SMART AND ROBUST COMPOSITE SCARF REPAIR USING VISUAL ASSISTANCE, CRACK ARRESTING AND CRACK DETECTION SYSTEMS

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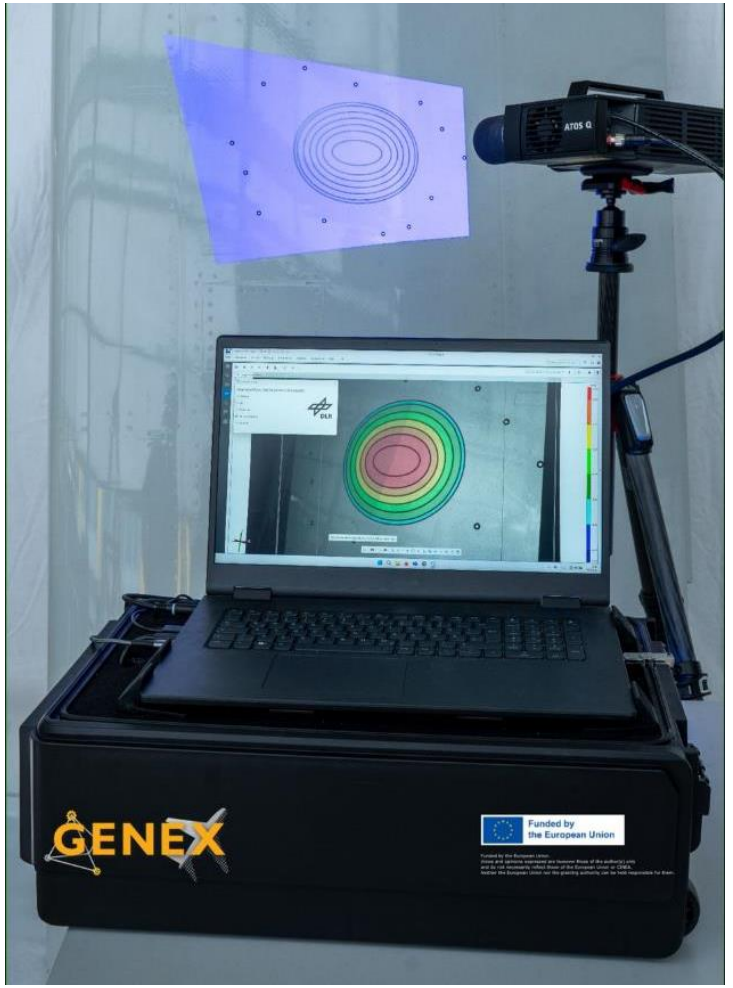
DLR

Outline

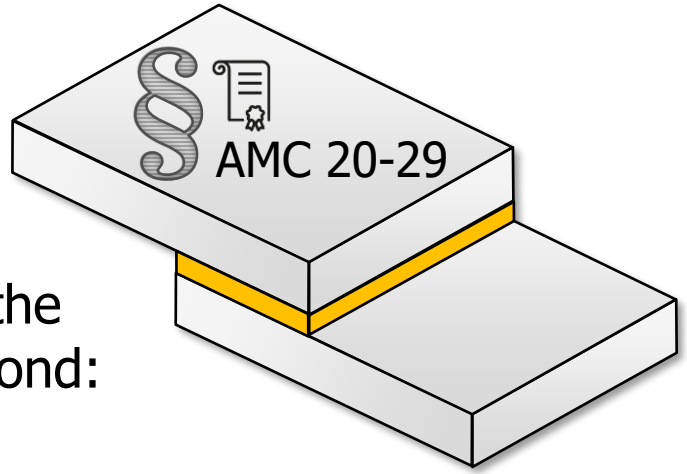
- Introduction
- Smart bondline using FOSS and TPU
- Visual Assisted Scarf Repair
- Smart and Robust Composite Scarf Repair
  - Using VAS
  - Crack stopping
  - And SHM with FOSS
- Summary



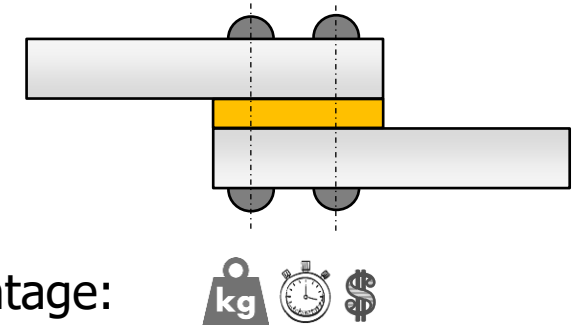
Certification requirements for structural adhesive bonds in aviation

EASA CS 25

Proof of the adhesive bond:

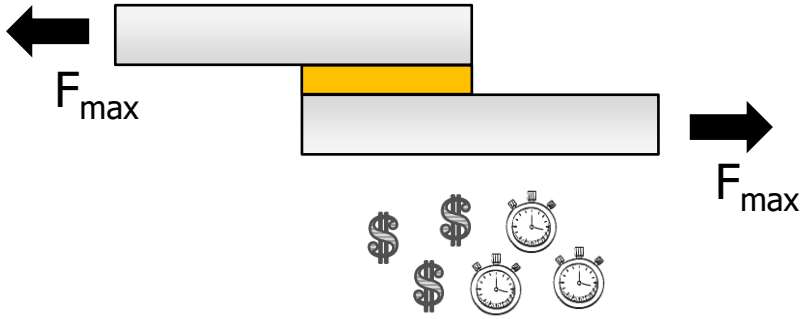


(i) Additional design elements

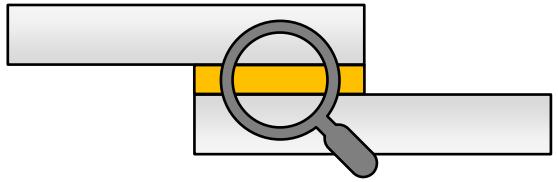


Disadvantage:

(ii) Load tests



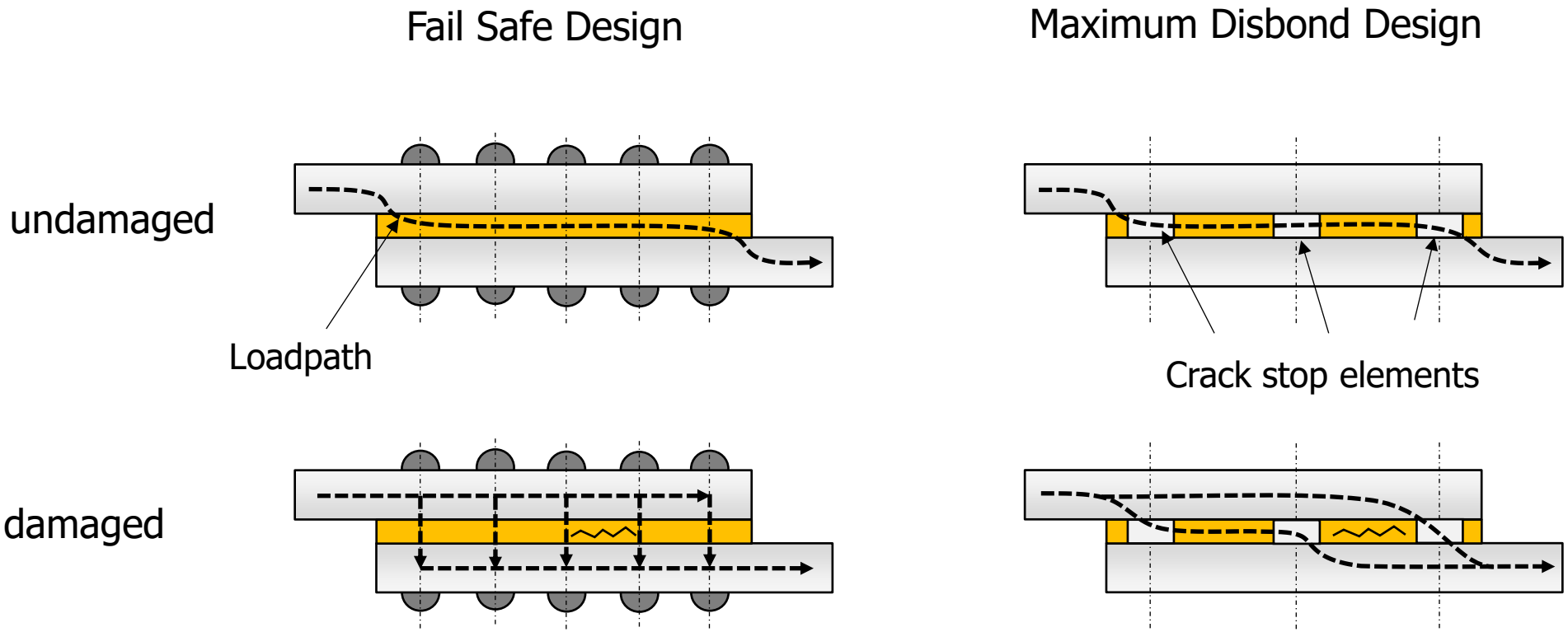
(iii) Inspection



Does not exist.

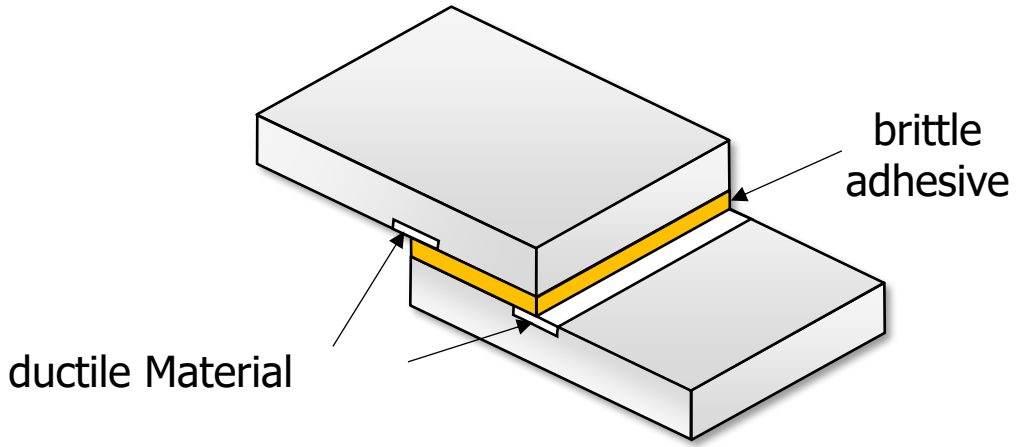
CS = Certification Specification
AMC = Acceptable Means of Compliance

From the bolted to the bonded joint



Aim: Robust pure adhesive bond with crack-stop effect!

Local Surface Toughening (ST) - Concept



Increase in joint strength

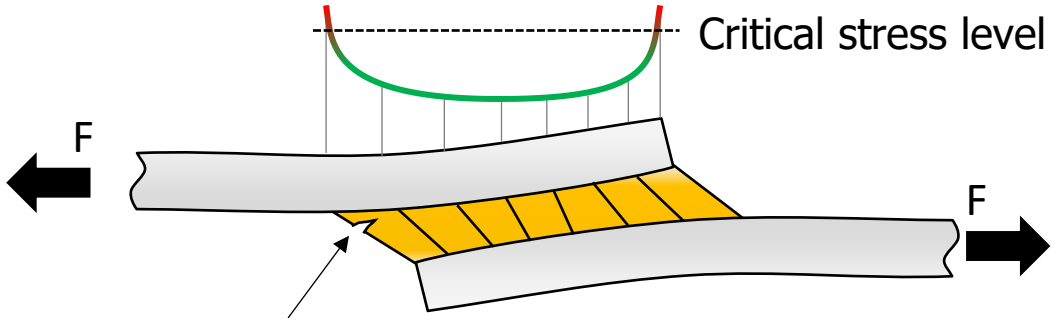
The targeted arrangement of the local surface modification in the bond improves the load distribution and thus increases the bond strength.

Crack stop

Crack growth in the bonded joint is stopped by means of localized surface toughening and the resulting reduction in stress concentrations.

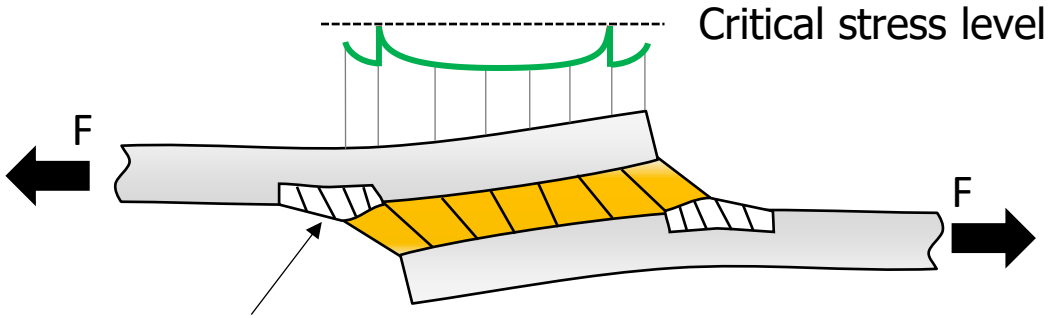
Local Surface Toughening - How it works

Reference



Stress concentrations lead to crack formation

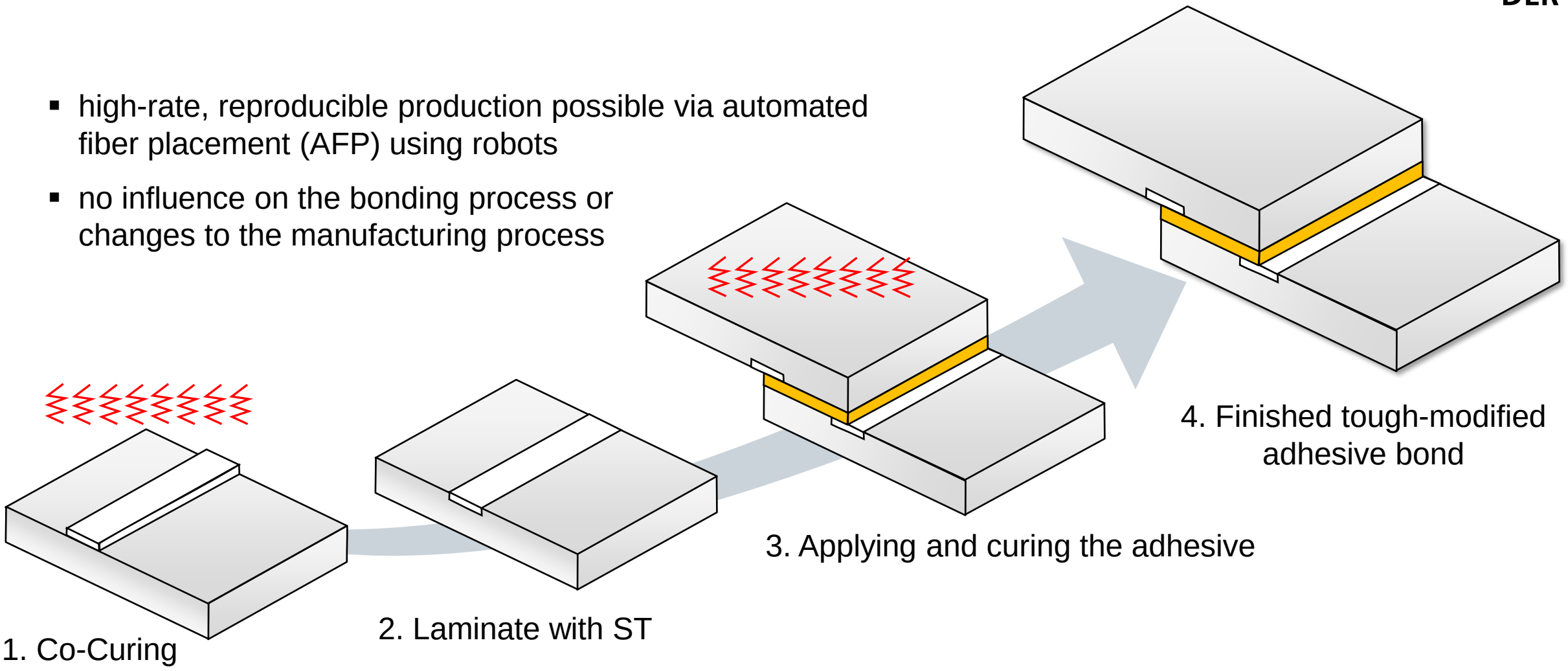
ST



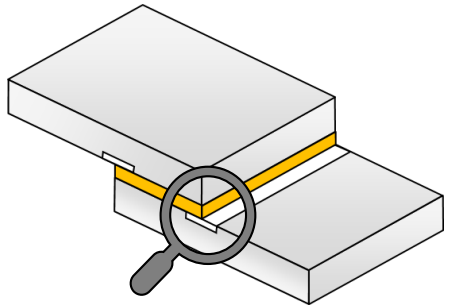
Ductile material absorbs strains and reduces stress concentrations

Manufacturing using the prepreg process as an example

- high-rate, reproducible production possible via automated fiber placement (AFP) using robots
- no influence on the bonding process or changes to the manufacturing process



Crosssection and materials

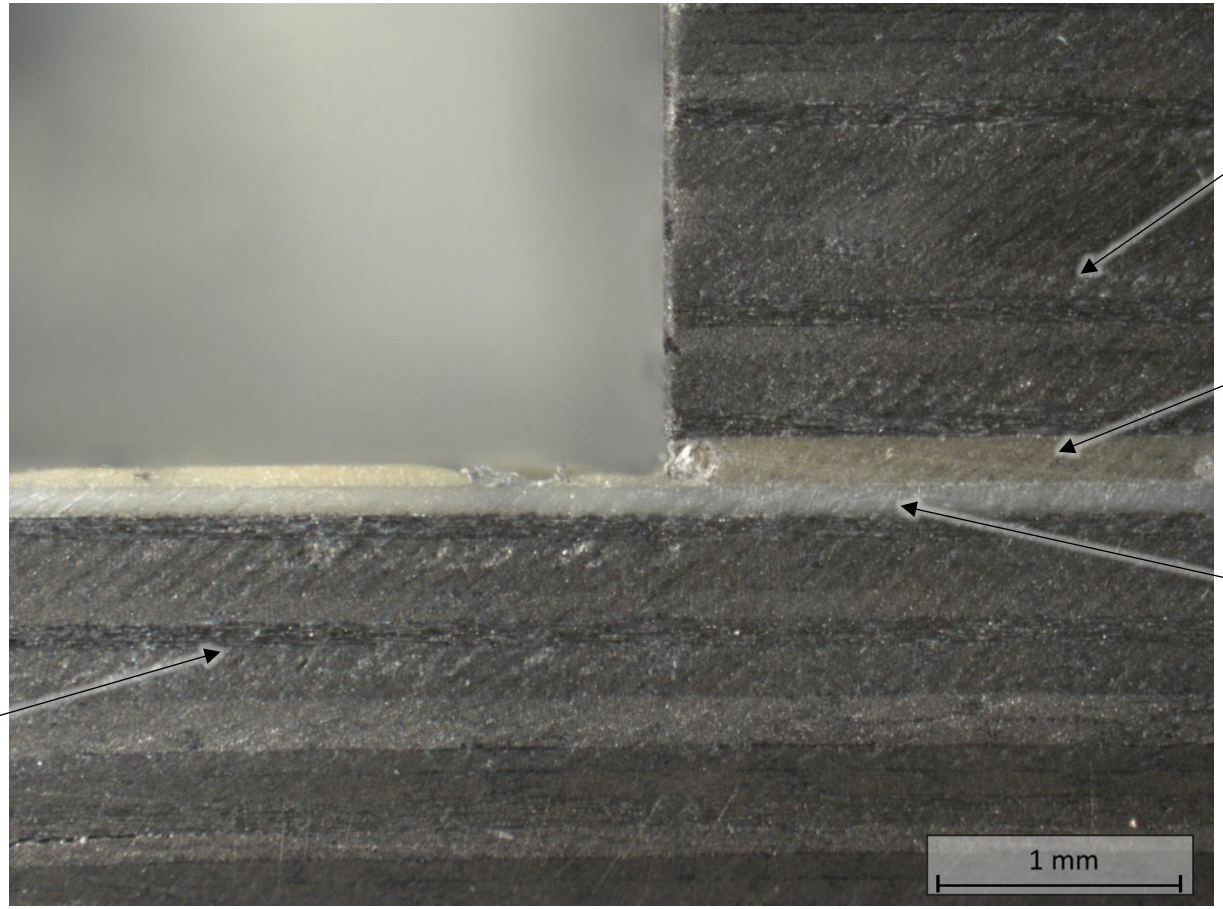


Young‘s modulus:

$E_{8552\ IM7}$ = 60.600 MPa

E_{EA9695} = 2.577 MPa

E_{PVDF} = 1.716 MPa



Adherend 2
8552 IM7

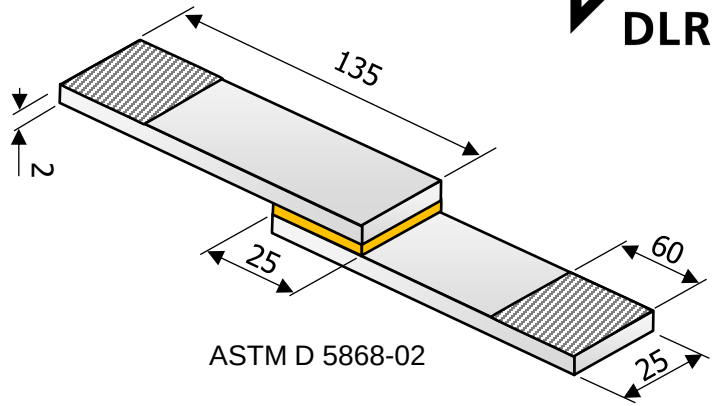
Film adhesive
EA9695 NW
t_{Kl} ~0,12 mm)

ST-Material
PVDF
t_{ST} ~0,1 mm

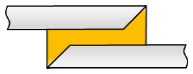
Adherend 1
8552 IM7

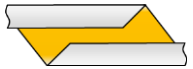
Strength increase under quasi-static load

- strength-enhancing methods from literature without much effect in our tested material combination
- increase in strength due to ST by 84%

