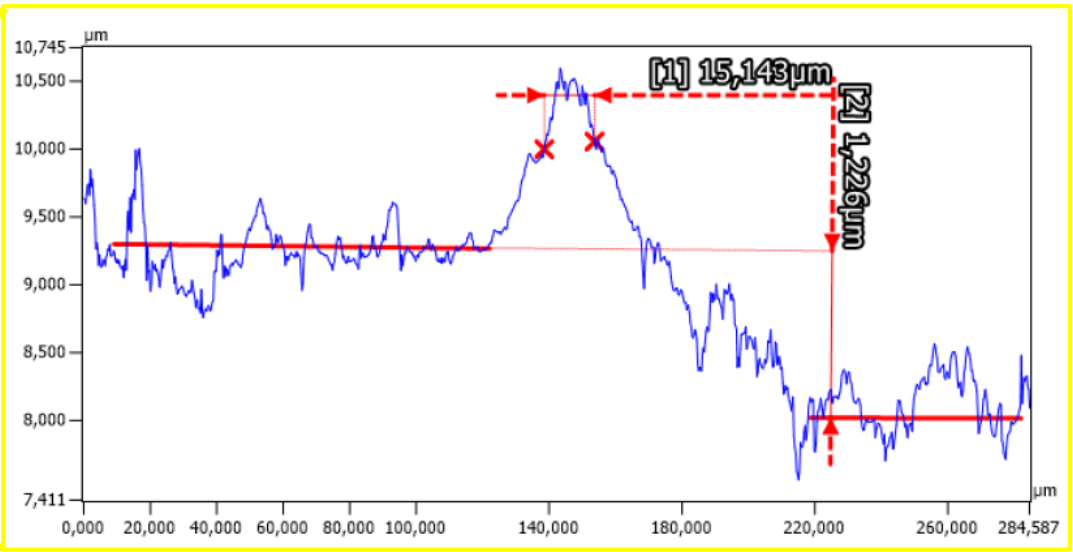
MATERIAL

- TPC hollow profile:
  Enka® TecTape GF-PA 1800tex 6733 (glass fiber 41 vol.%)
- TPC sheet:
  Lanxess Tepex® dynalite 104-RG600(x)/47 (glass fiber 47 vol.%)
- PA (for injection molding)
- Al AW1050 | AW5754, Steel 1.4301 (for hot pressing)







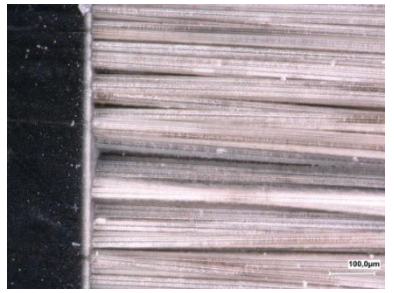


Confocal microscopy images of native consolidated hollow section profile with close-to-surface glass fiber

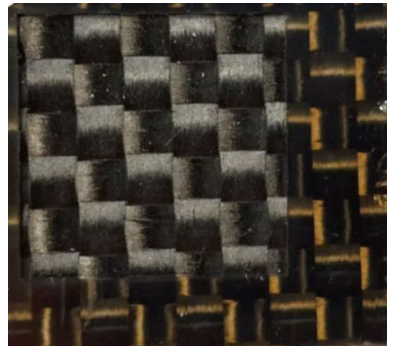
LASER PRE-TREATMENT | Arguments

Advantages of pulsed laser processing of fiber-reinforced plastic:

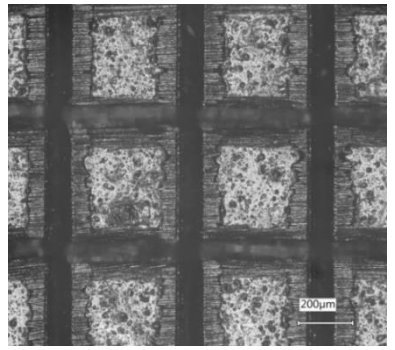
- Defined material ablation of matrix or matrix & fibers
- Damage-free exposing of load bearing fibers
- Selective matrix removal enables form fit with joining partner
- Flexible, localized treatment without masking
- High design flexibility
- Avoiding mechanical load
- “Cold” material ablation possible



