ROBUST BONDED JOINTS WITH SURFACE TOUGHENING DESIGN FEATURE

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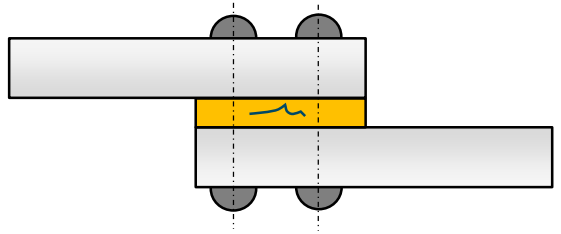
DLR

Motivation

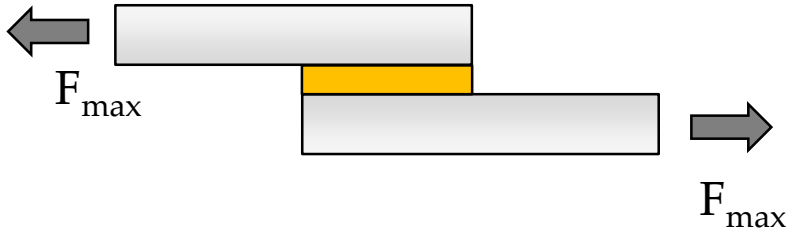
Certification of Bonded Joints

§ AMC 20-29

i) Disbonds of each bonded joint greater than the maximum critical disbonding must be prevented by design features



ii) Full single part testing of bonded joints



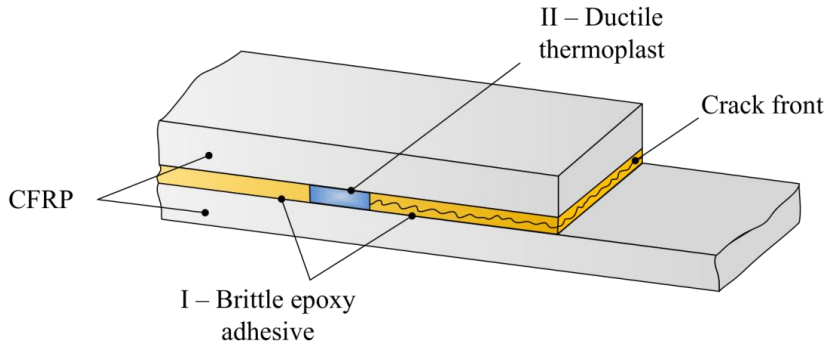
iii Repeatable and reliable non-destructive inspection techniques must be established that ensure the strength of each joint.

Hybrid Bondline

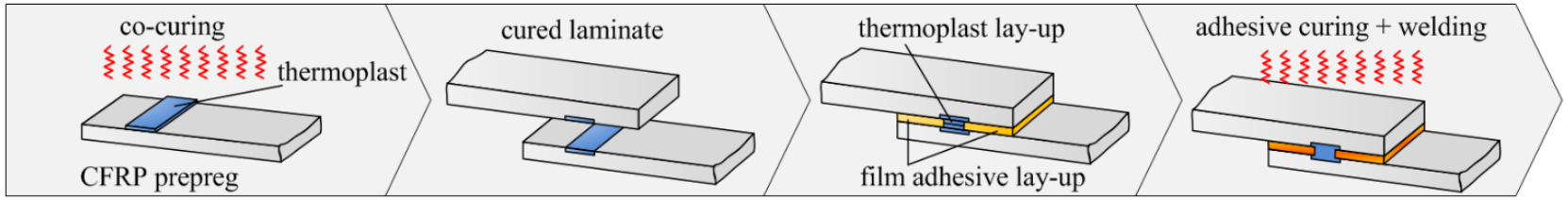
Design & Manufacturing

- Crack constraining physical barrier
- Uses two different adhesives with different properties
- Divides the bondline into separated independent zones