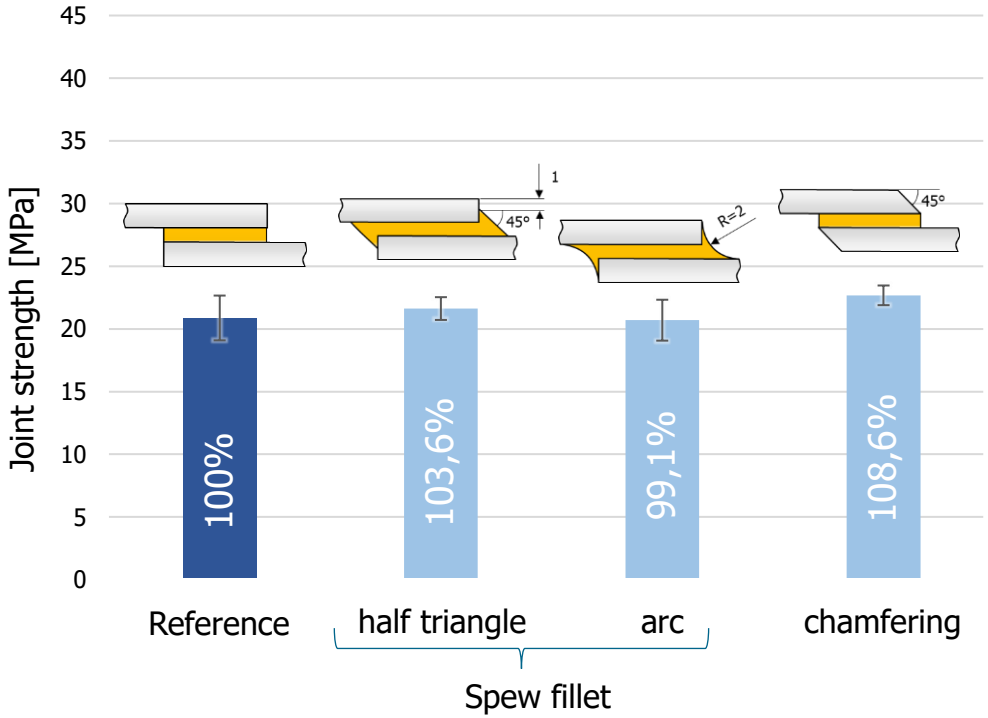


ASTM D 5868-02

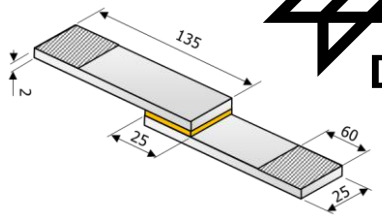

Internal taper


Internal taper + spew fillet

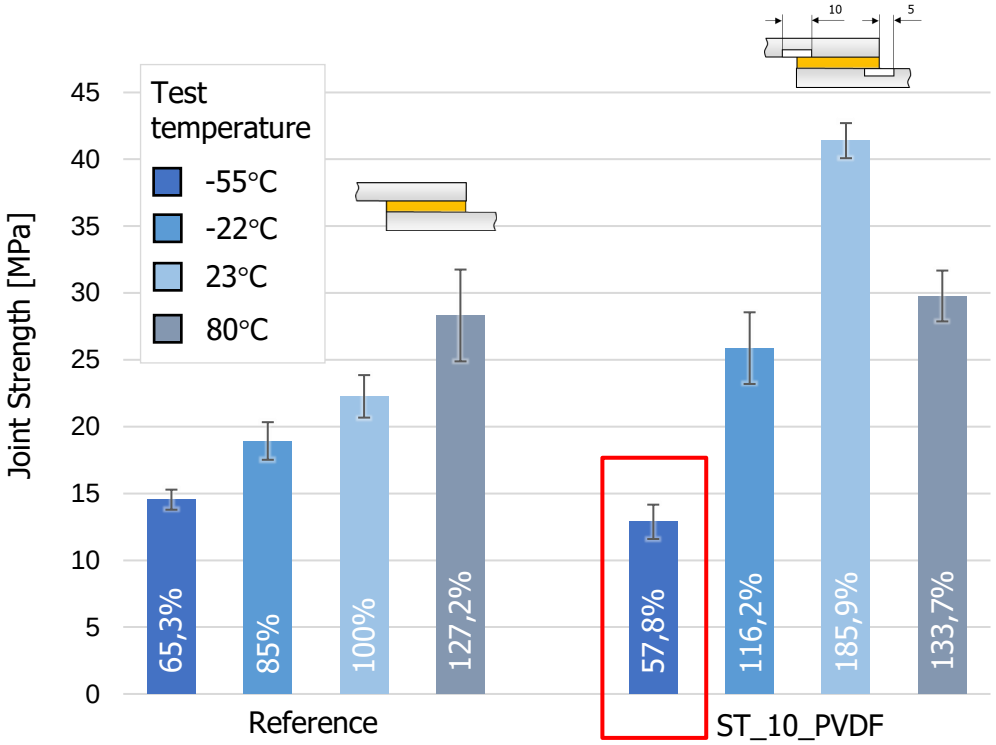
Not tested yet, but planned!



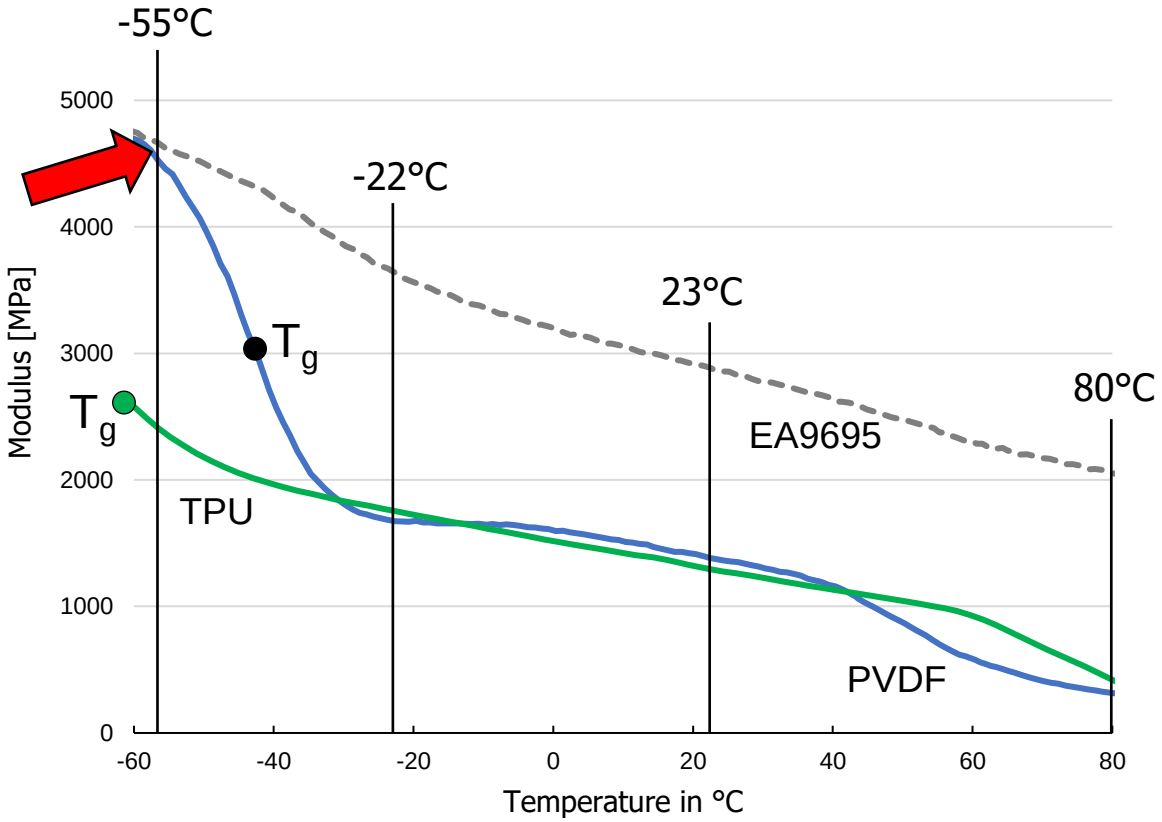
Problem with PVDF



SLS tests PVDF



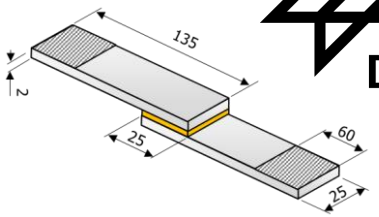
DMA



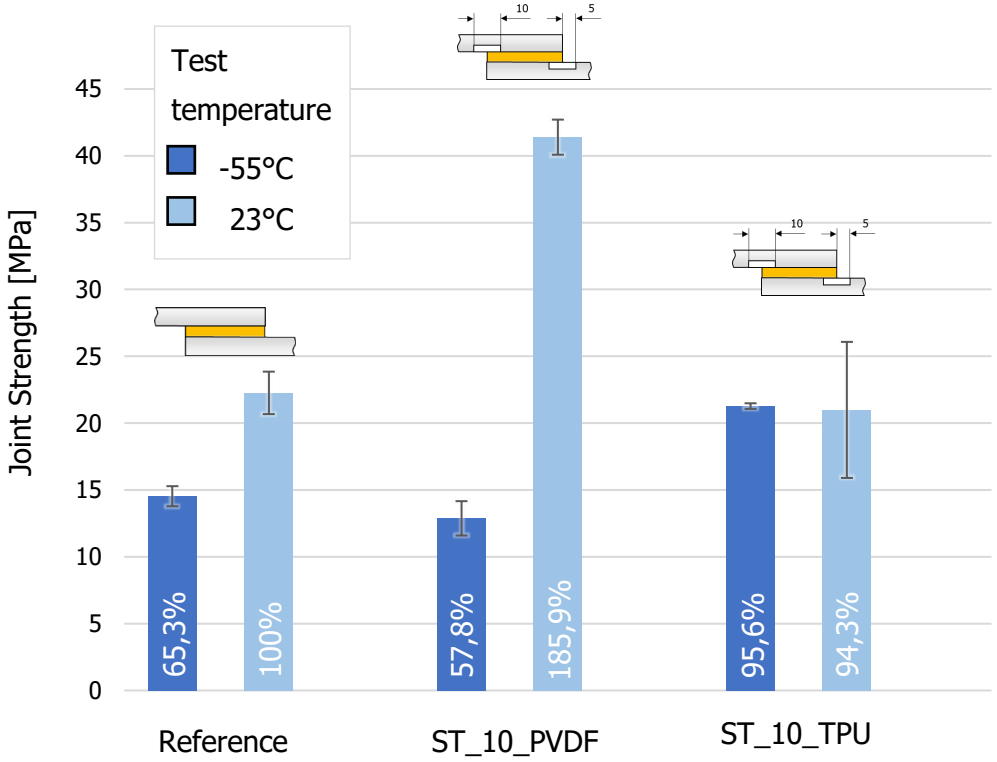
→TPU for next trials!

PVDF: Nowoflon Copo FL2608, Nowofol
TPU: Elastollan 1165D13U, BASF

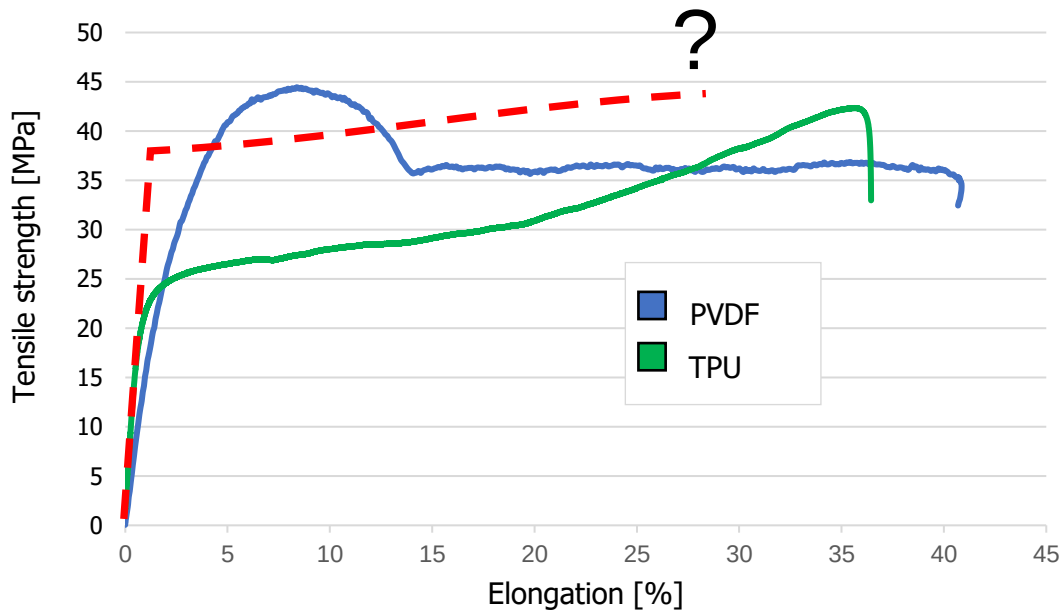
Comparison of PVDF and TPU - SLS



SLS tests PVDF and TPU

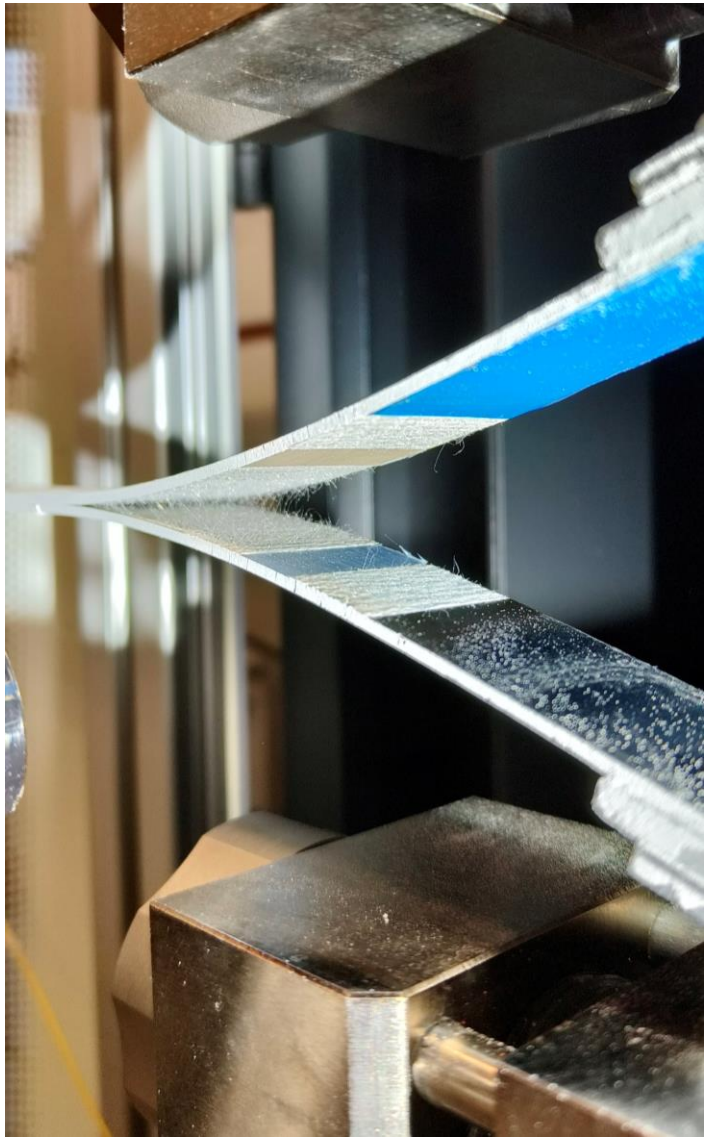


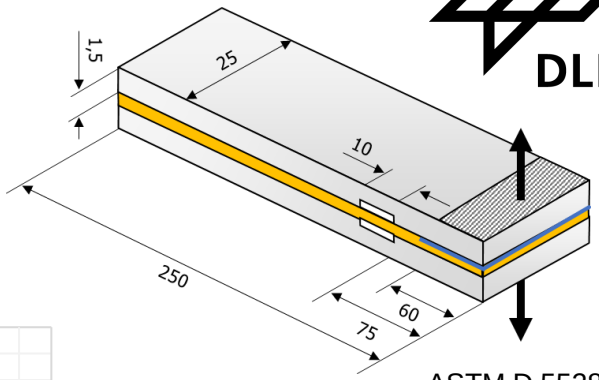
Tension test



→ Thesis: Strength of yield point increase at -55°C?
→ Use specimen design with higher internal strain of the ST-material?

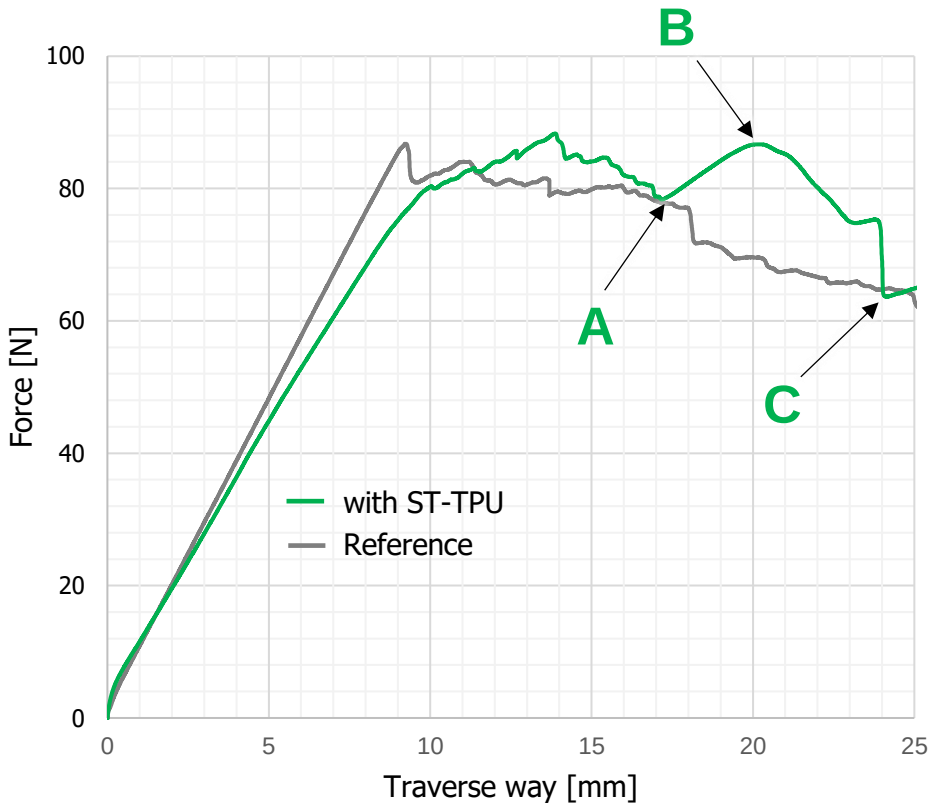
Double Cantilever Beam tests with TPU





ASTM D 5528-21

DCB test with TPU



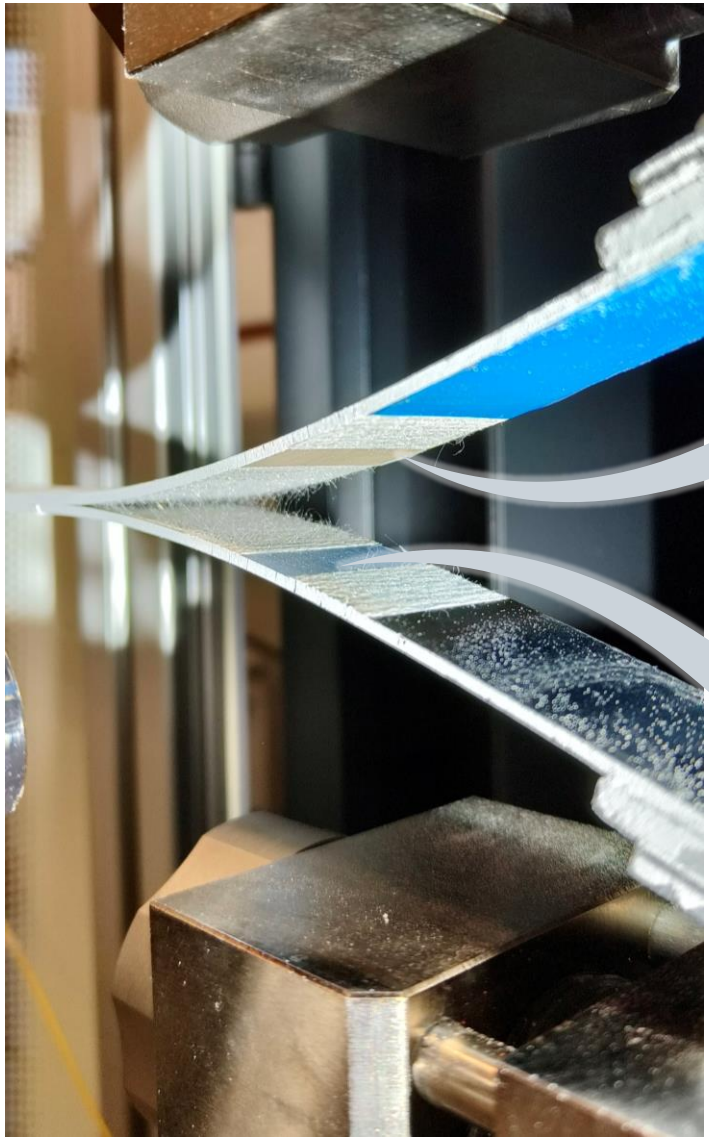
A: Crack stop

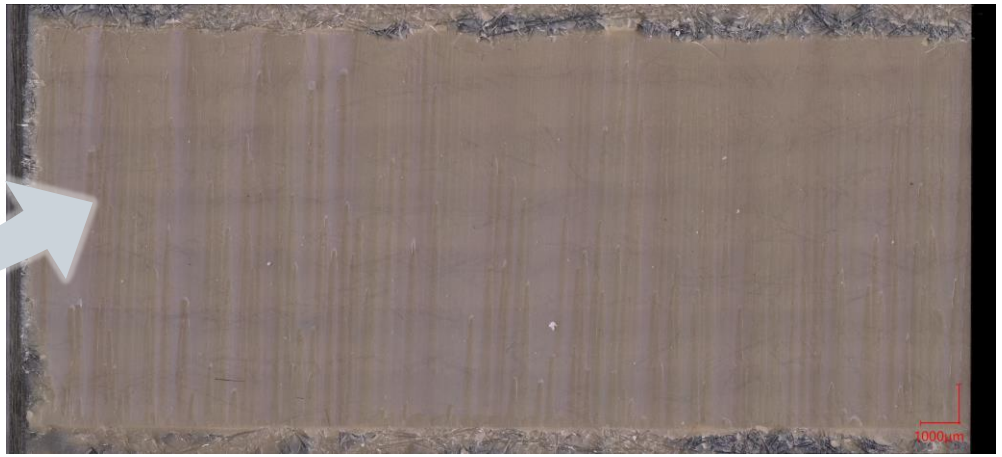
B: Crack starts again

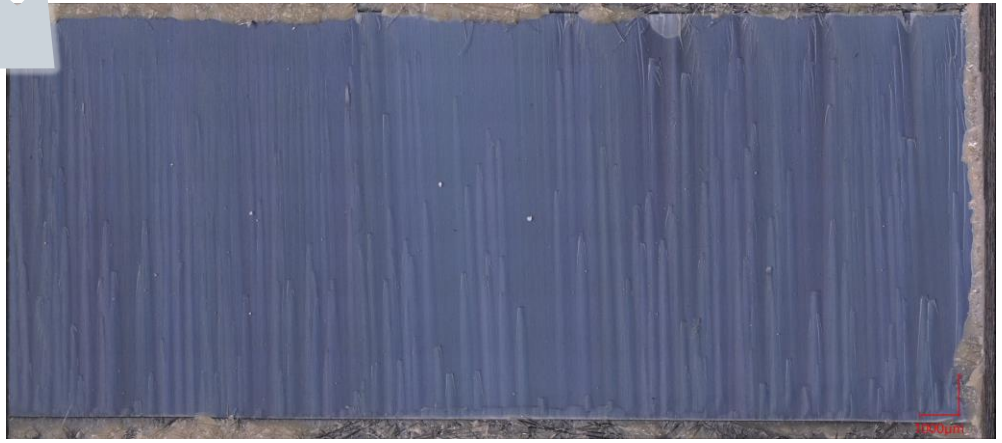
C: Crack jumps to the pure adhesive (end of crack stop element)