Selective matrix removal on glass fiber reinforced polyamide, unidirectional



Selective matrix removal on carbon fiber reinforced epoxy, woven

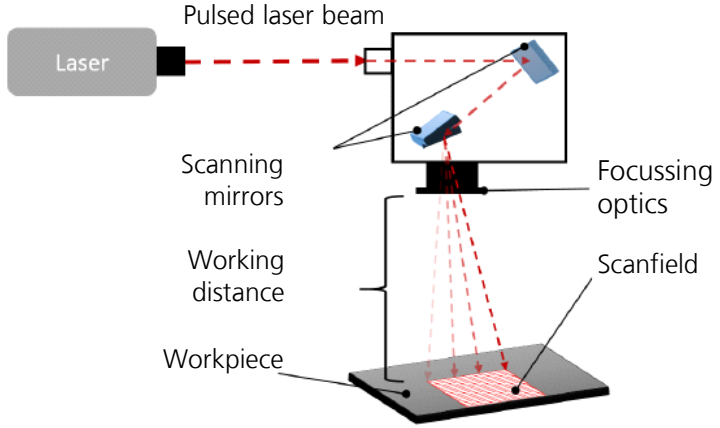


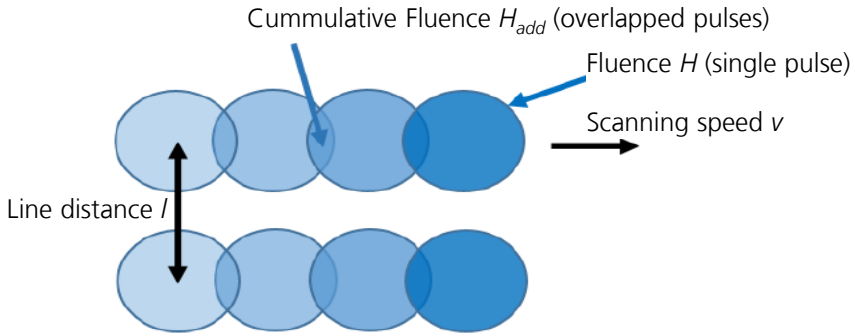
Trench-like pattern on carbon fiber reinforced epoxy , unidirectional

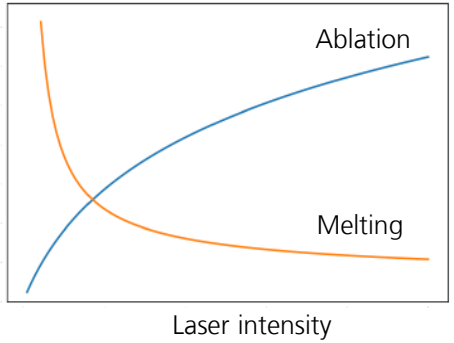
Laser based surface structuring is the most promising alternative

LASER PRE-TREATMENT | Setup & processing

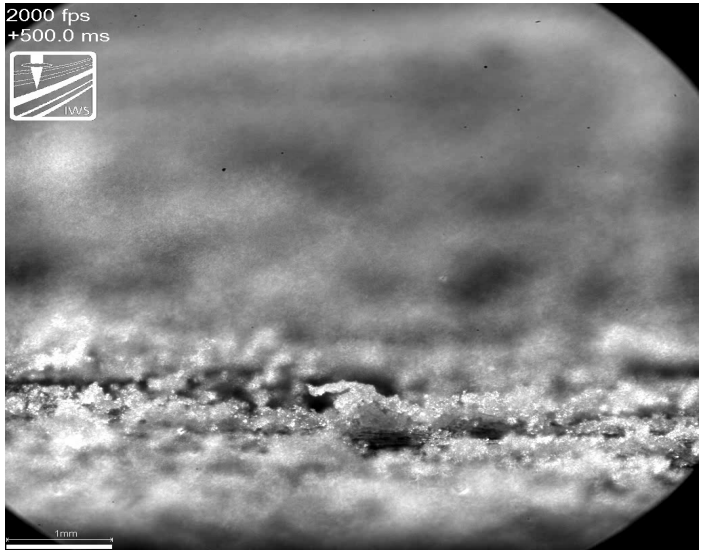
- Solid-state Nd:YAG laser
  - Wavelength: 1064 nm
  - Pulse duration: ~150 ns
  - Pulse frequency: ≤ 100 kHz
- F-Theta plan-field focusing lens
  - Focal width: 300 mm
  - Scanfield size: 240x240 mm²
- Removal process
  - Ablation regime = f (H | H_{add} | v)