Hybrid Bondline

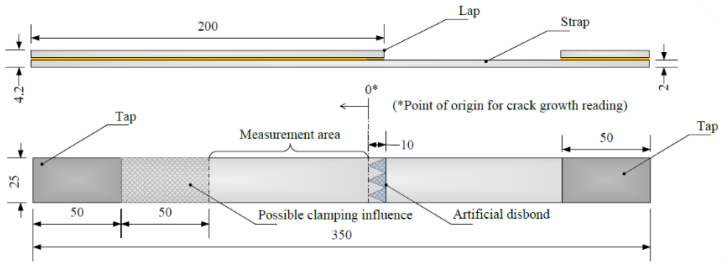


- Thesis by T. Löbel (developed in EU FP7 Project BOPACS)



Combines thermoplastic welding and adhesive bonding in one process step

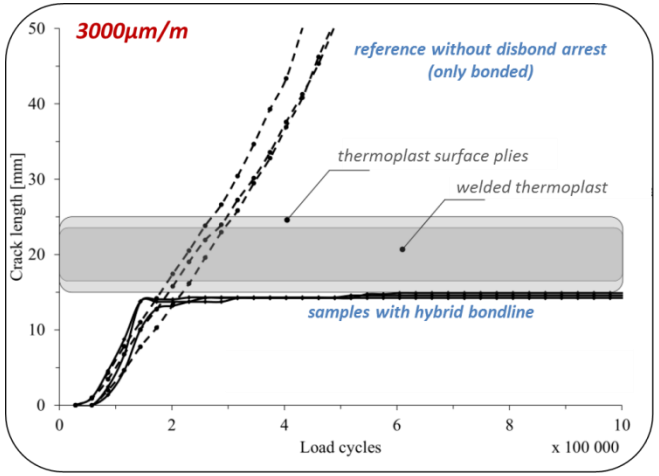
Hybrid Bondline

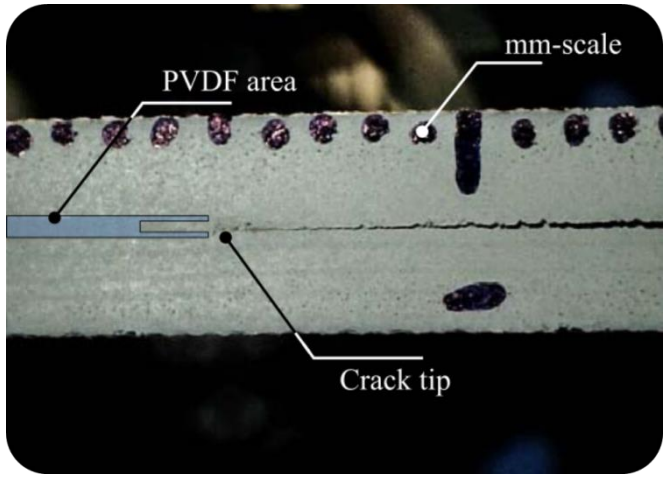


Crack Lap Shear Specimen (CLS)