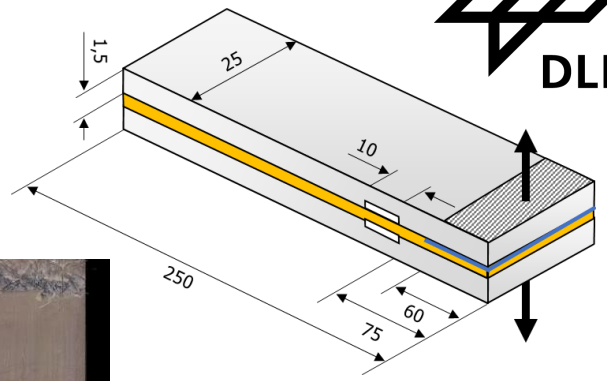
Increase of G_{IC} by ~30% (MBT)

Double Cantilever Beam tests with TPU



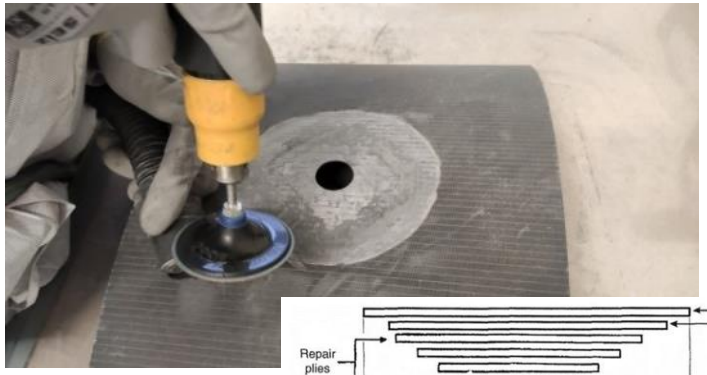




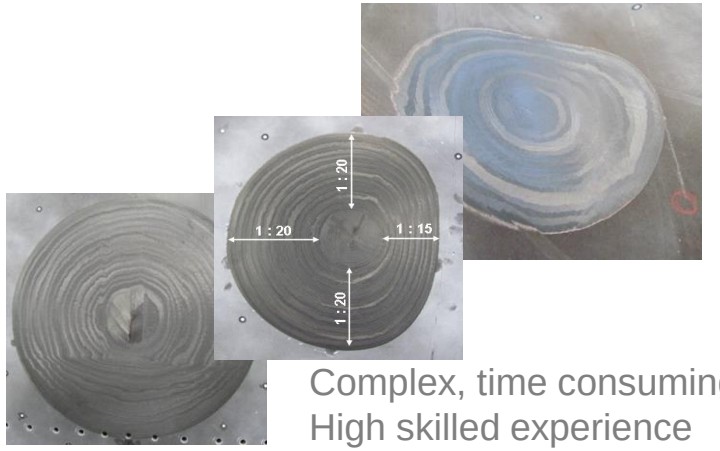


Surface near cohesive failure in TPU

State of the Art vs. Visual assisted Scarfing

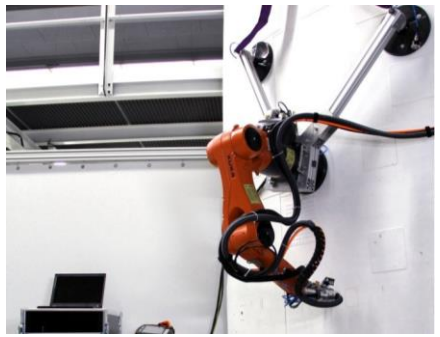


Manual scarfing



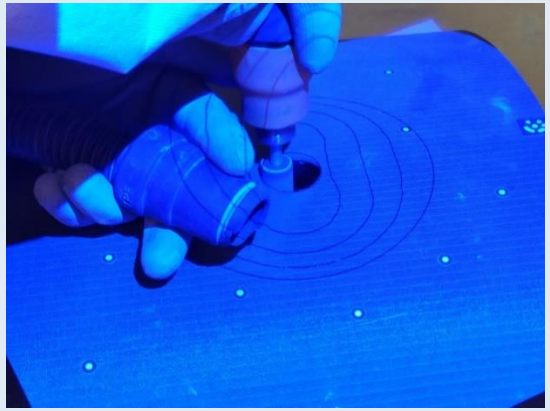
Complex, time consuming,
High skilled experience

State of the art → **Visual Assisted Scarfing**



Robotic Automation
- no busines case
- high invest and labor costs

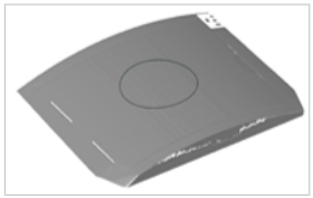
Leslie Tool (GMI©)
Accurate Stepping /
Scarfing following
simple templates

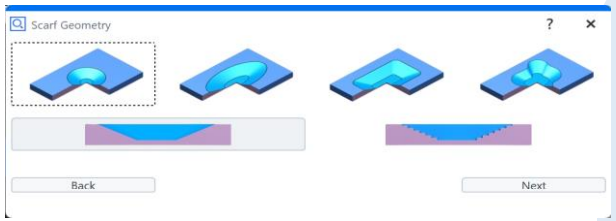


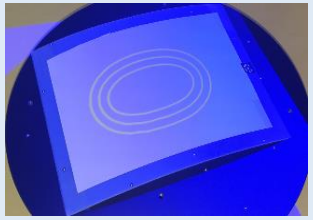
Visual Assistance System for the laborer

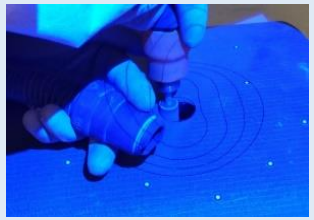
- complex scarfs
- curved geometries
- large repairs
- automated generated templates for Leslie tool
- support of additional processes like ply placement

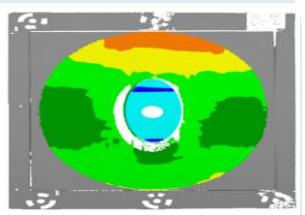
Visual Assisted Scarfing in a Nutshell

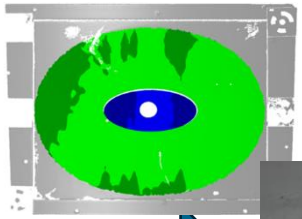


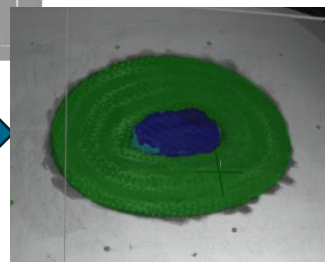












Scan of Geometry

Parametric Repair definition

Projection of geometry difference

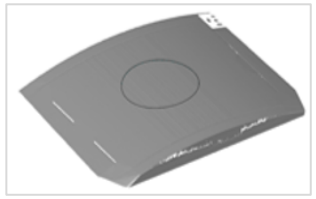
Manual Scarfing

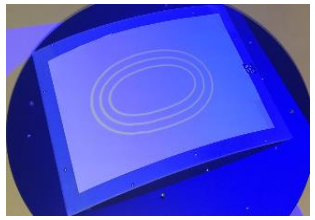
Comparison of actual and target geometry

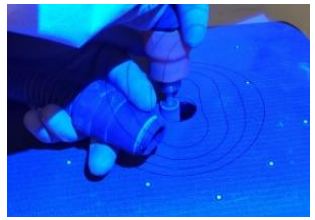
Low tolerance

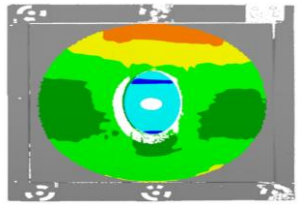
Iterativ process

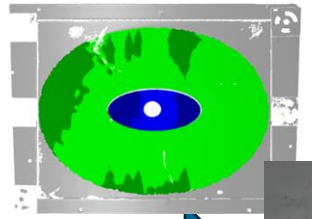
Visual Assisted Scarfing in a Nutshell

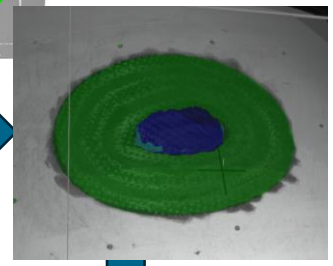












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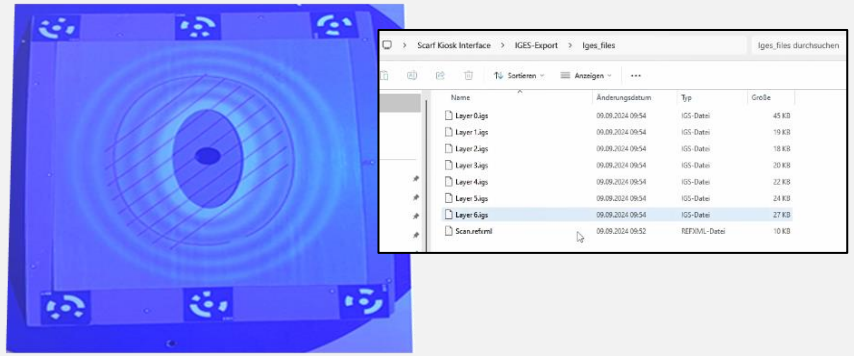
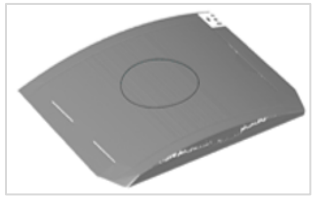


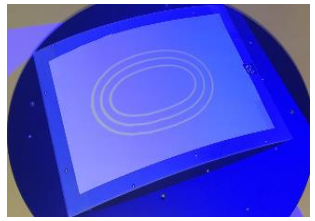
Repair Process

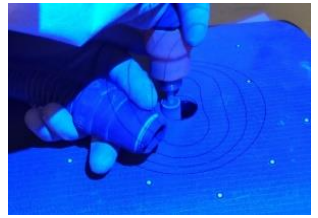
Support of

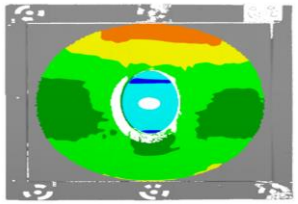
- Cutting ply contours for NC cutting
- repair ply placement
  outline of bagging
- Projection of thermocouples
- Projection of backing structures

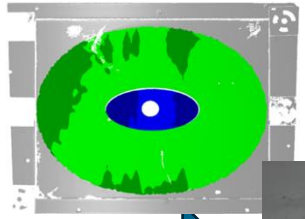
Visual Assisted Scarfing in a Nutshell

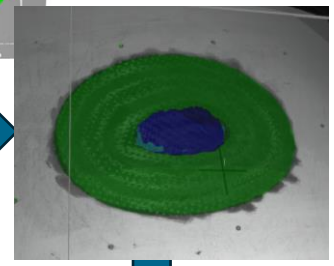












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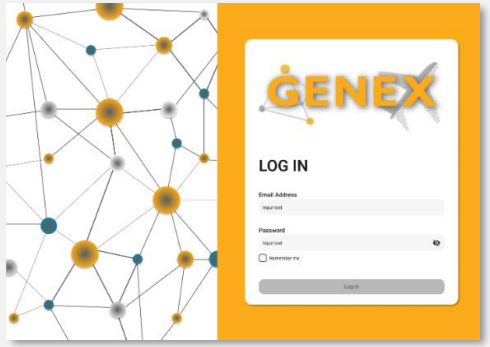
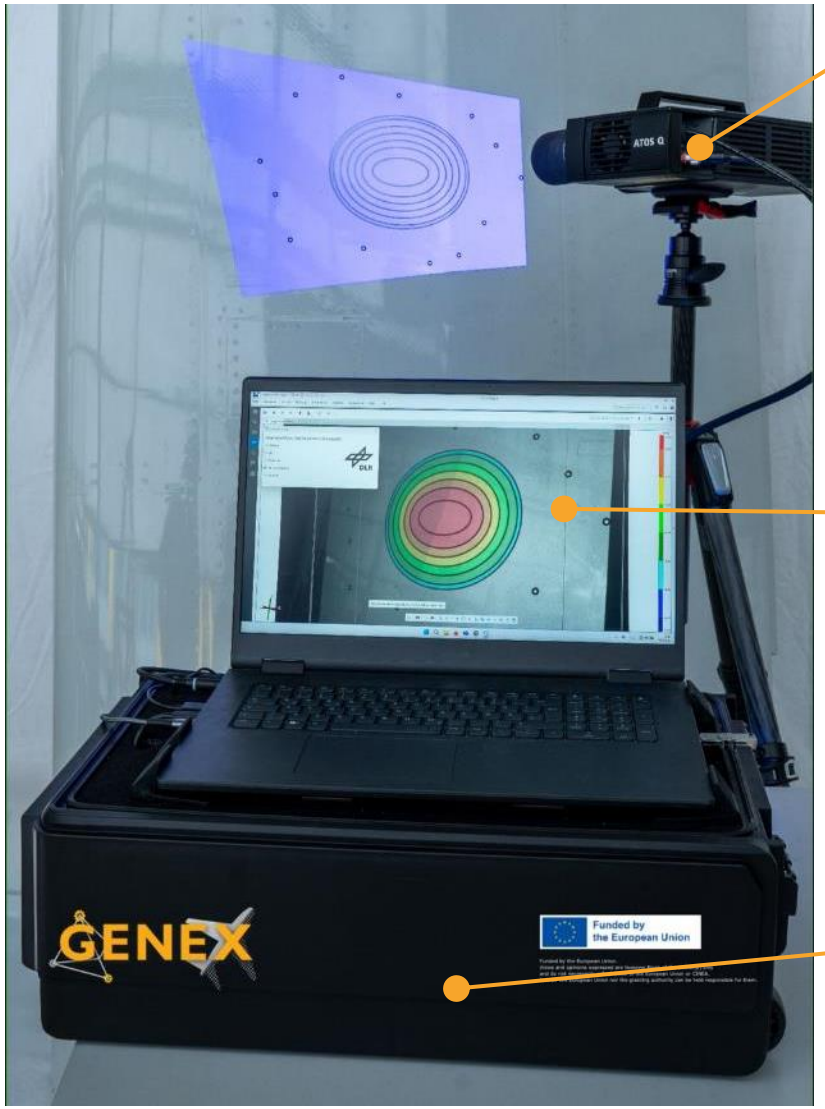


Documentation

Digital documentation of
- final scarf geometry
- number of repair plies
- repair ply position
- thermocouples position

Visual Assited Scarfing - Components

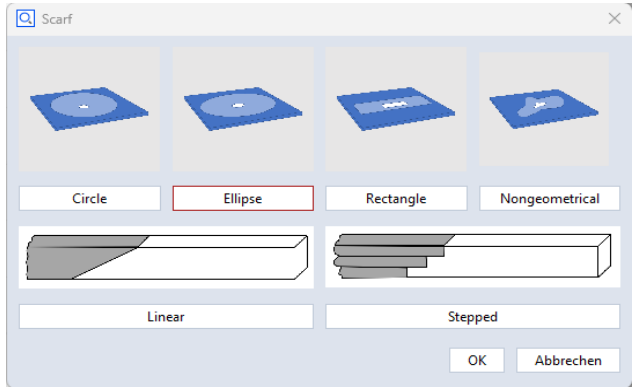


Hardware Zeiss ATOS Scanner

- 3D Scanning and projection in one system
- Industrial available system
- Dust proof housing for commercial use
- Mobile system for infield repair operation
- Suitable field of view for repair purposes

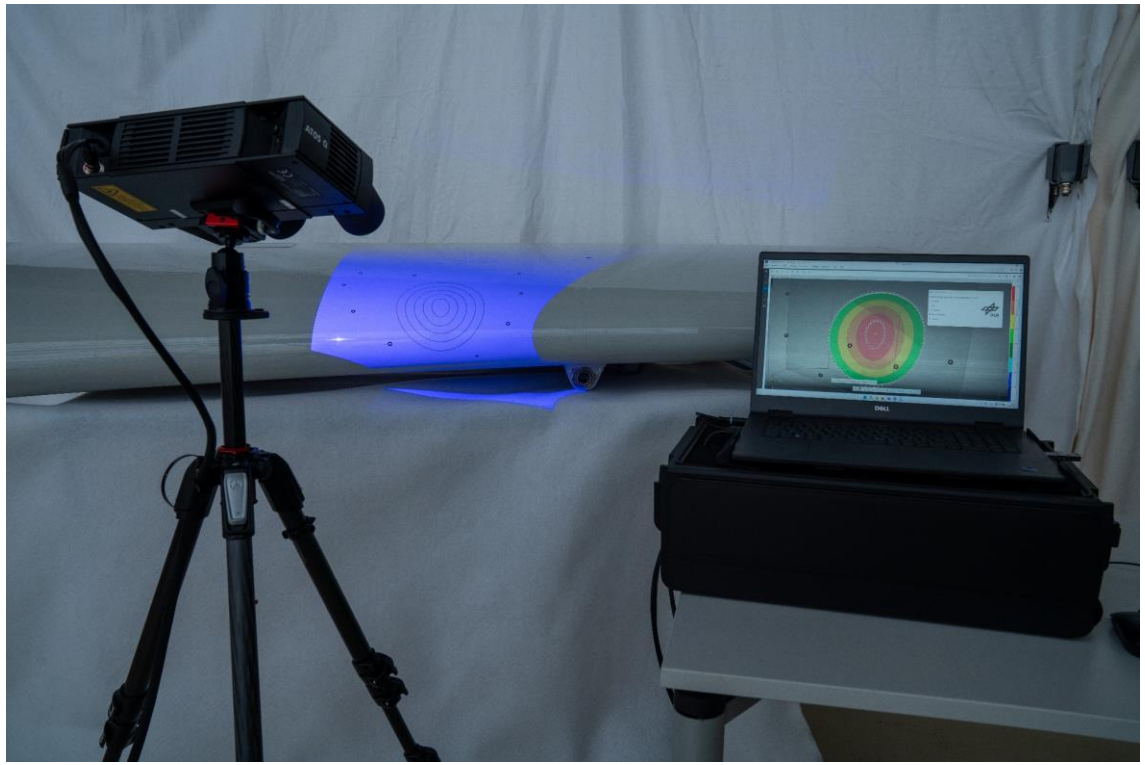
Control Software

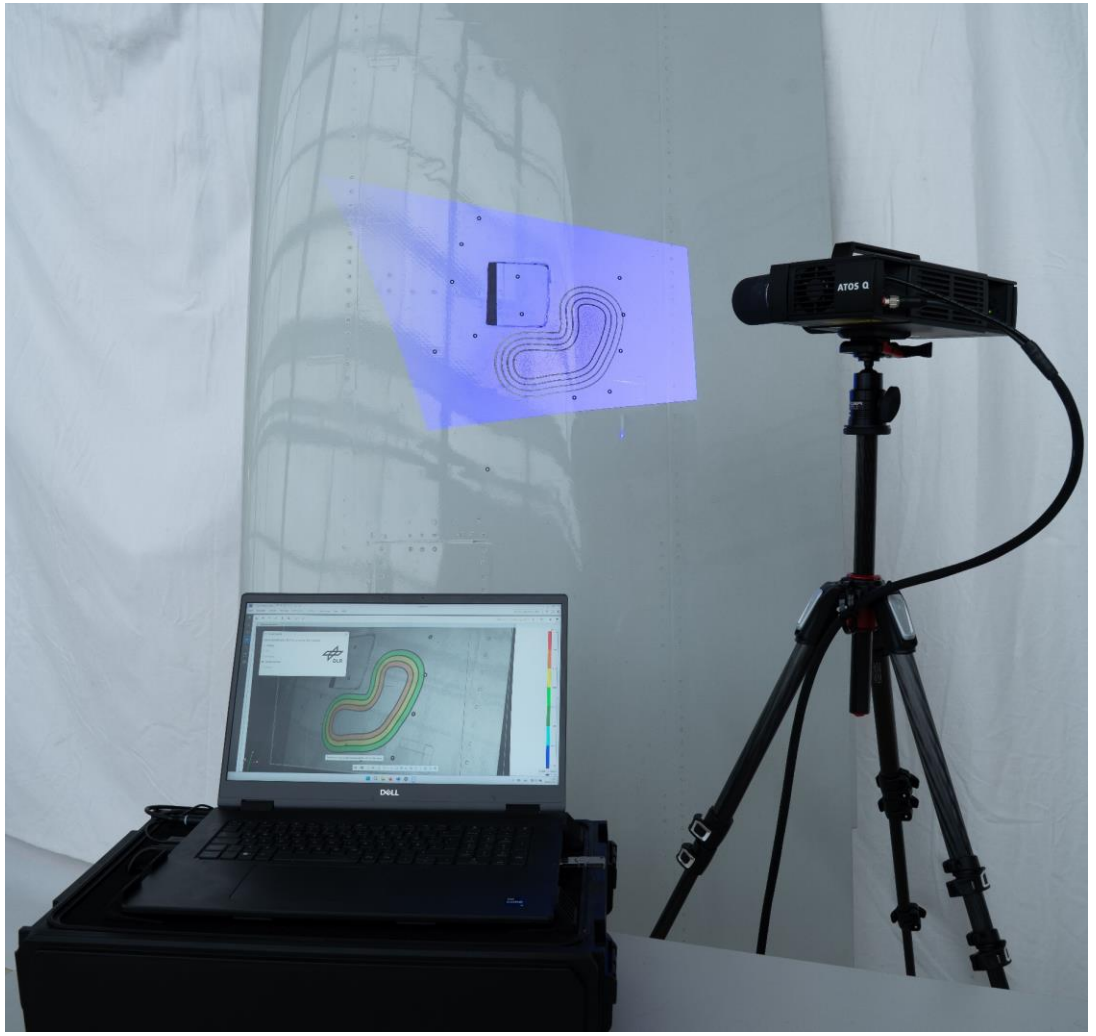
- Flexible and adaptive software interface
- Automates Repair Design
- Visualizes & Manages Comparisons
- Interfaces with other software