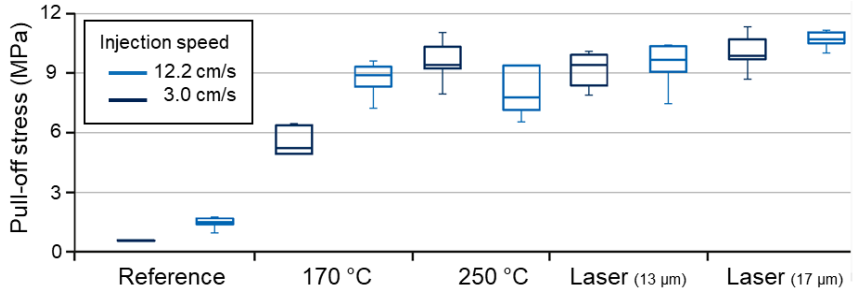
Overlapping pulses during laser irradiation | Trends of laser processing behaviour

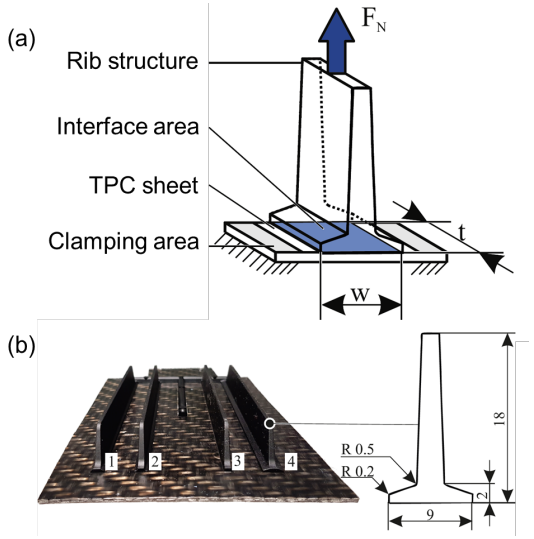


High-speed video of selective matrix removal with pulsed laser

LASER PRE-TREATMENT | Injection molding results

- Comparison of pulsed laser structuring (ns pulsed laser, 1064nm) with alternative pre-treatment methods
- Conditions: untreated, hot over molding, selective matrix removal (two line distances)





Shape of the test specimens,
from: ILK, Technische Universität Dresden,
DOI: 10.1016/j.procir.2019.09.047

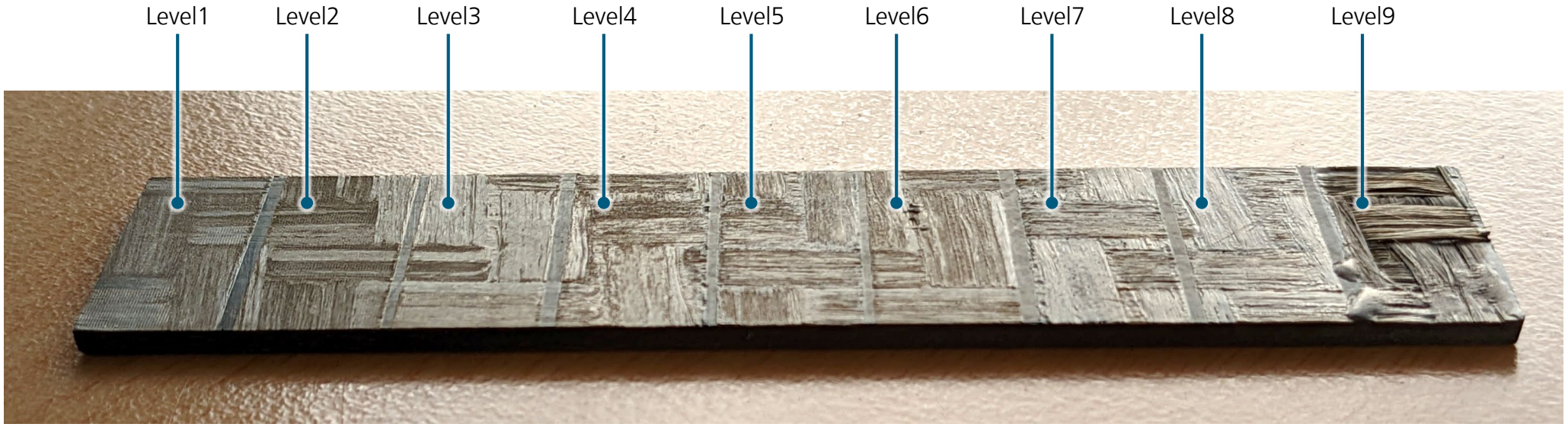
Seven times higher adhesive strength with surface pre-treatment with pulsed laser compared to untreated surface.