Fatigue Performance

3000µs



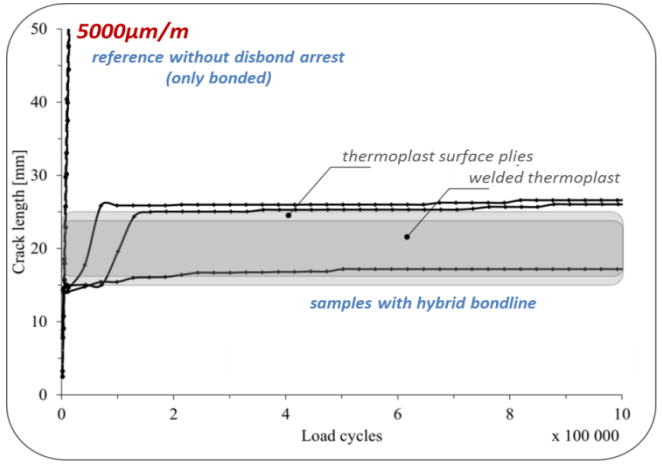


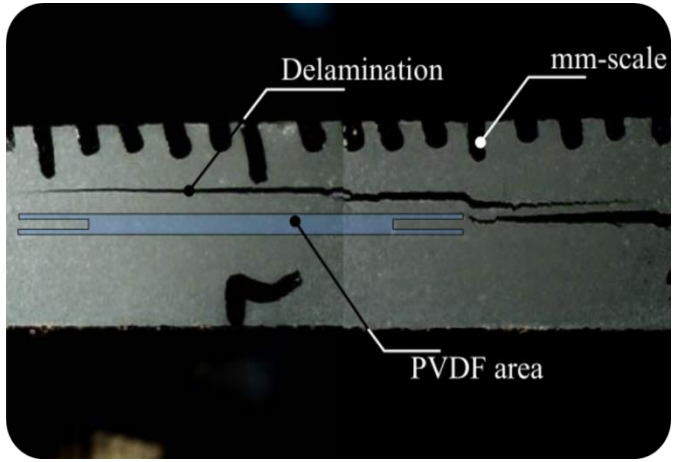
Crack fully stopped up to 1Mio load cycles.

No re-initiation of crack.

Crack front stopped at Hybrid Bondline.

5000µs





Adhesive crack stopped up to 1Mio load cycles!

Crack in laminate also stopped at backside of Hybrid Bondline!

Hybrid Bondline

Lessons Learned

Cracks stop at the Hybrid Bondline surface plies!

Why?

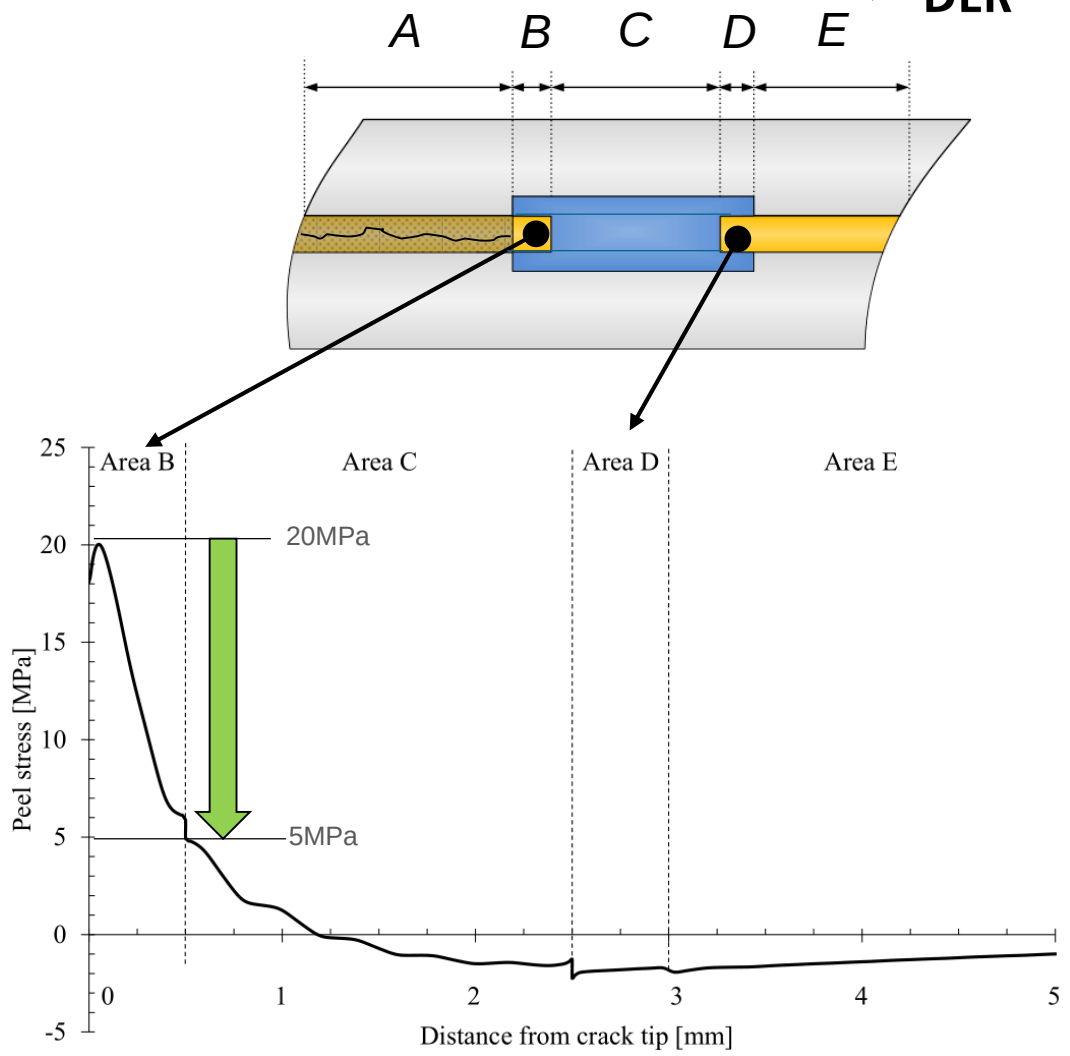
- Toughening of surface already reduces the driving peel stress by 75%!