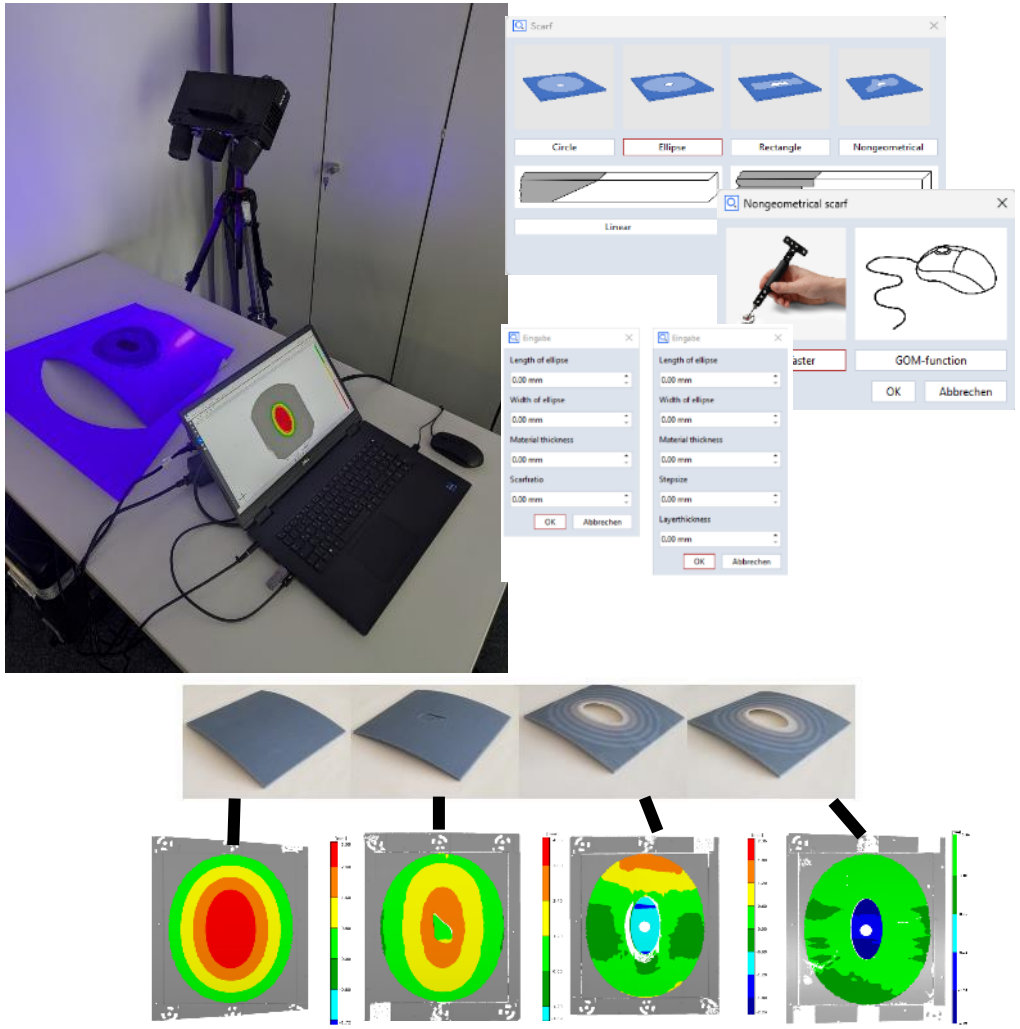
Power Unit and Control PC

Visual Assited Scarfing - Components

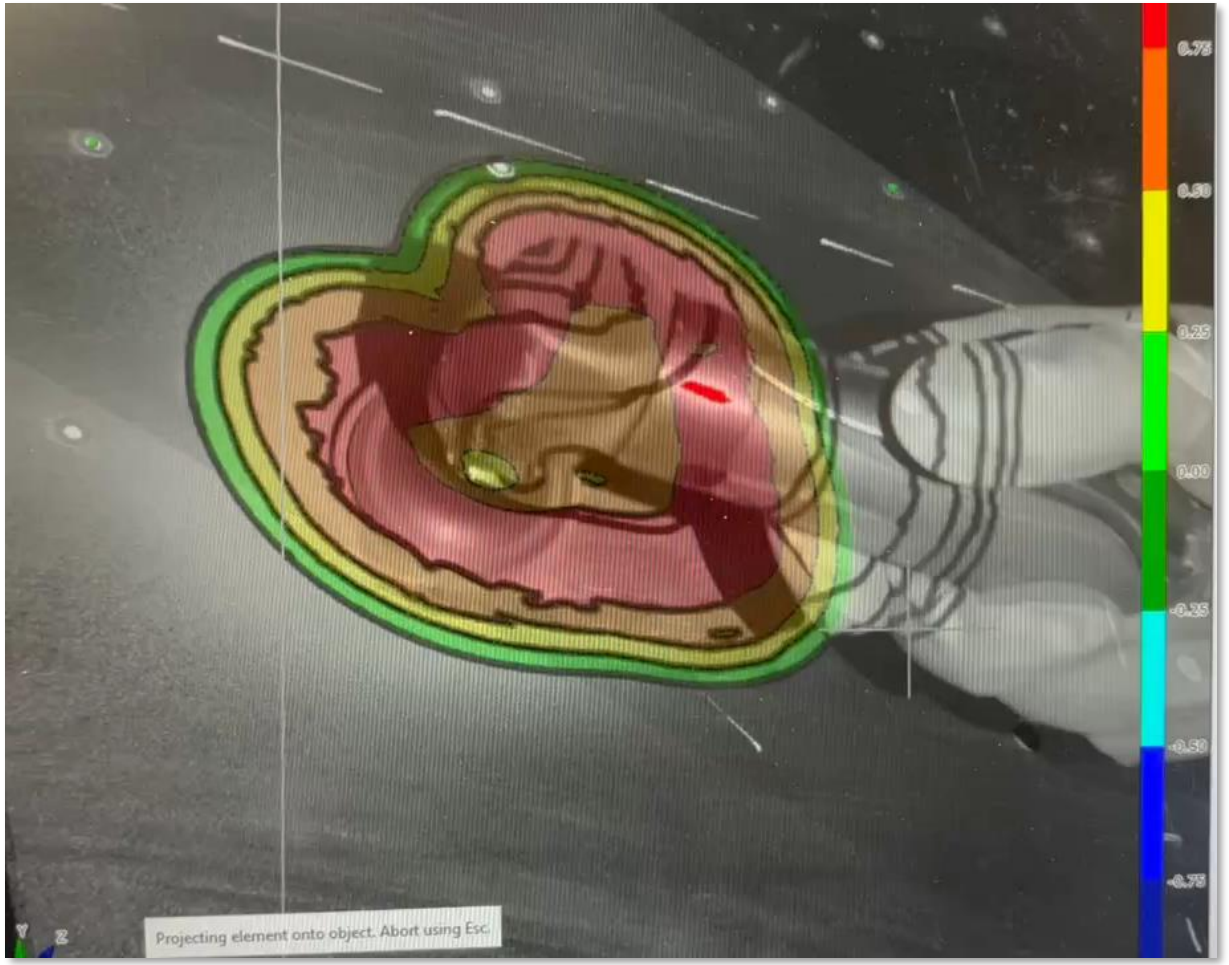




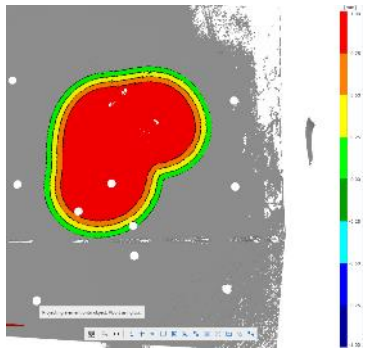
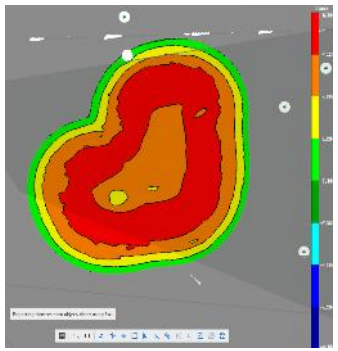
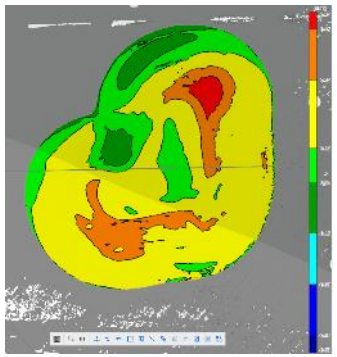
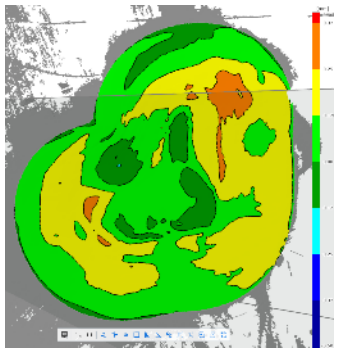
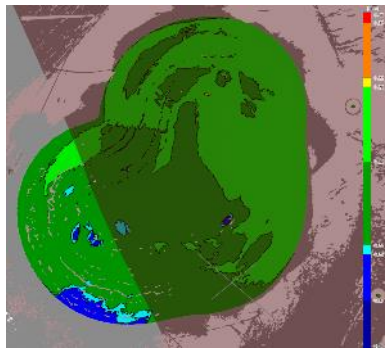
VAS - Lab-Scale test

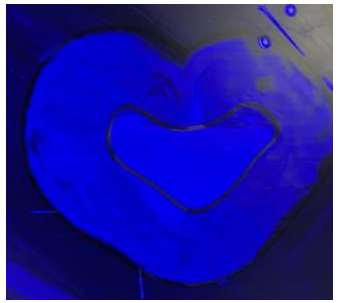
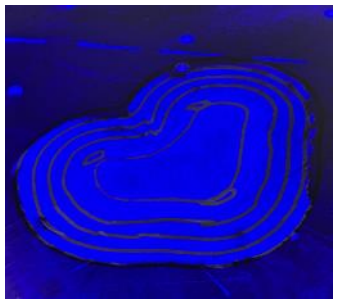
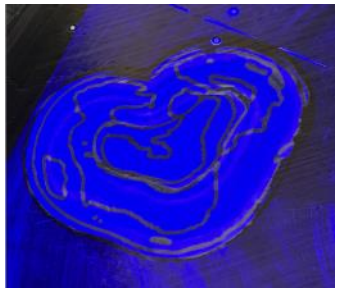
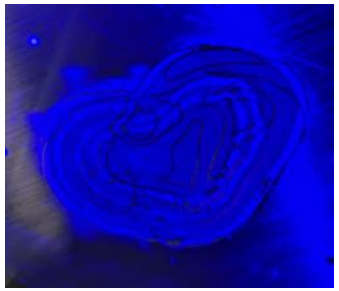


Augmented View



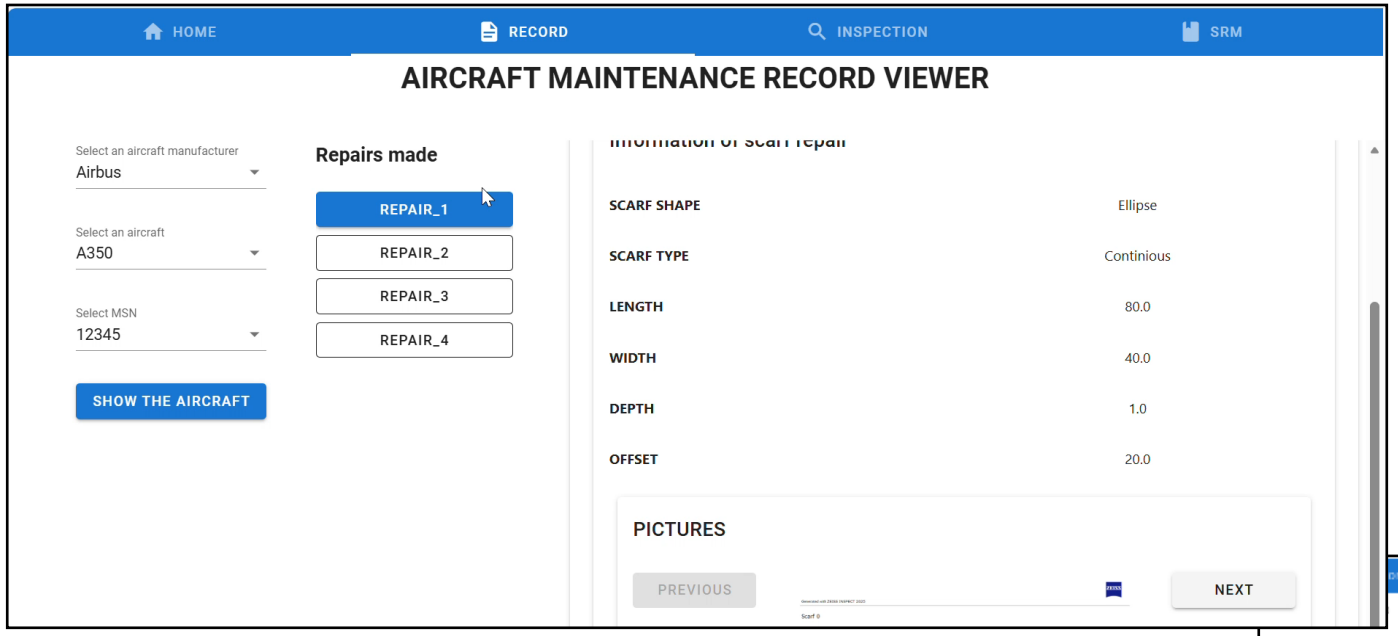
VAS - Lab-Scale test

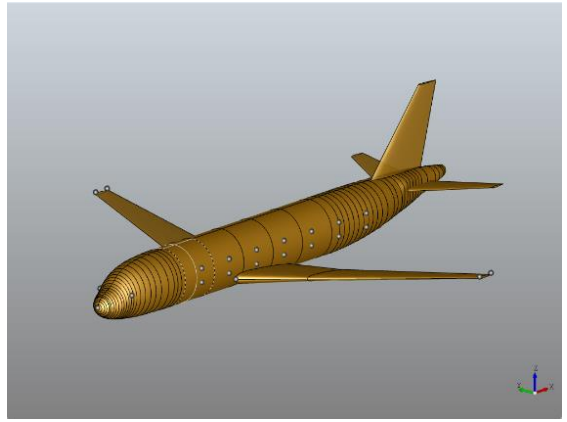






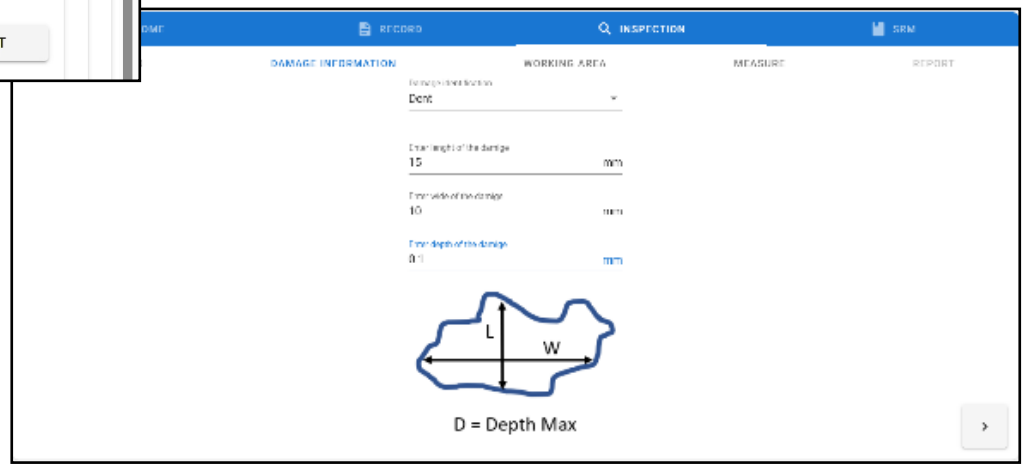






The „worker“ was our student grinding his second scarf in his life…

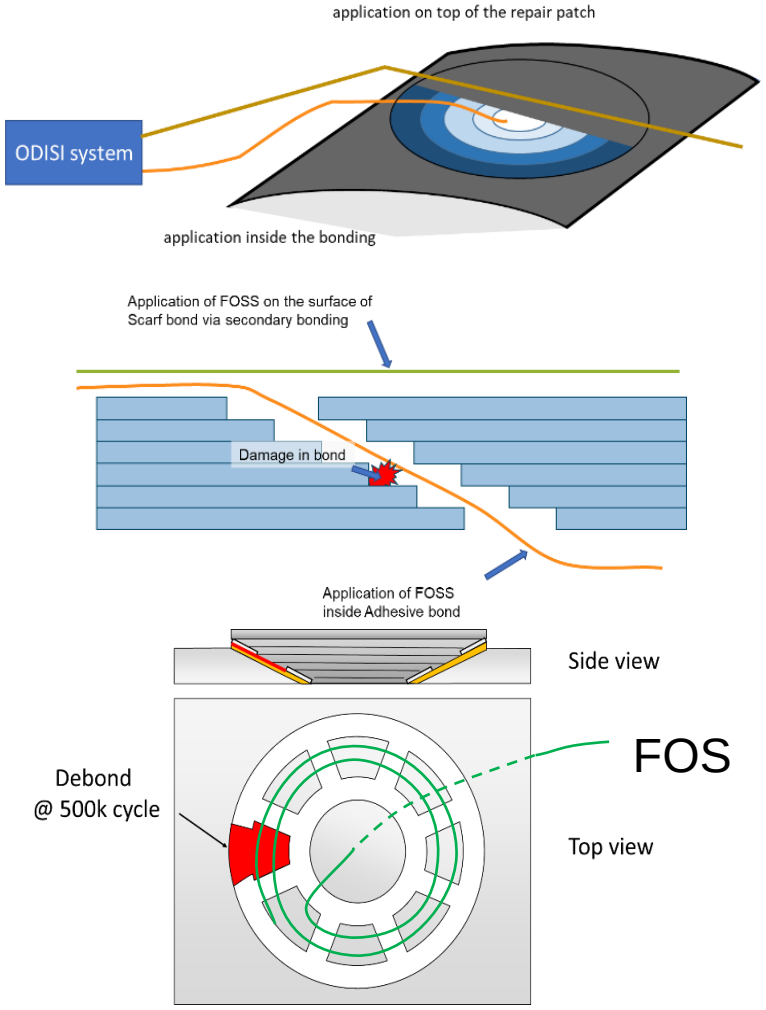
Local Data Management - IoT Plattform – Digital Twin

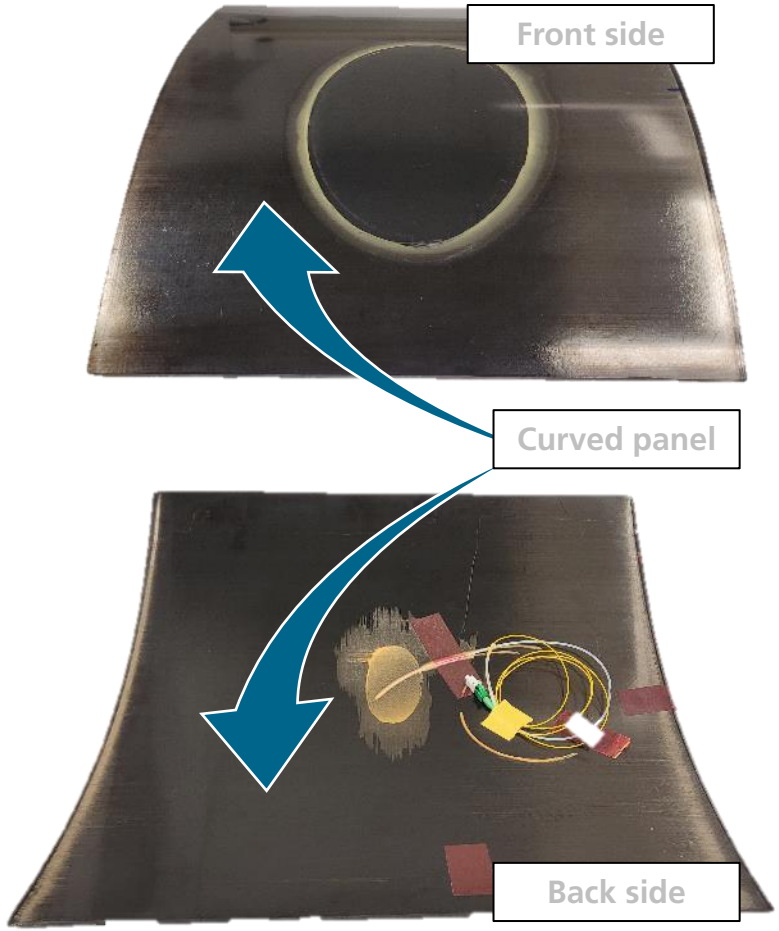


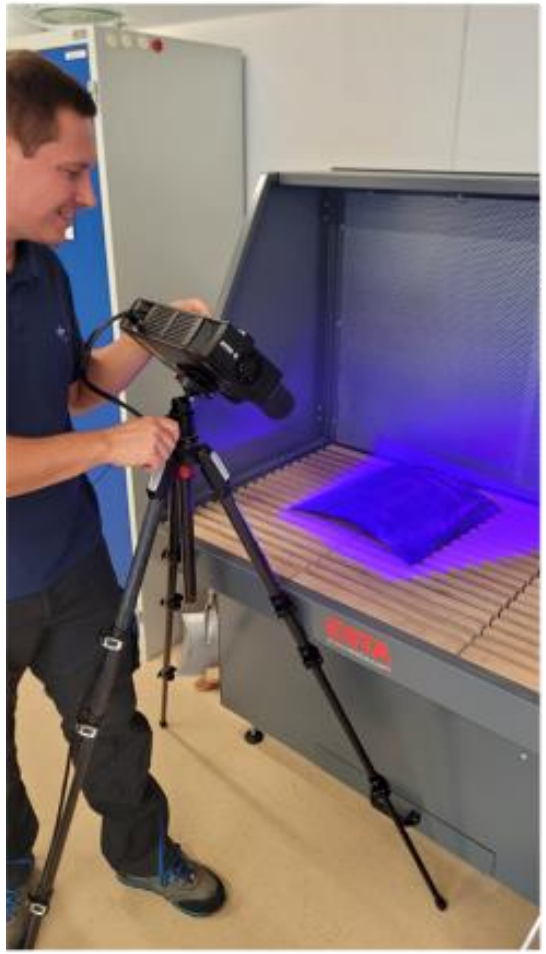




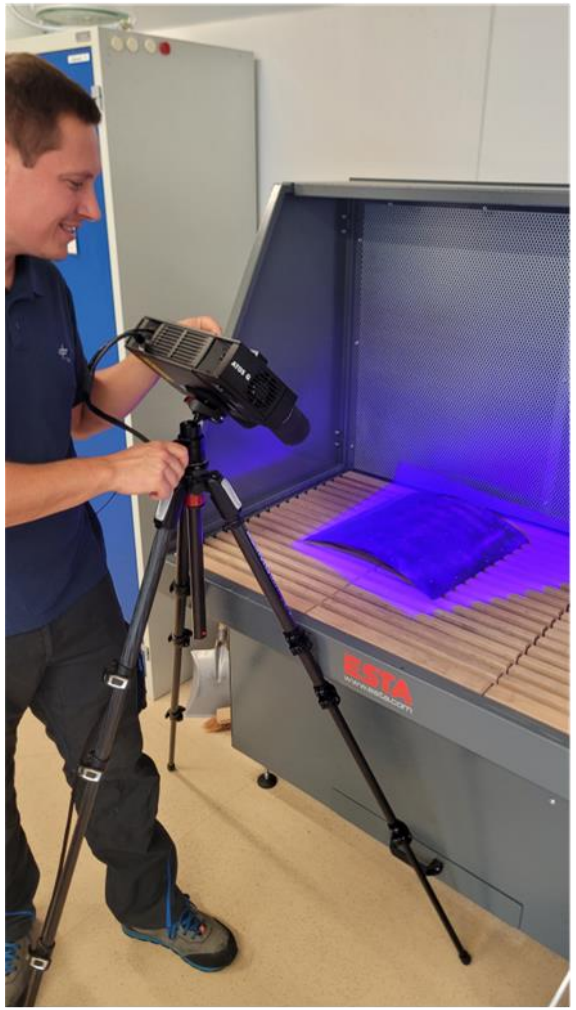
Combining FOSS, Crack stopper and VAS
Smart and Robust Composite Scarf Repair