28% higher adhesive strength with laser structuring compared to hot over molding.

Load through system of a car (TPC sheet, laser treated, hot over-molded),
in cooperation with Chemnitz University of Technology

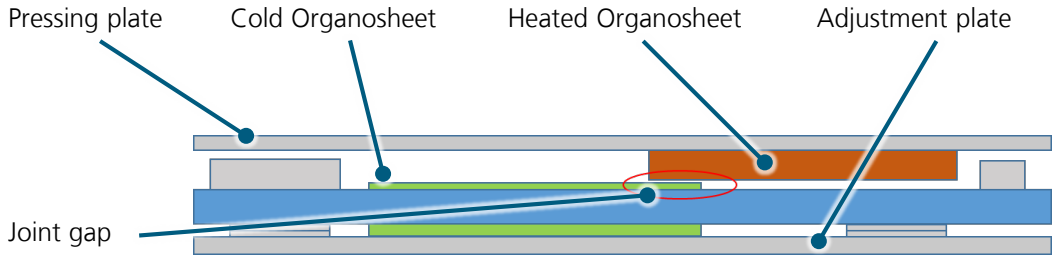
LASER PRE-TREATMENT | Press-joining results

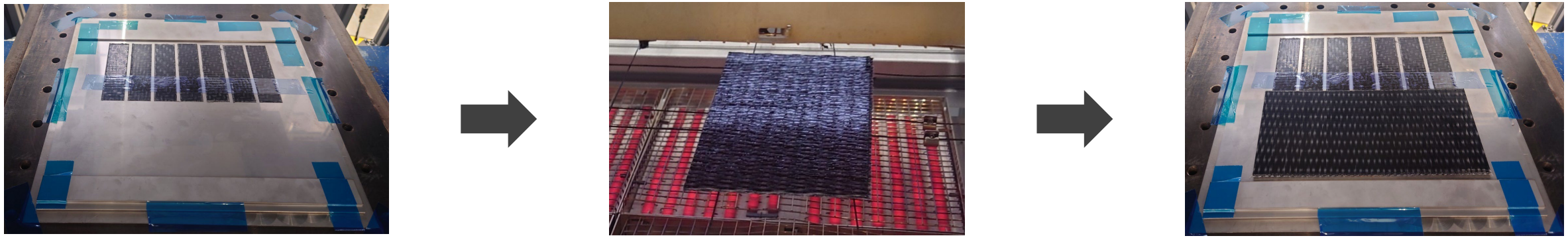
- Comparison of various pulsed laser structuring intensities (ns pulsed laser, 1064nm)
- Various degrees of fiber bundle exposure
- Scope:
  - Influence of different surface structures on joining strength
  - Influence of different joint gaps on joining strength



LASER PRE-TREATMENT | Press-joining results

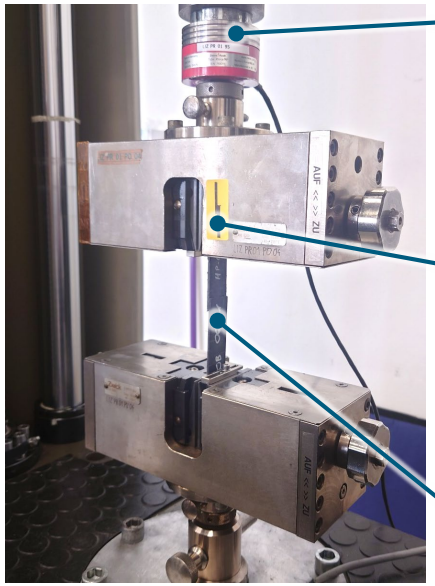
- Specimen preparation:
  - Placing cold specimen in carrier
  - Heating up of Organosheet in IR-oven
  - Isothermal pressing