Idea

- Reduction of Crack Stopper to thermoplastic surface plies (no welding of the parts)

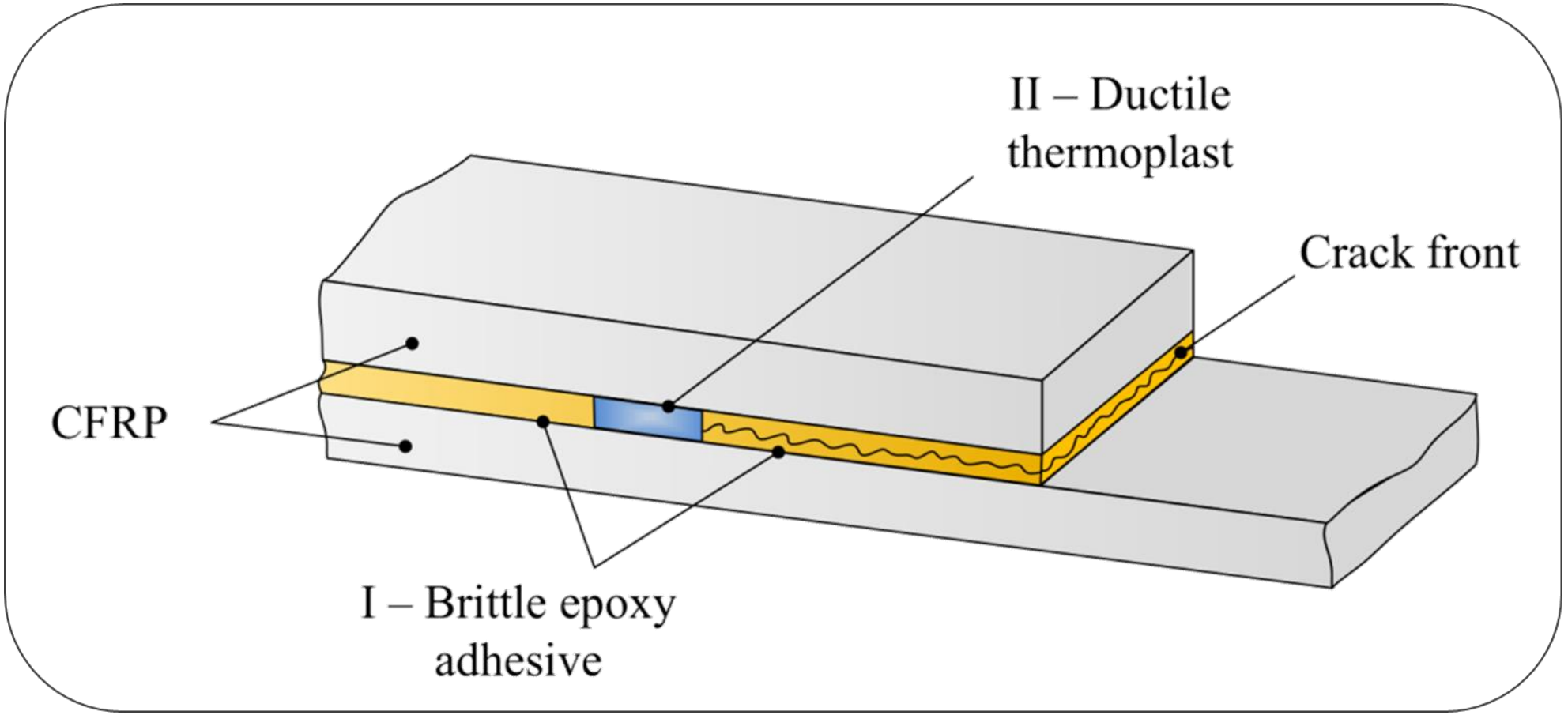
Result

- Surface Toughening