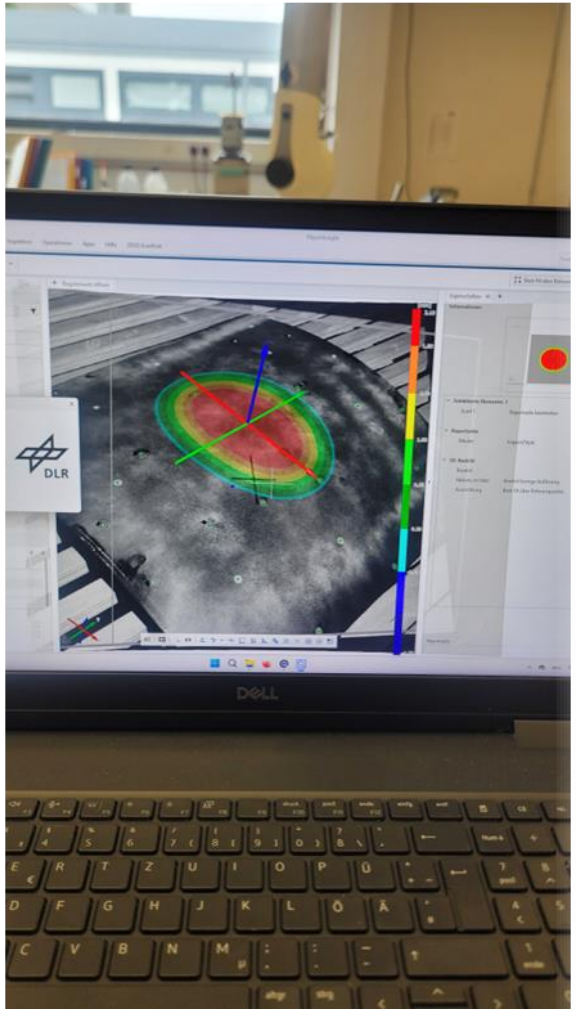




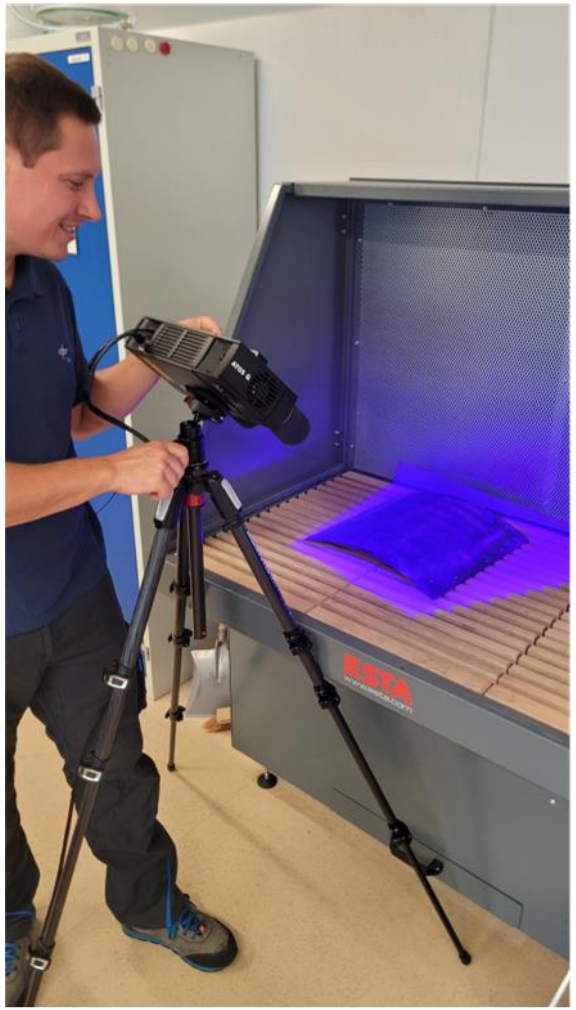


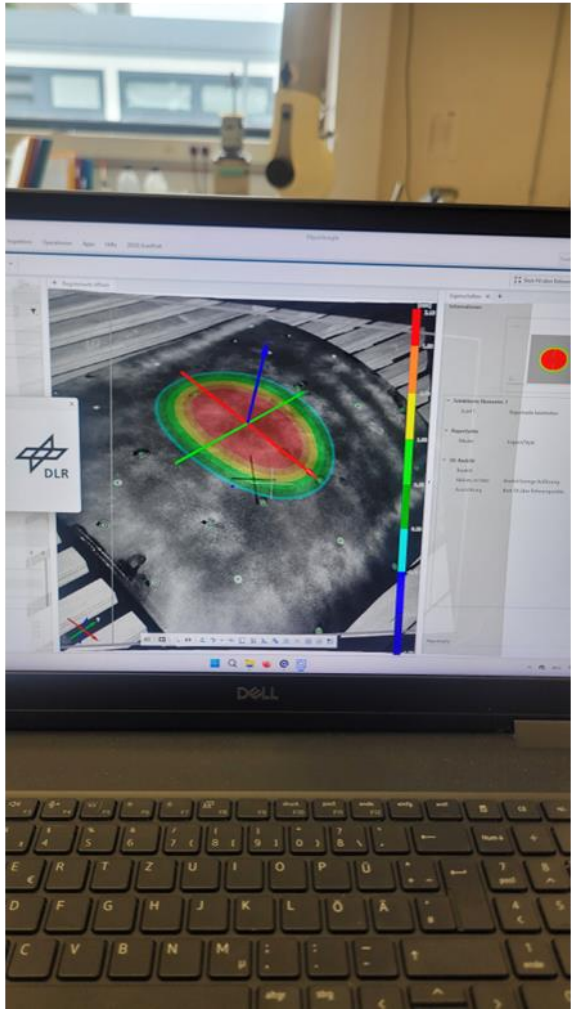
Smart and Robust Composite Scarf Repair

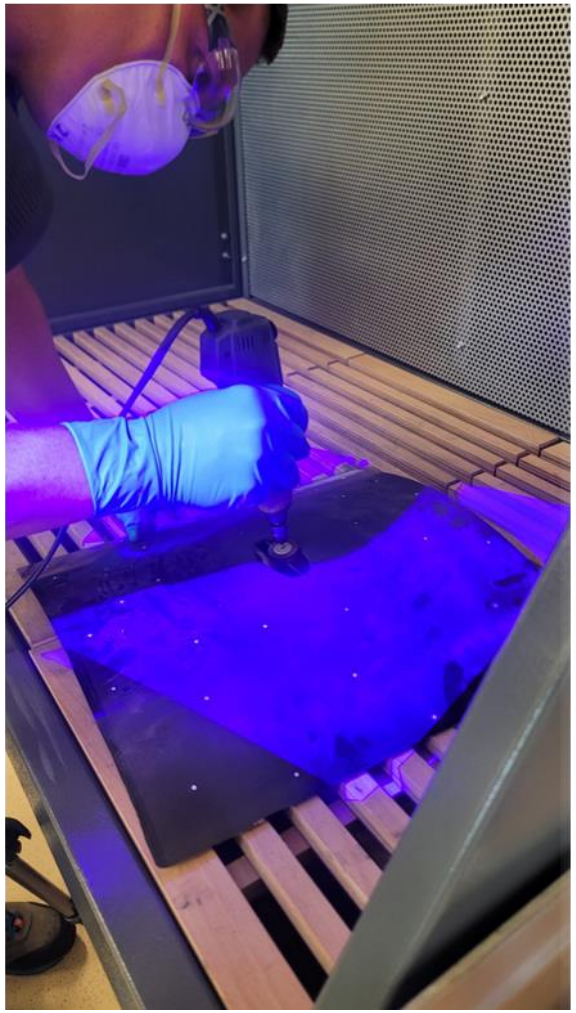




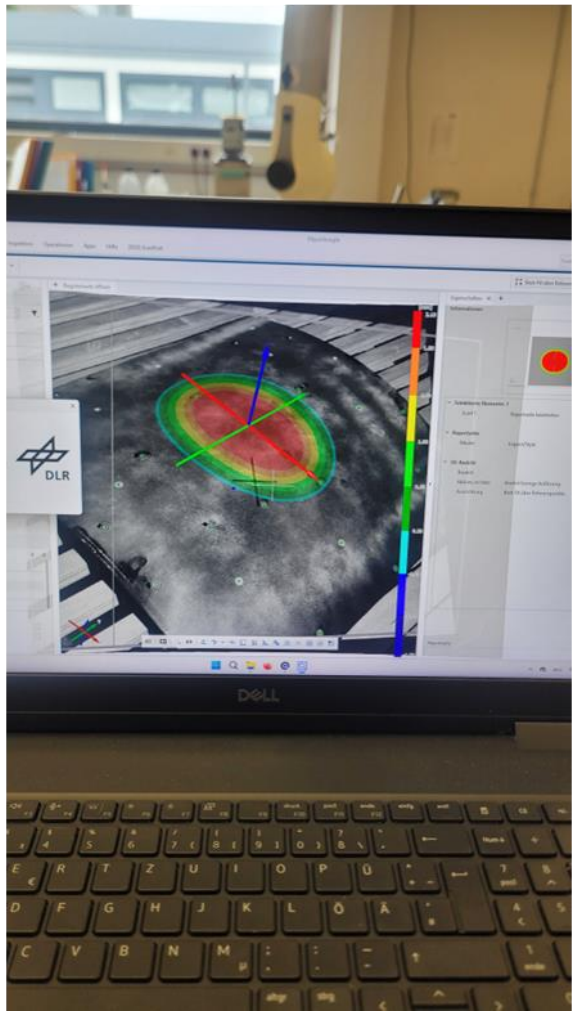
Smart and Robust Composite Scarf Repair

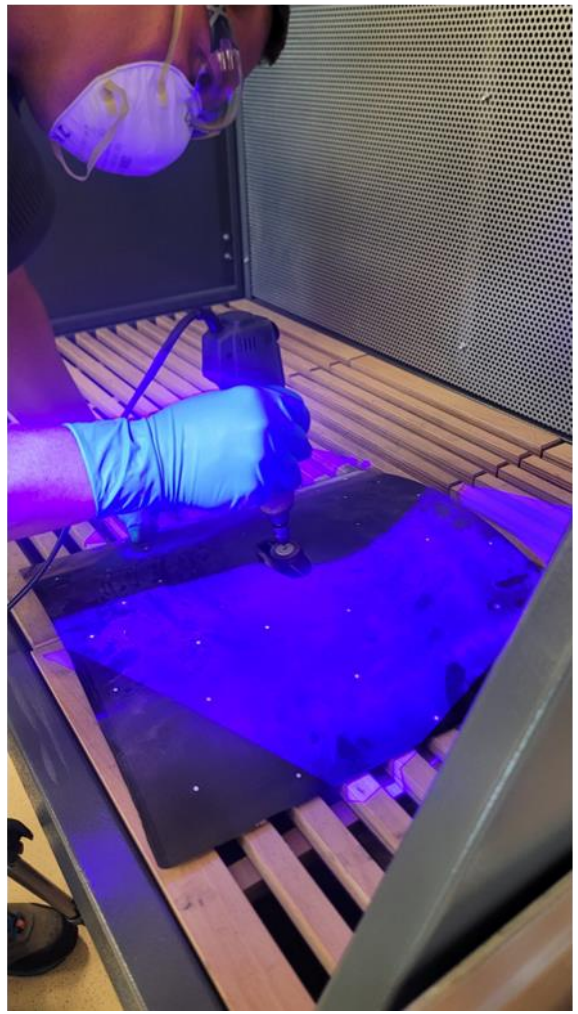


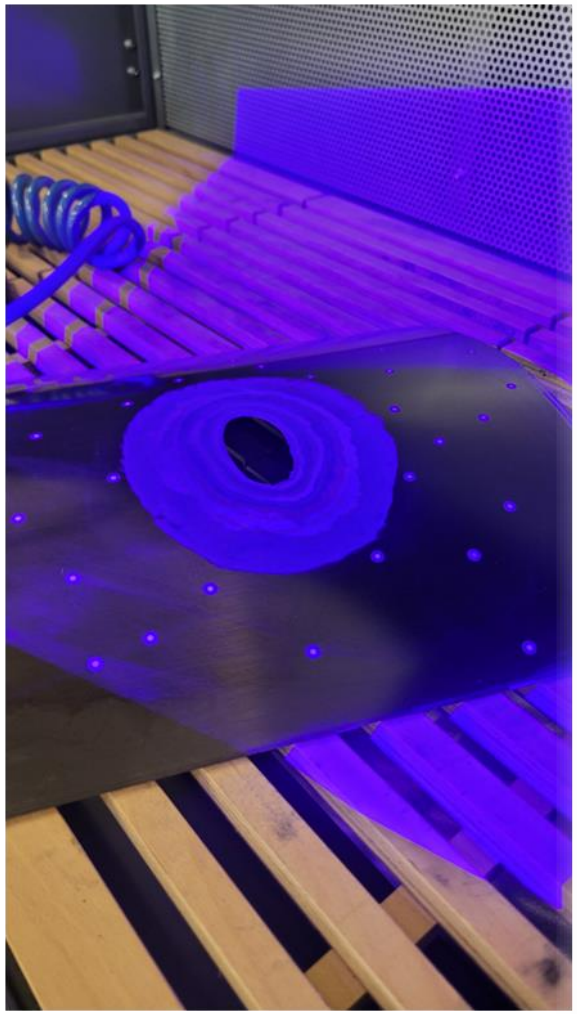




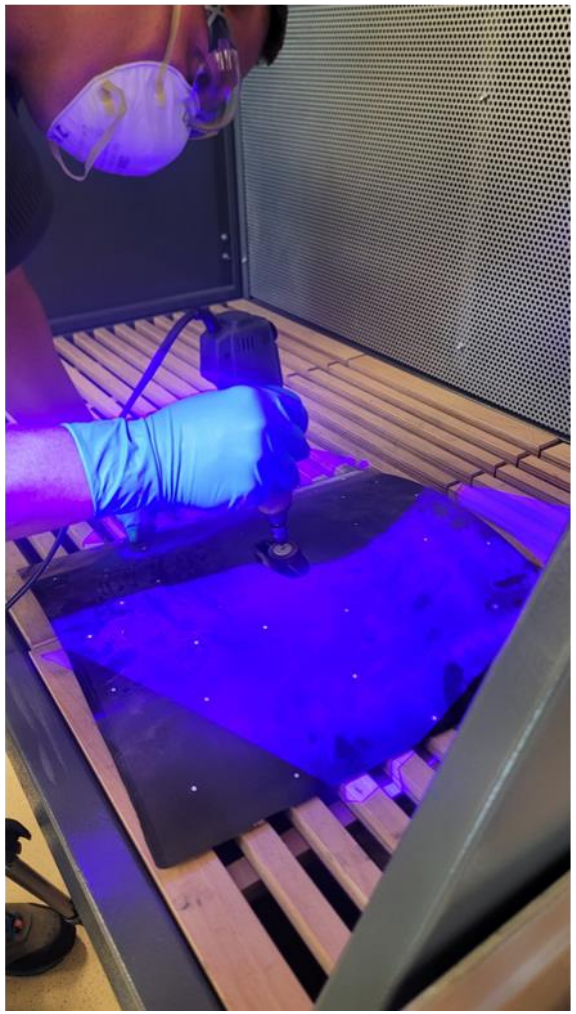
Smart and Robust Composite Scarf Repair

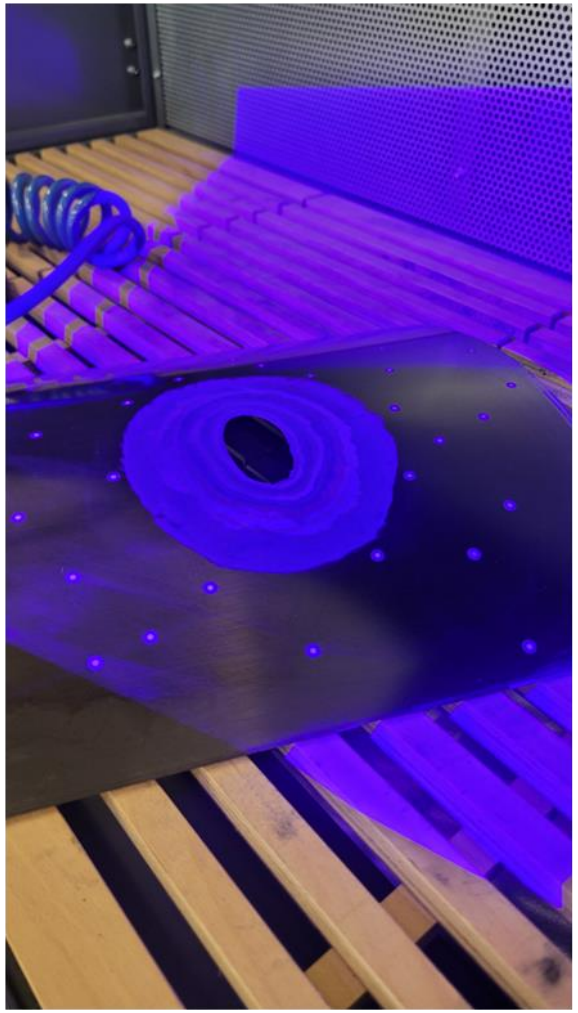


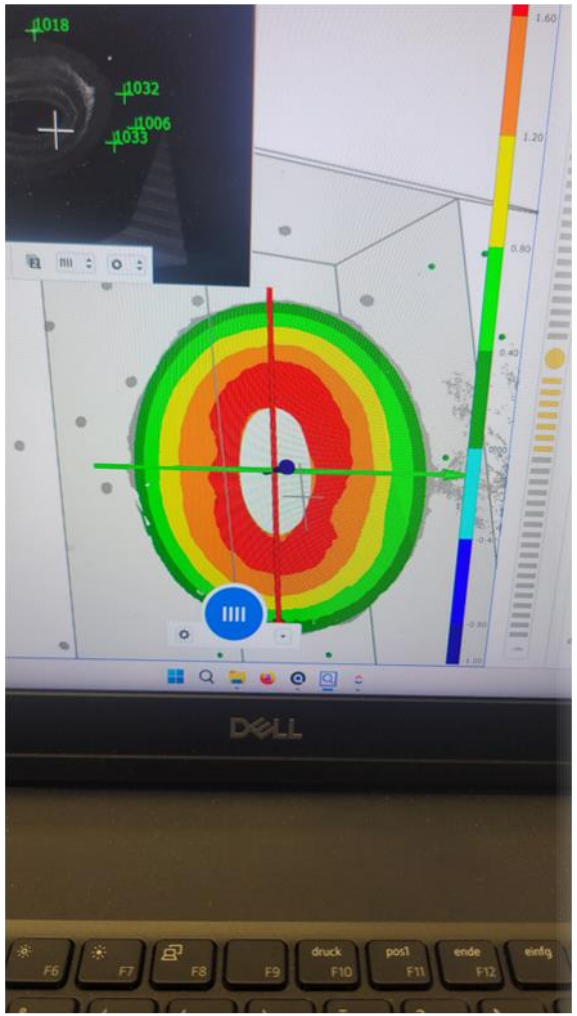




Smart and Robust Composite Scarf Repair







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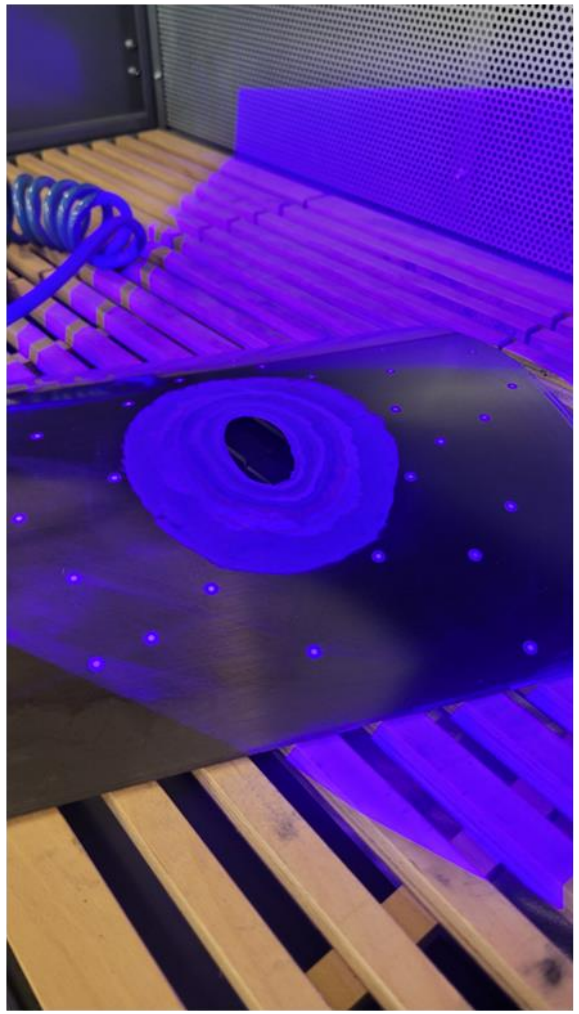