LASER PRE-TREATMENT | Press-joining results

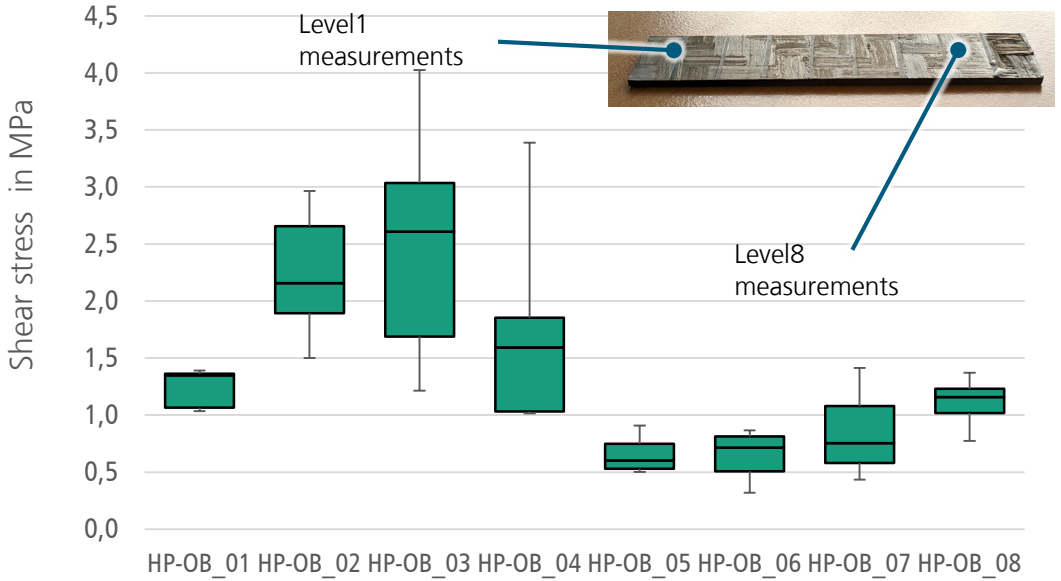
- Single-lap-shear testing:
  - Standard: DIN EN 1464
  - Pre-force: 10 N
  - Testing speed.: 1 mm/min
  - Test climate: 23°C, 50% rLF



Clear Impact of laser treatment and joint gaps on shear stress, but quite large value range

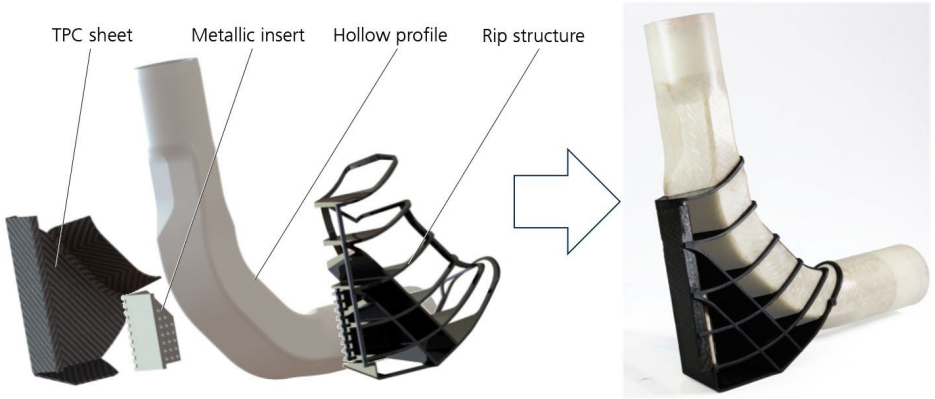
DIN joining area not homogeneously filled with fiber bundles

Enlarging of pre-treated | joining area



LOOKING FORWARD

- Laser processing as a surface treatment on FRP offers multiple chances in lightweight sector:
  - Pulsed laser structuring enables material-sensitive FRP surface pre-treatment without damage
  - Exposed fibers enable form fit with molten polymer structure
  - Adhesive strength of applied ribs (Injection molding) are increased by 28% with laser structuring compared to hot over molding
  - Adhesive strength of TPC-TPC press-joining is influence by laser pre-treatment, results will be validated by processing larger areas
  - Good confidence to meet the automotive demands on all three joining types



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