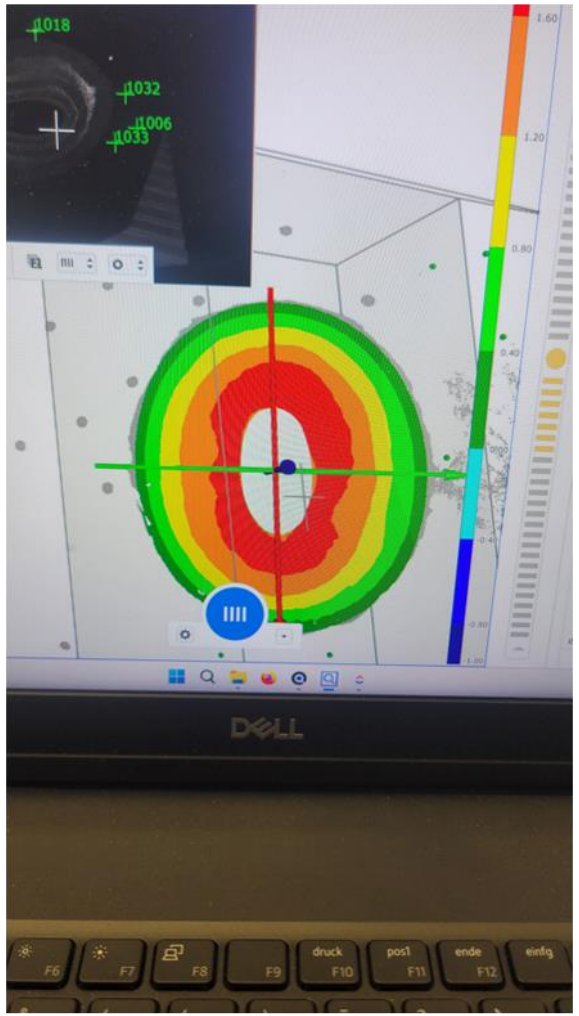

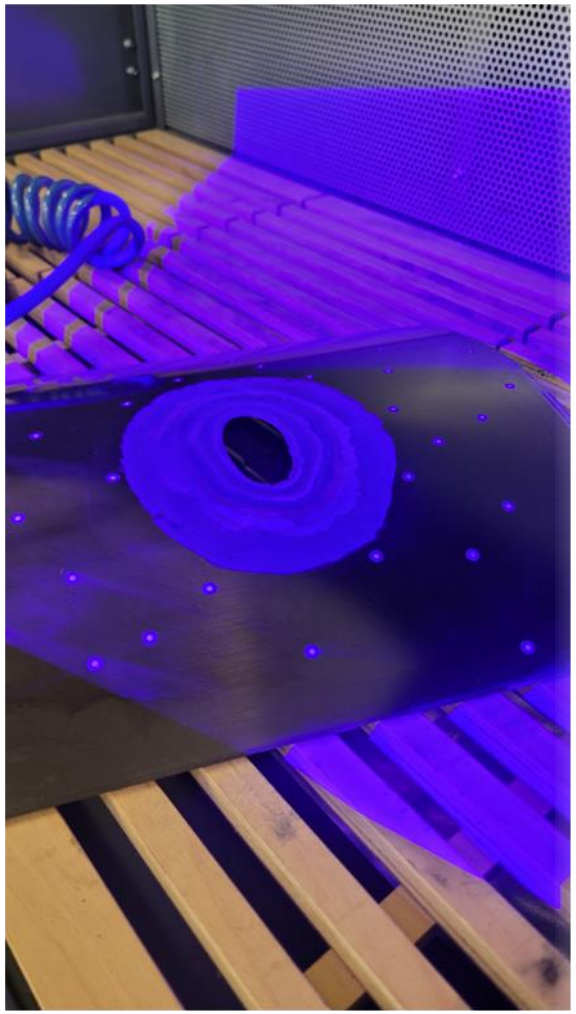

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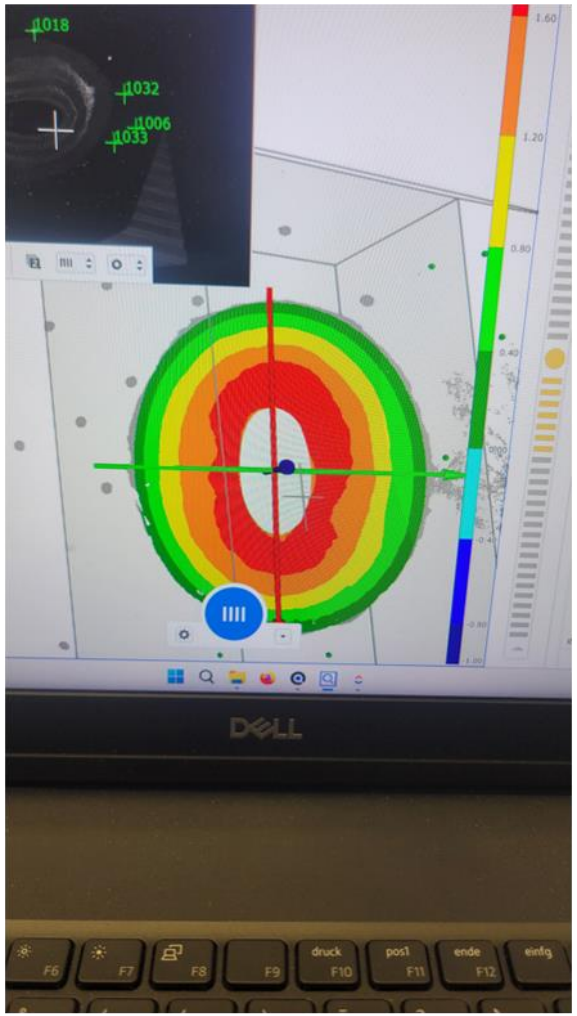
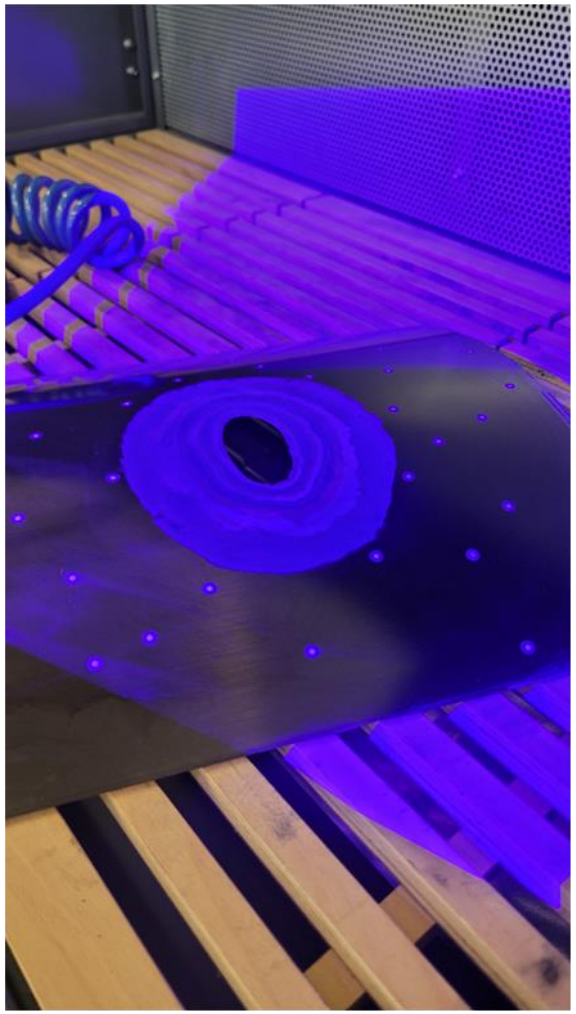
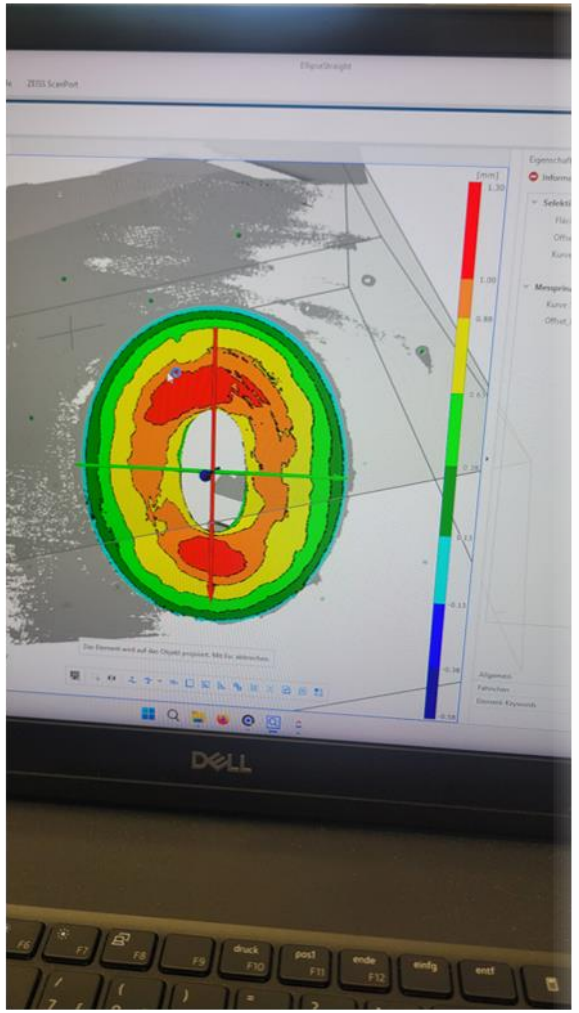
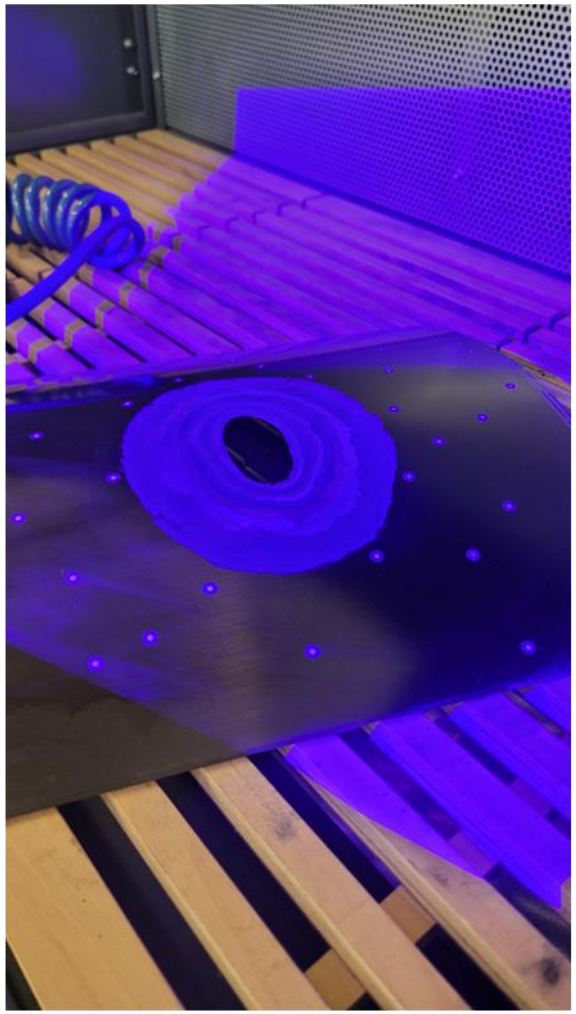
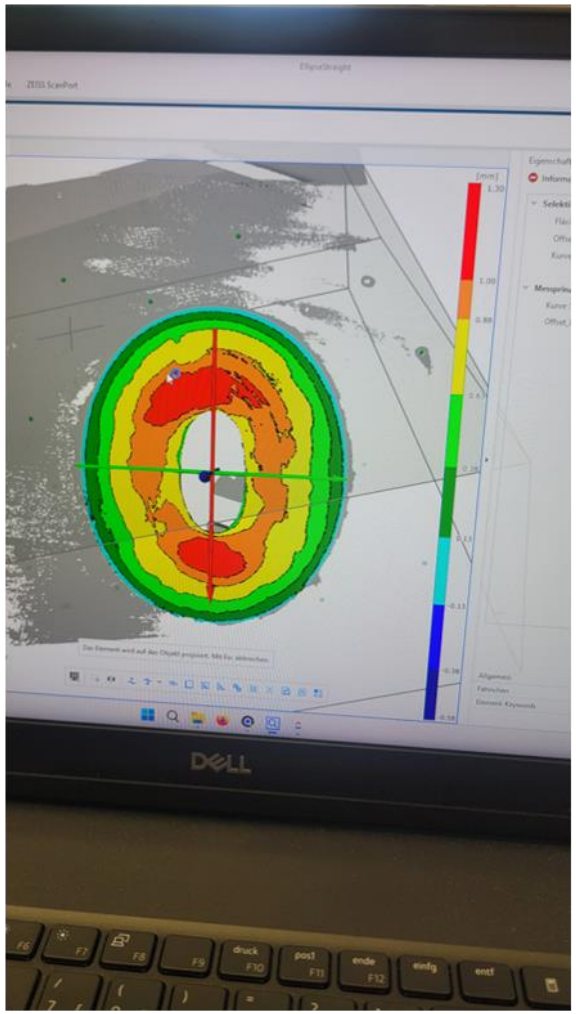






Smart and Robust Composite Scarf Repair





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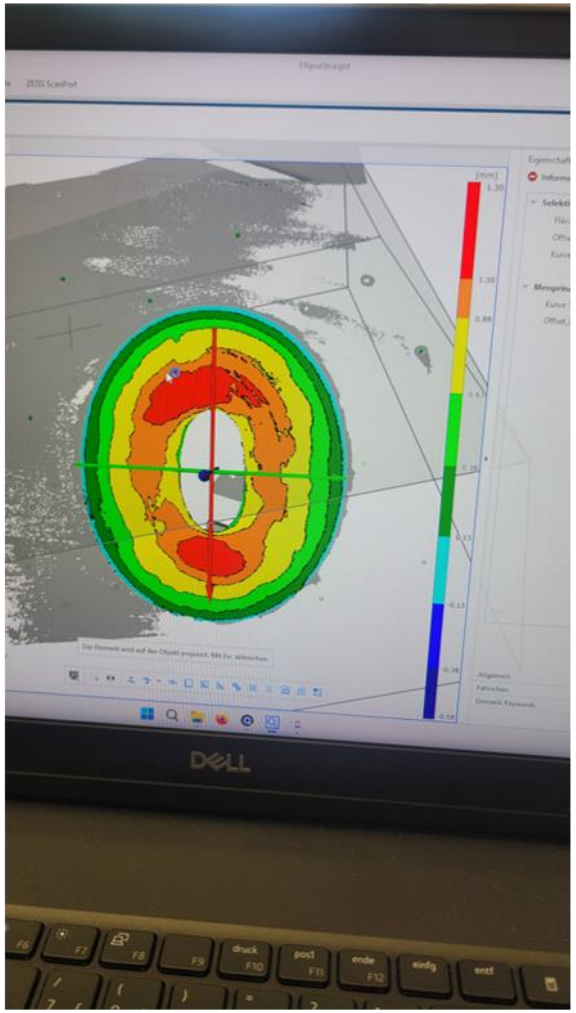

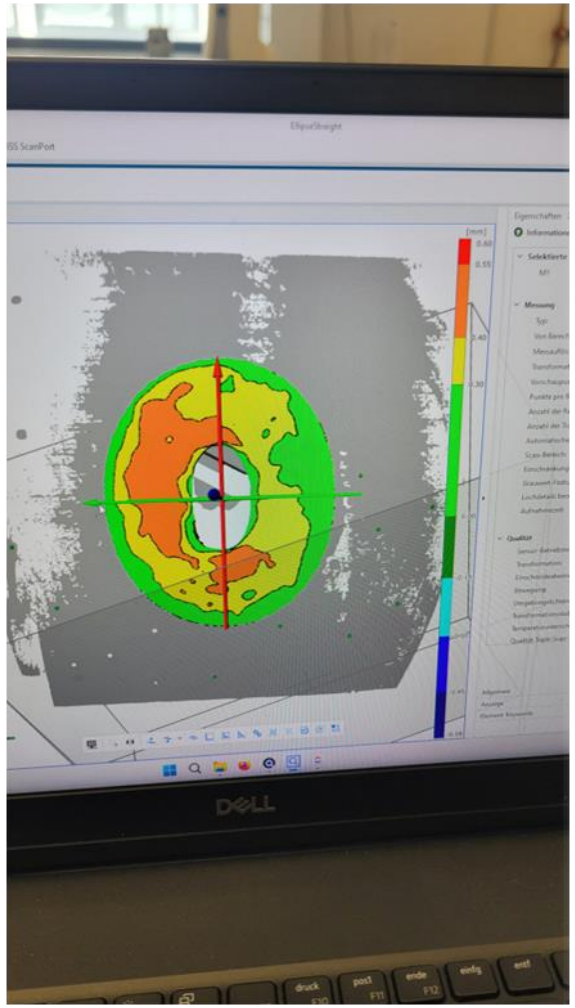

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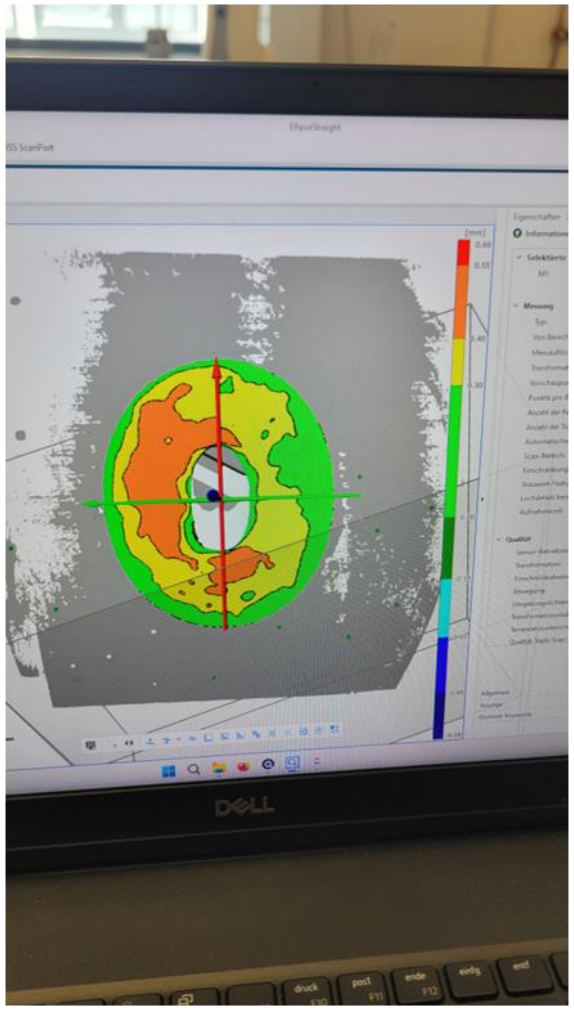

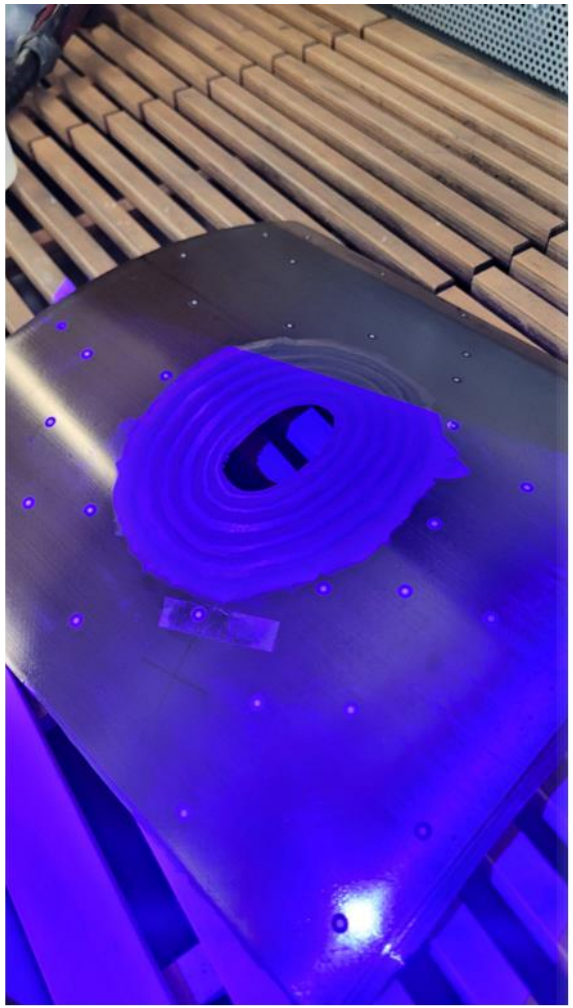

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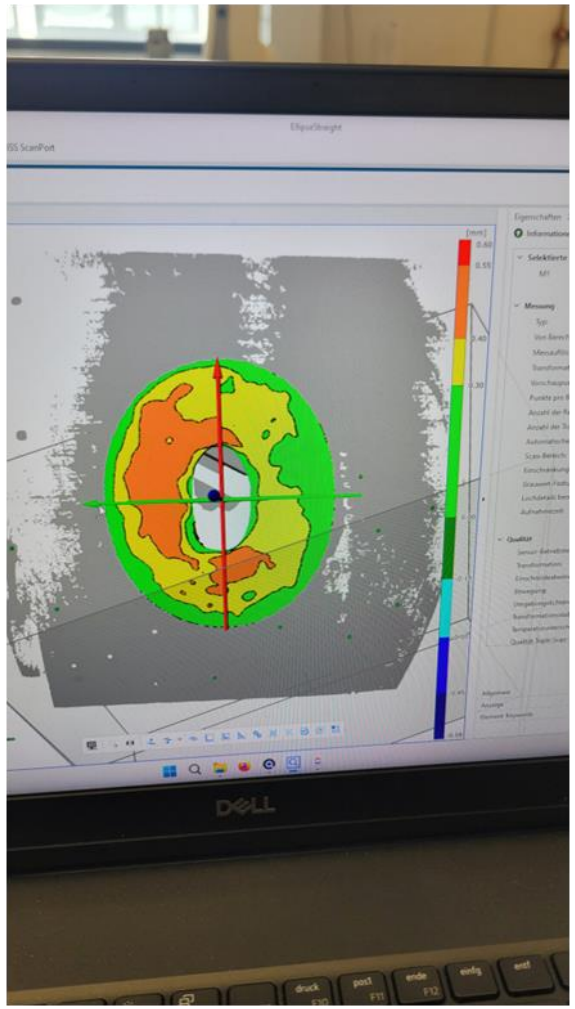

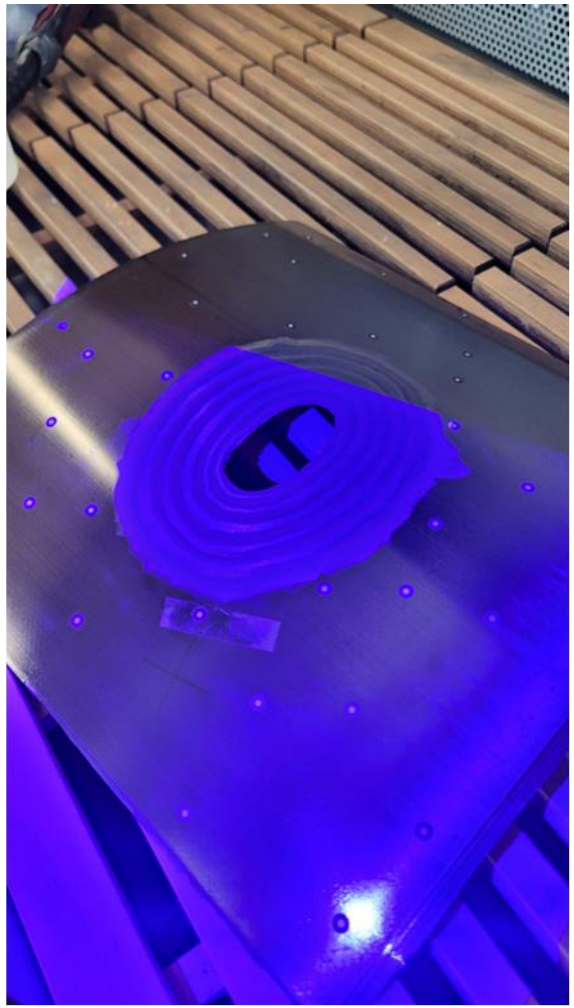

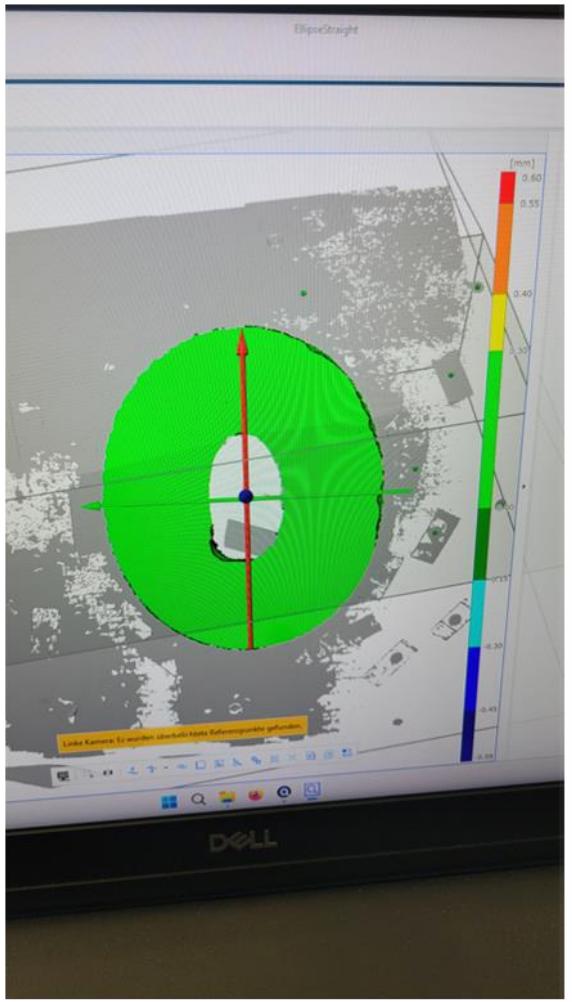

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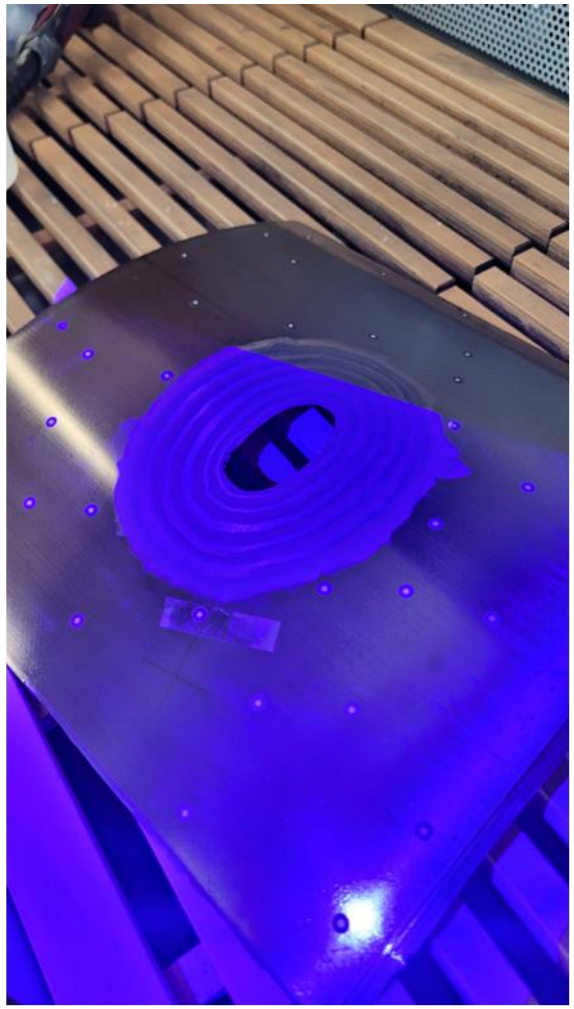

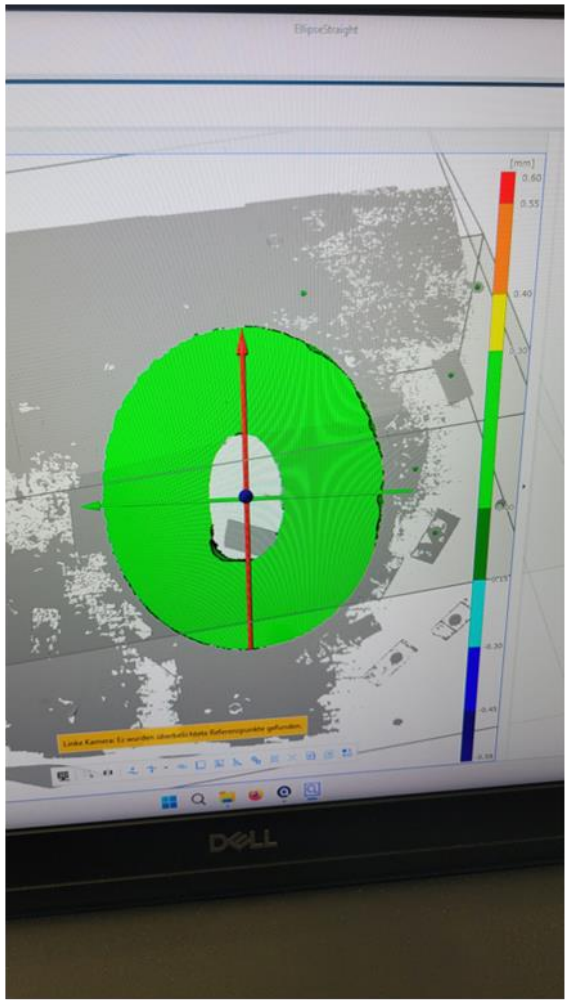

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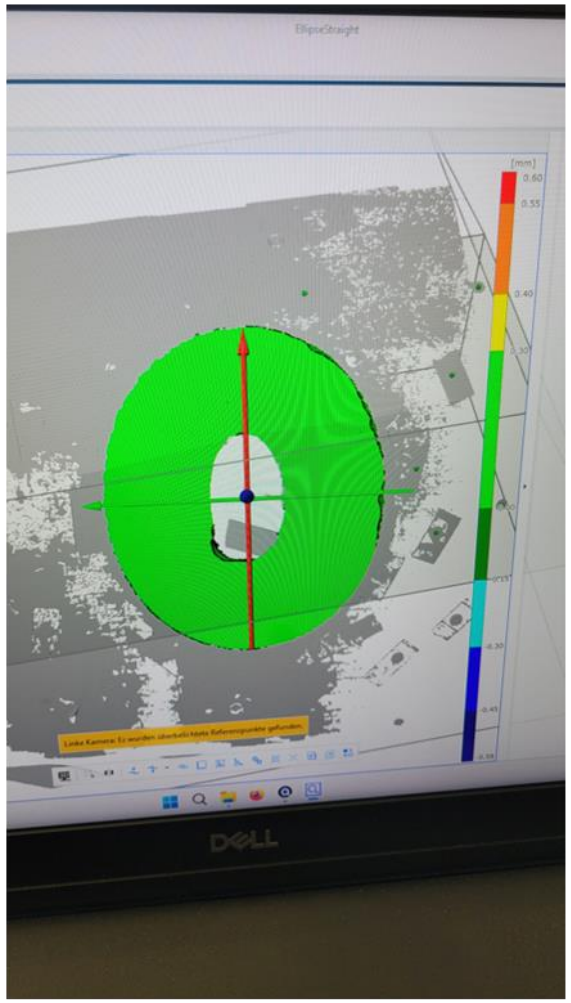

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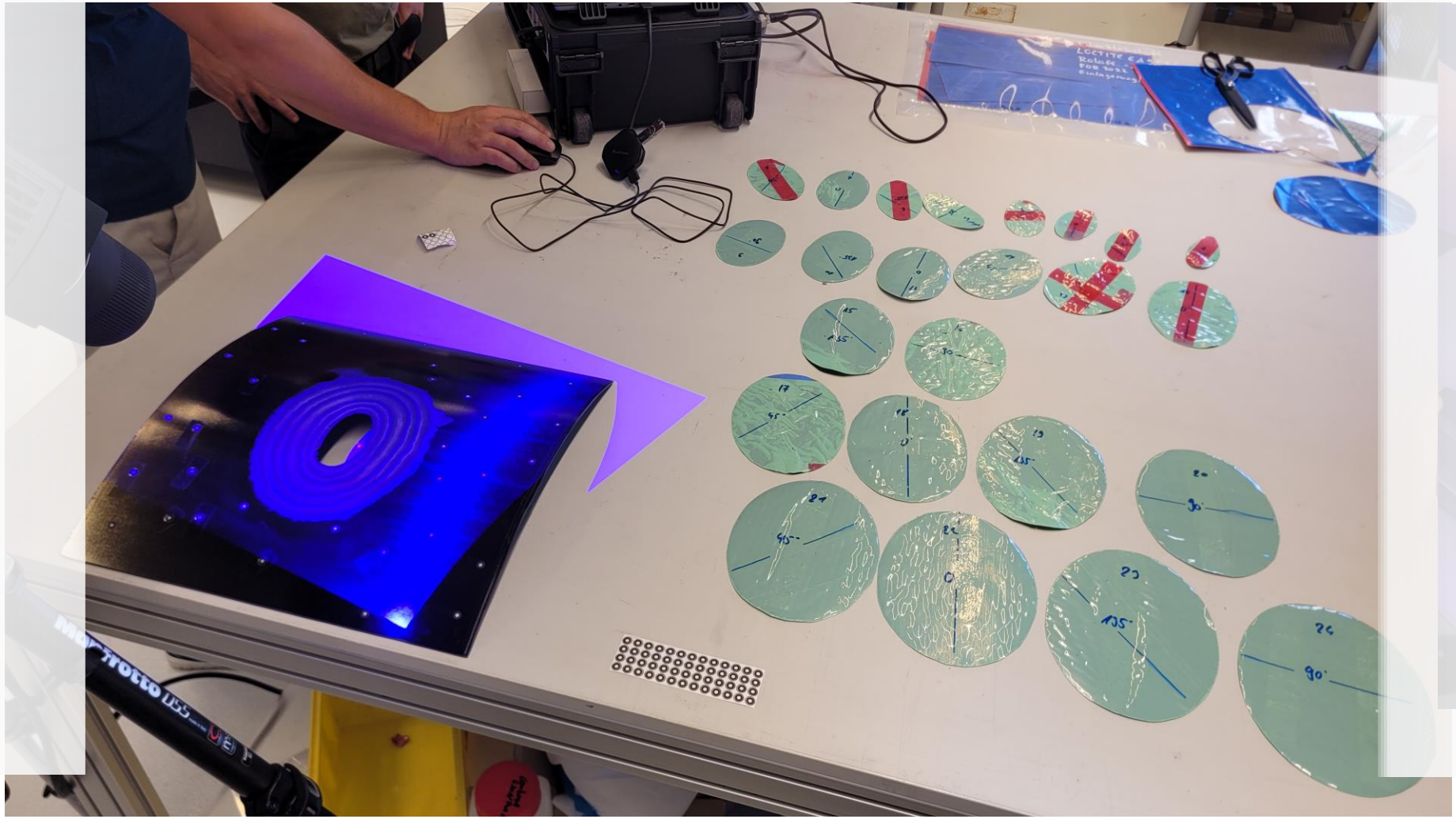

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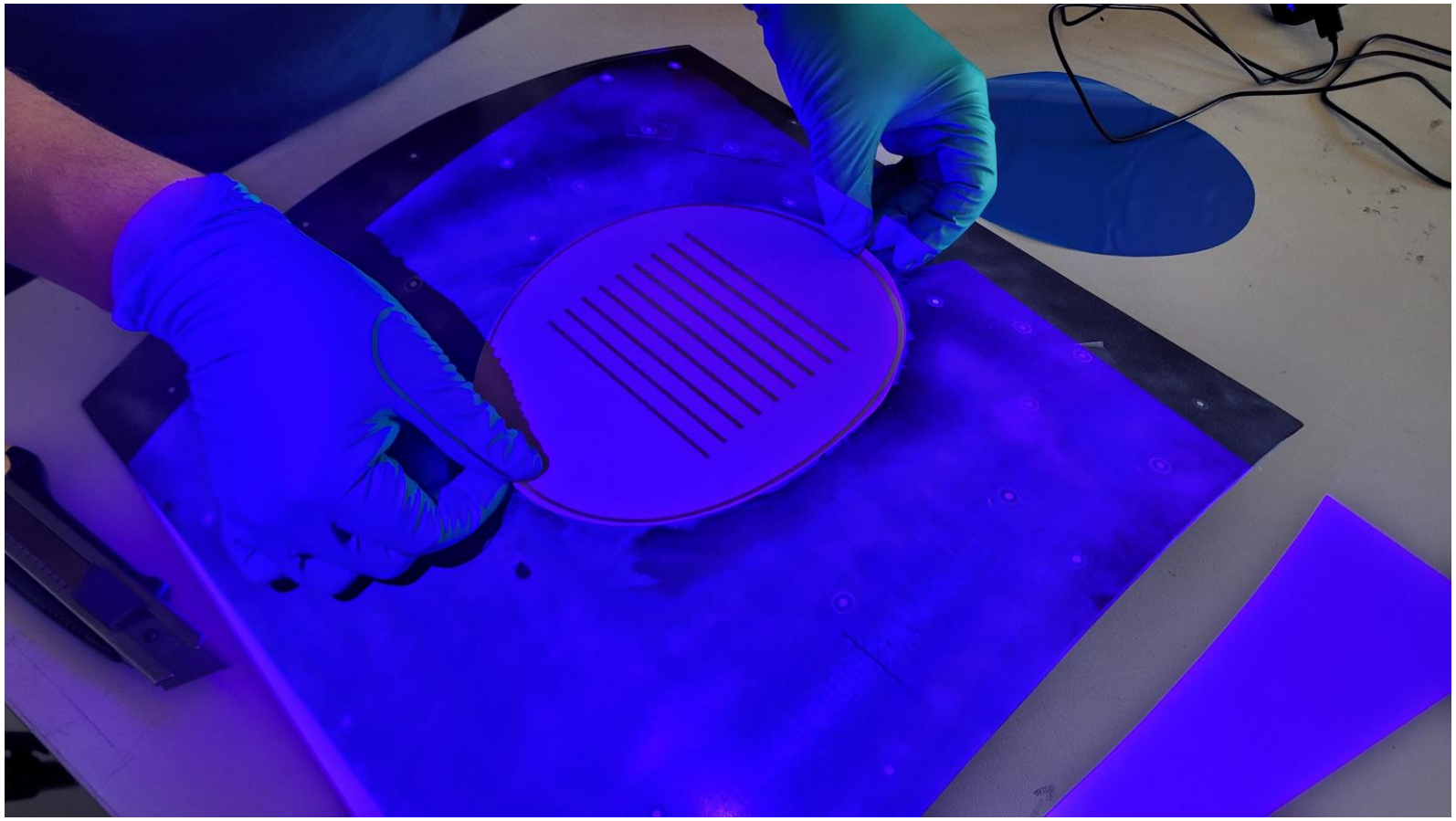

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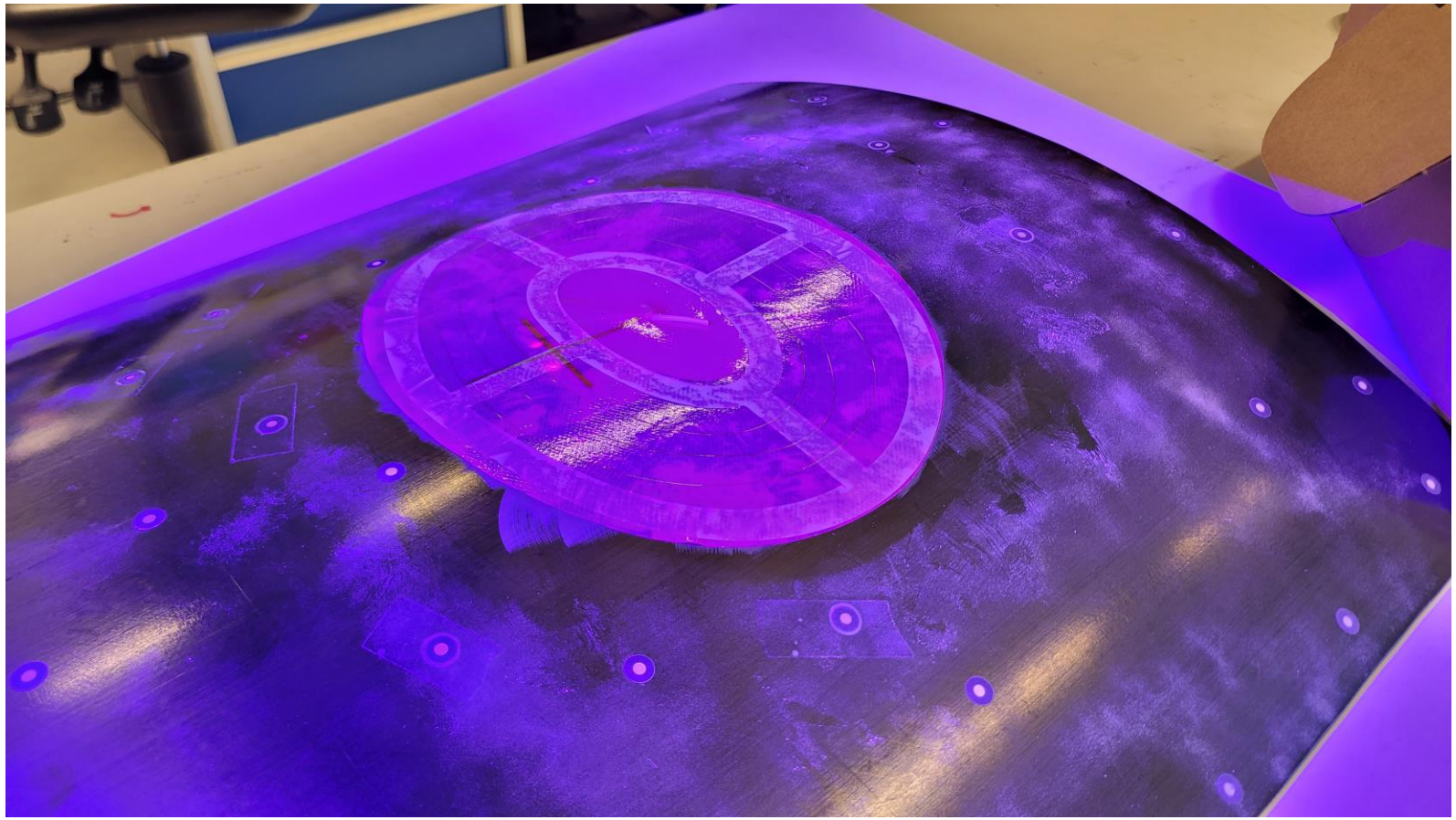

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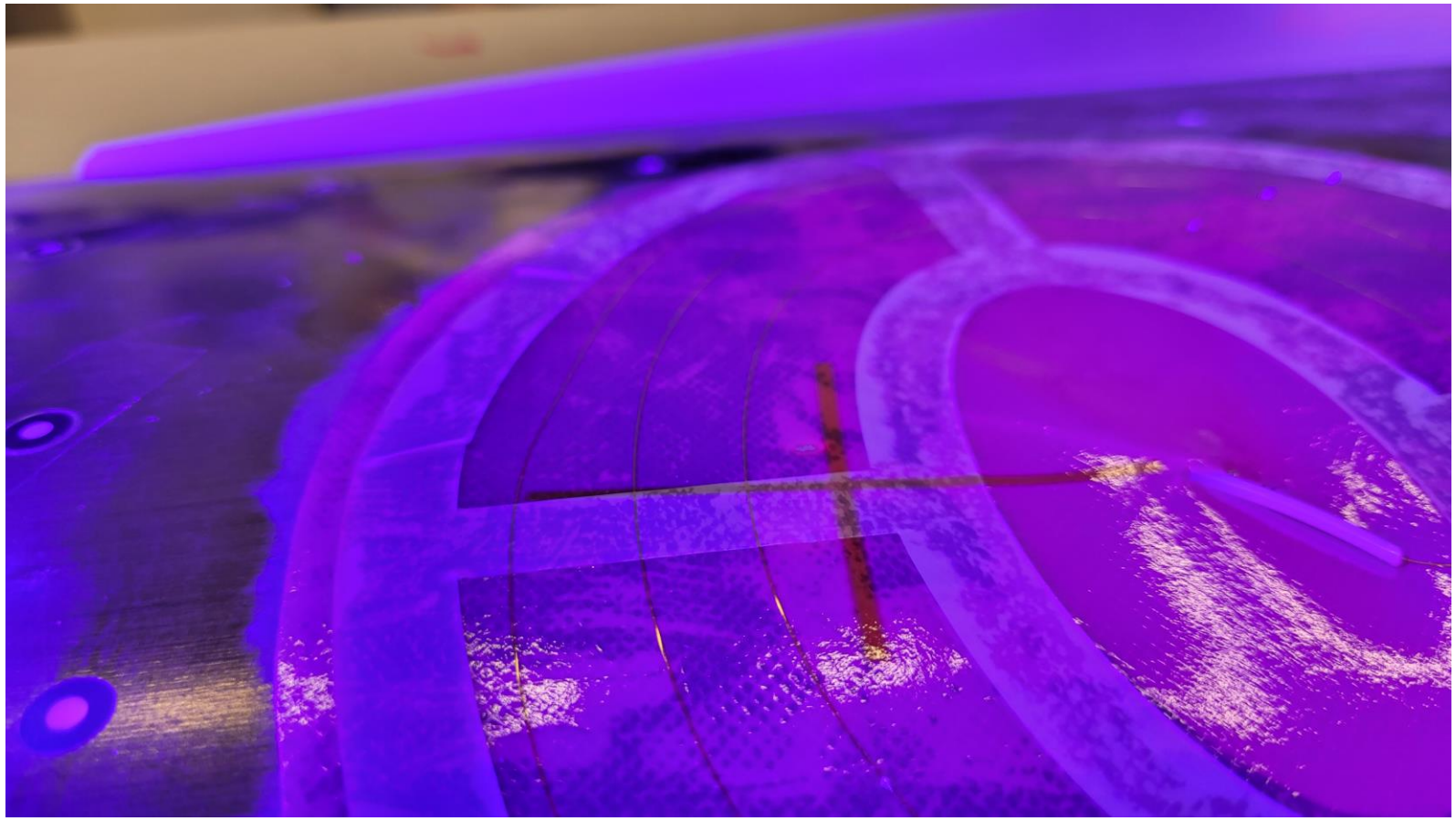

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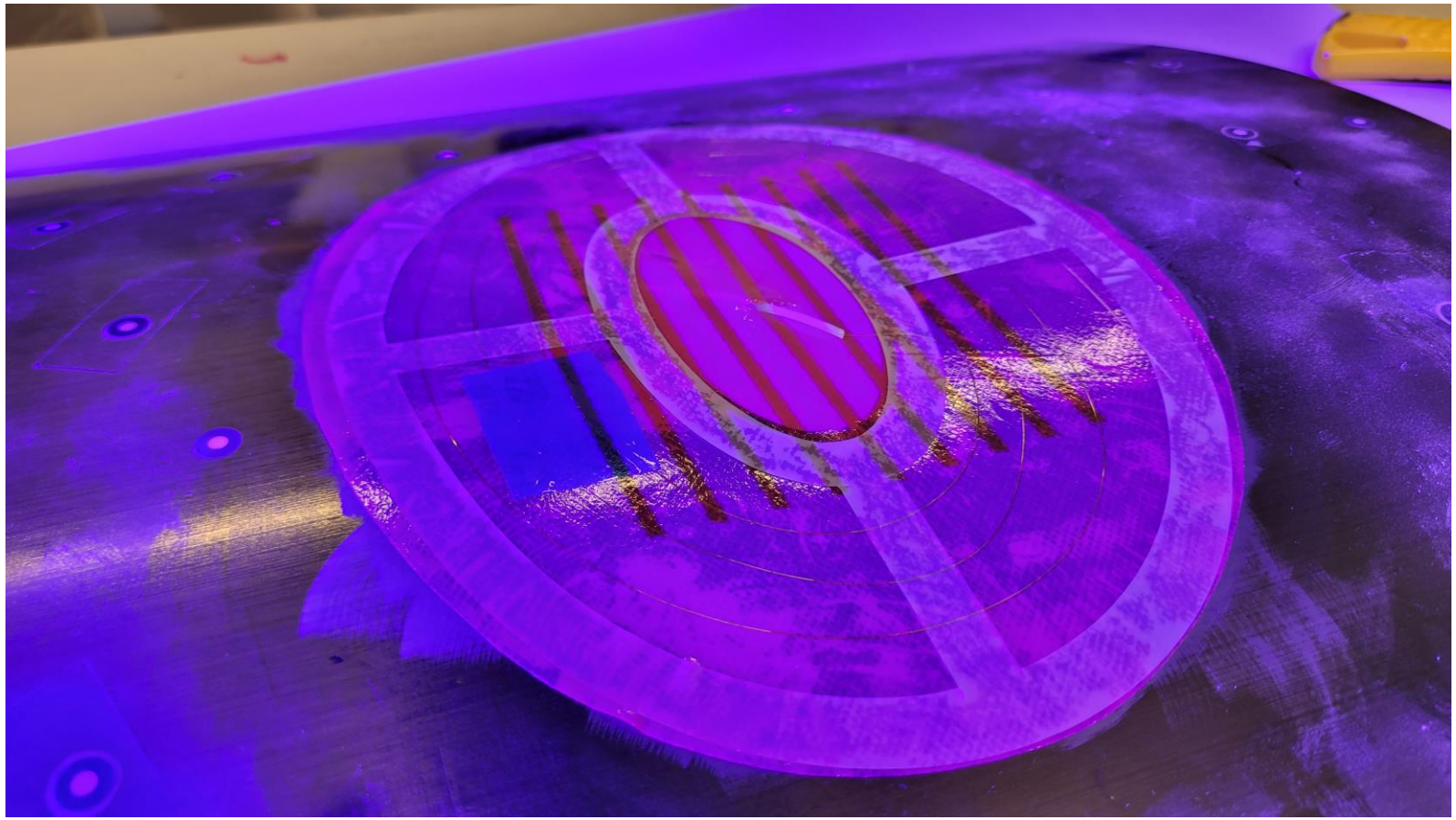
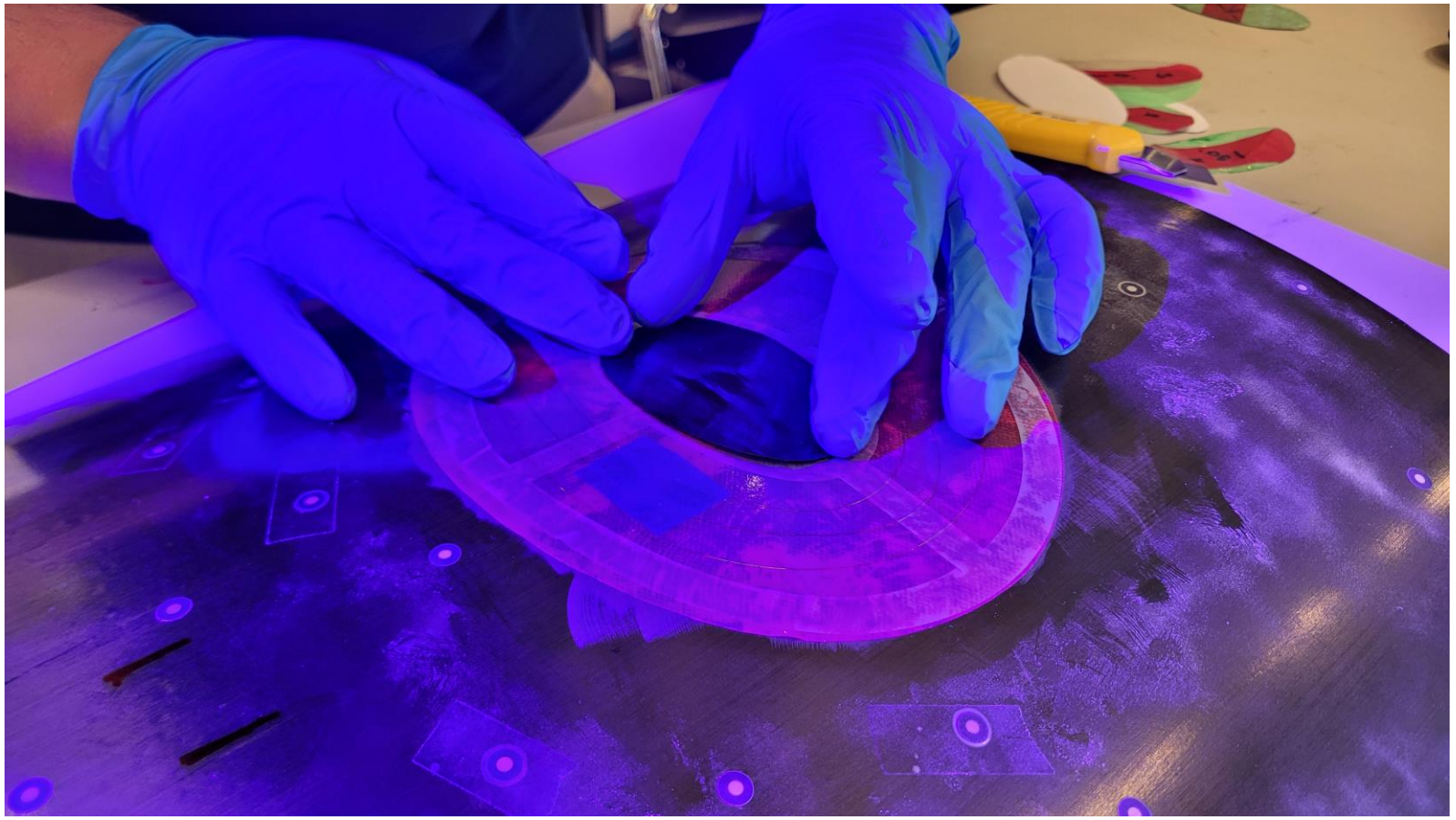


Smart and Robust Composite Scarf Repair



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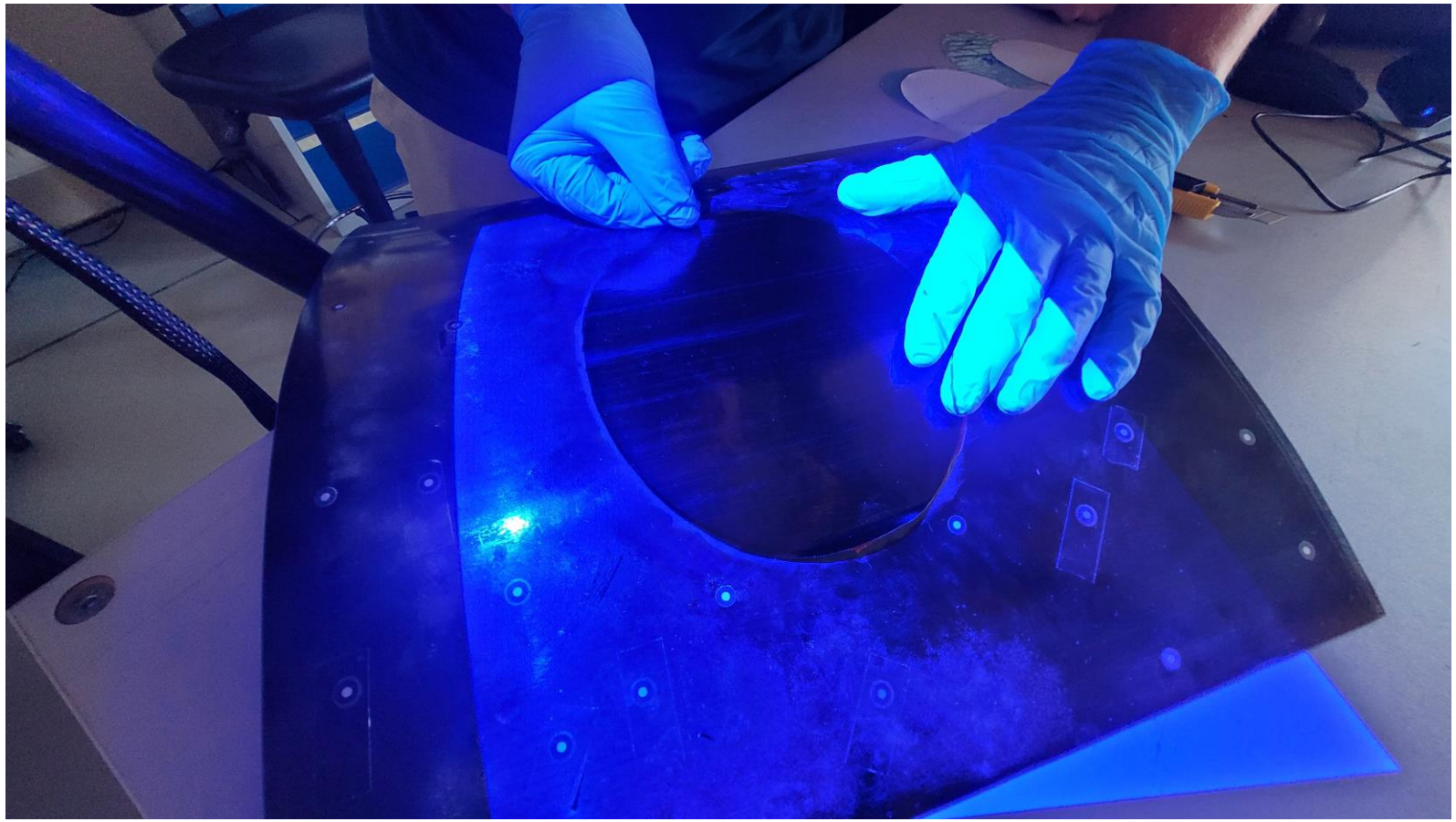

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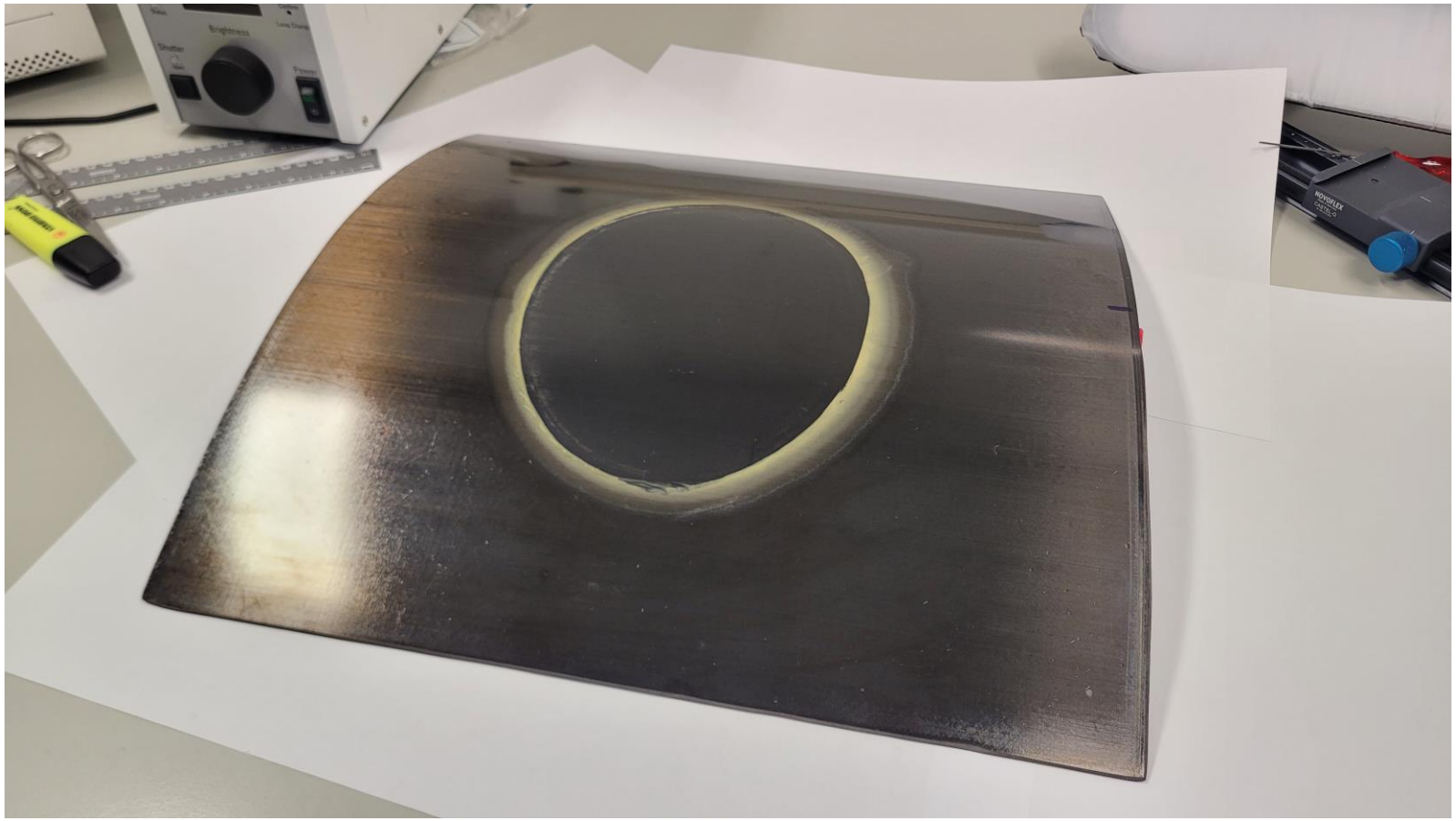
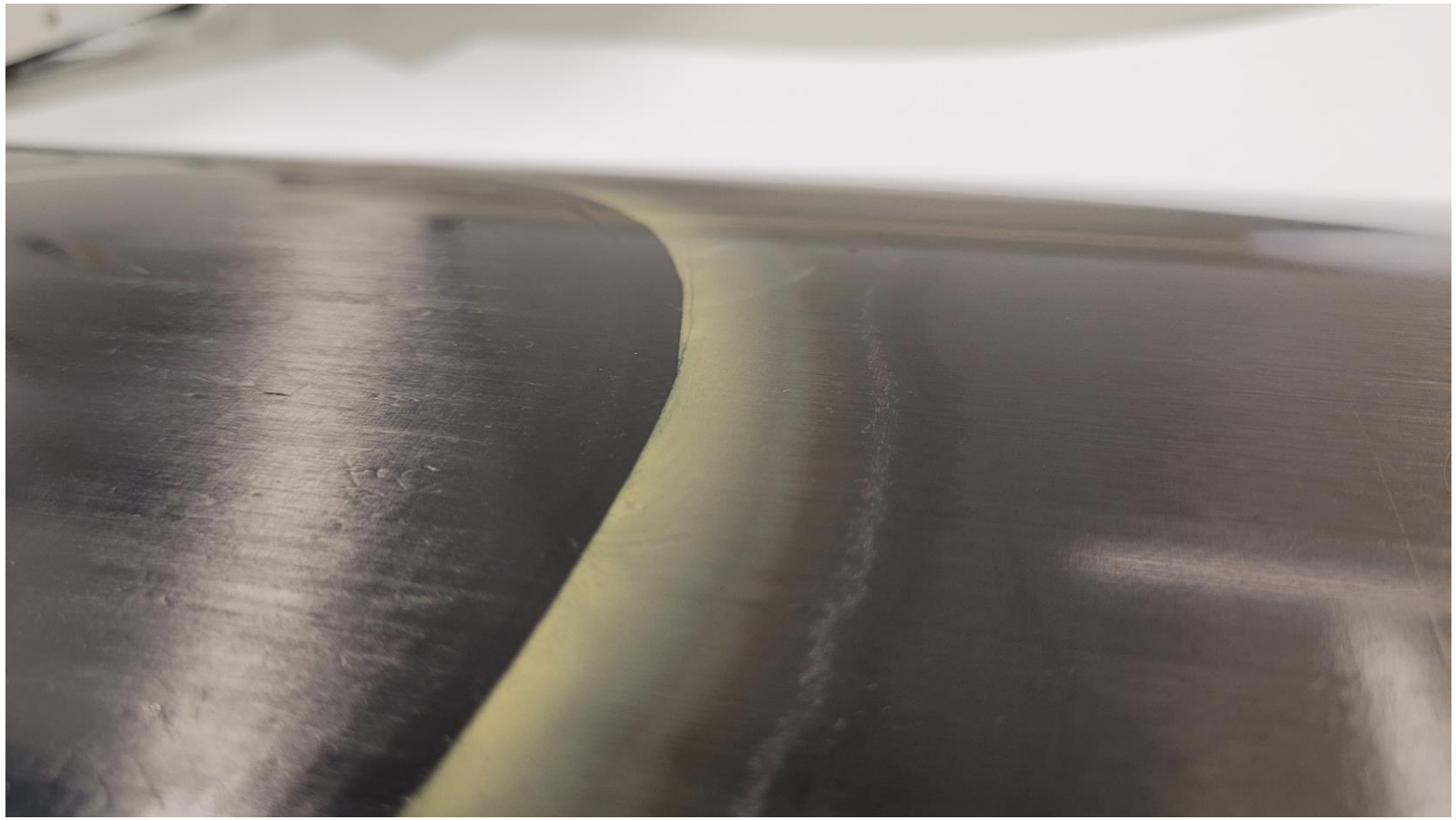
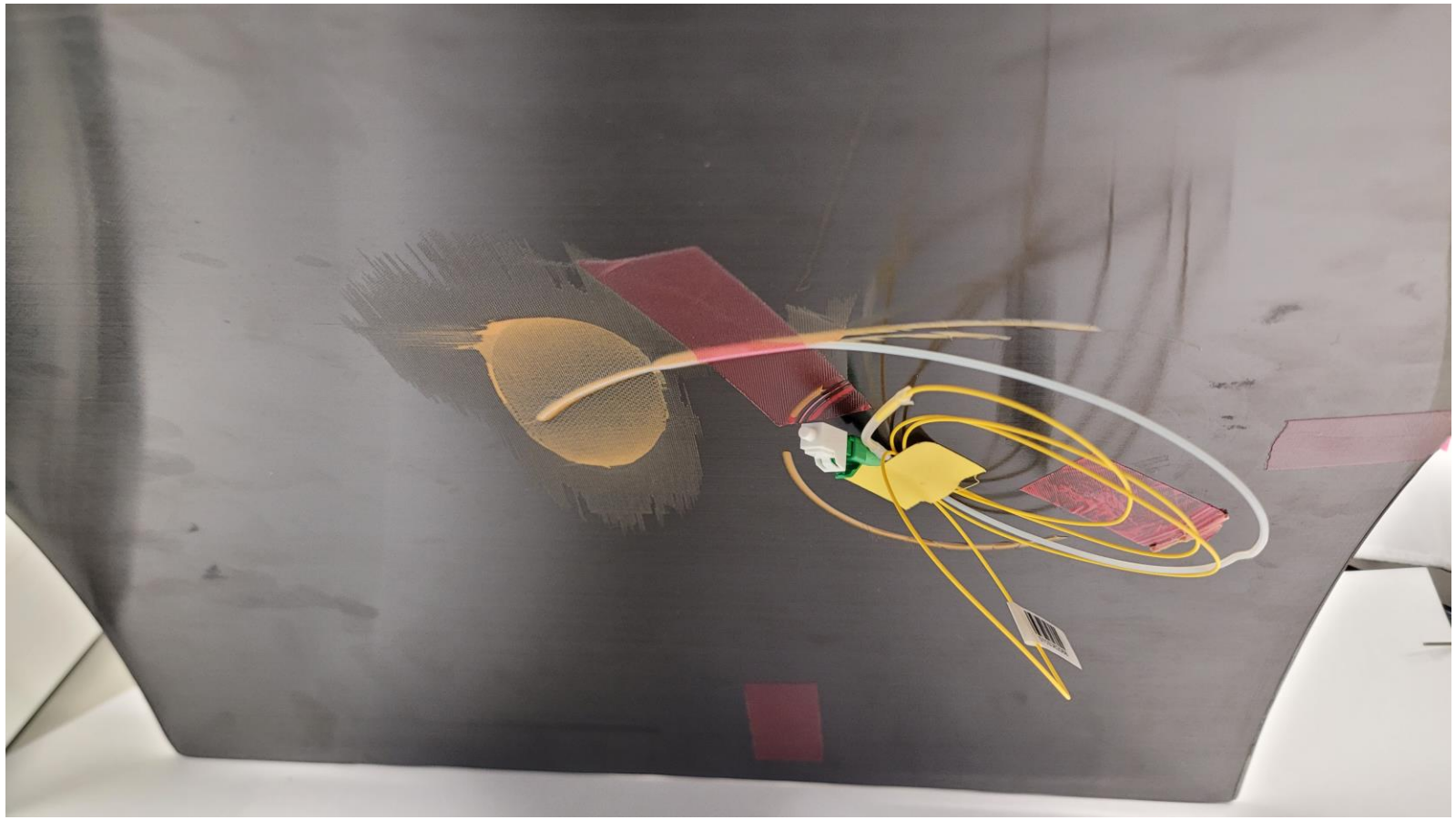


Smart and Robust Composite Scarf Repair

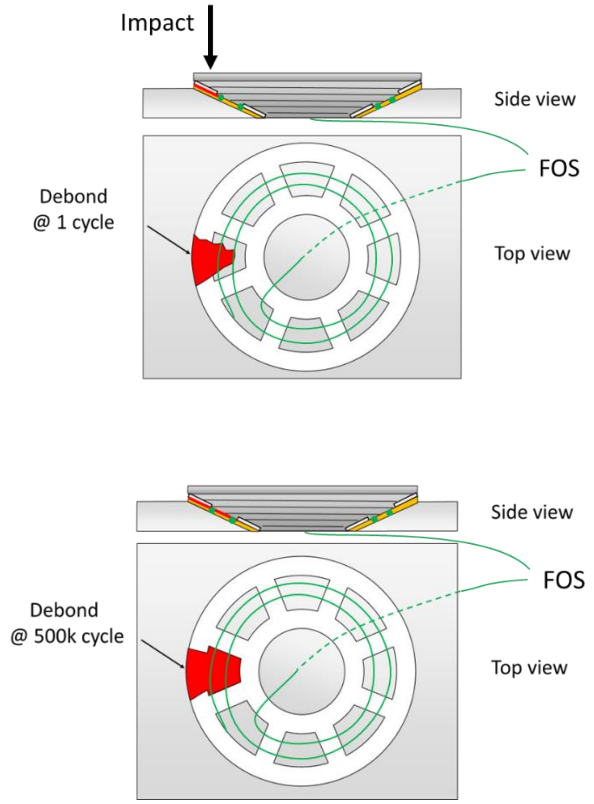


Smart and Robust Composite Scarf Repair



Smart and Robust Composite Scarf Repair

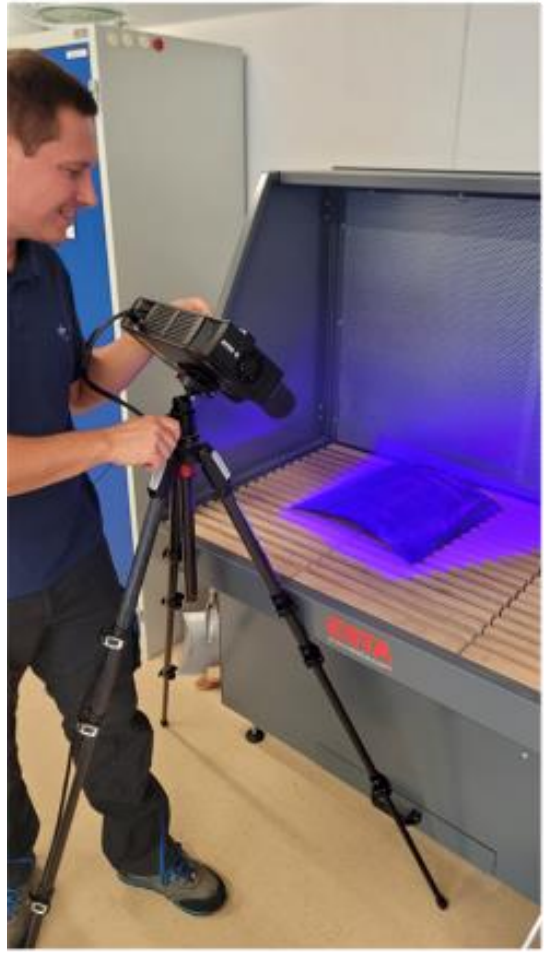
- Quality controlled and guided scarf repair by VAS
- Continuously measuring fibre-optic sensor (FOS) offering a highly accurate capability for monitoring crack propagation.
- Crack arrest function by thermoplastic polyurethane (TPU)



Conclusion -VAS

- Fully automatic scarf contour generation based on original aircraft surface
- Fully integrated user interface
- Augmented reality ready
- Validation tests successfully completed
- More realistic structures in shop floor environments upcoming

Input and Support appreciated!



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