- Usage of state of the art bonding process without any modification



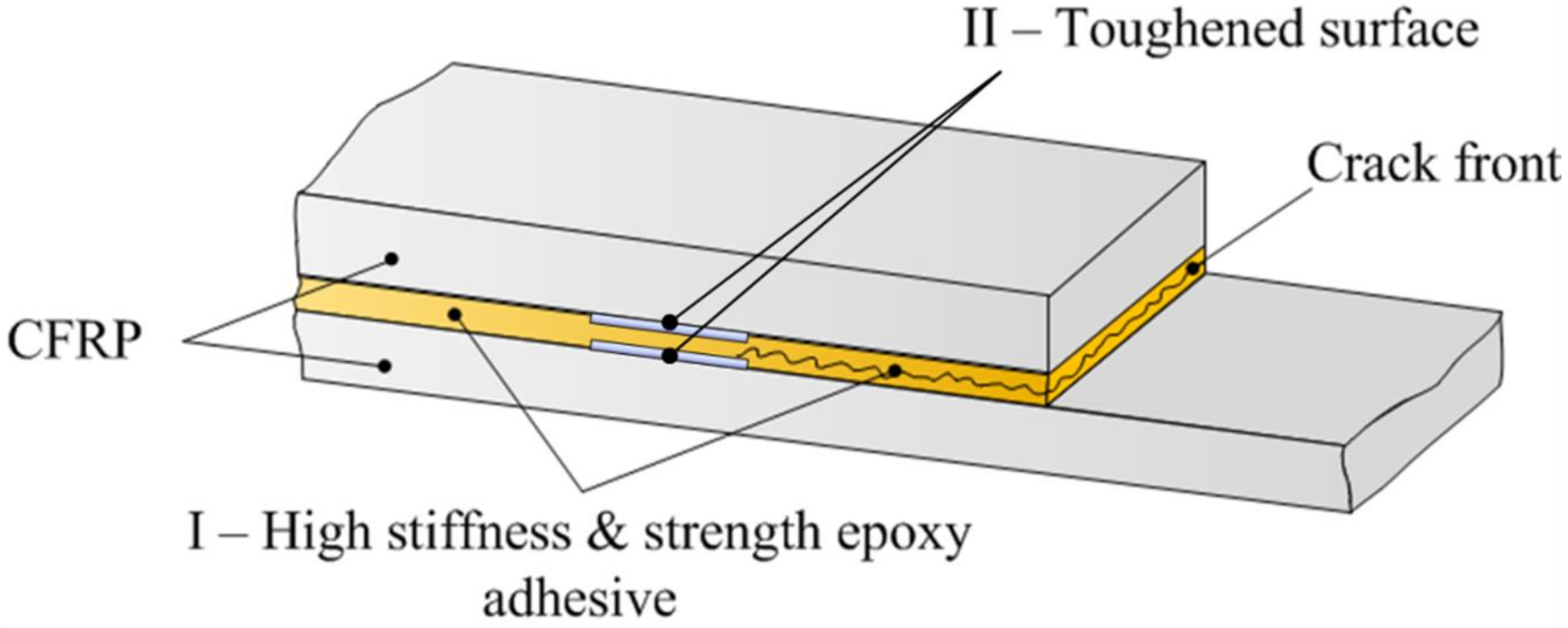
From Hybrid Bondline to Surface Toughening

Hybrid Bondline



From Hybrid Bondline to Surface Toughening

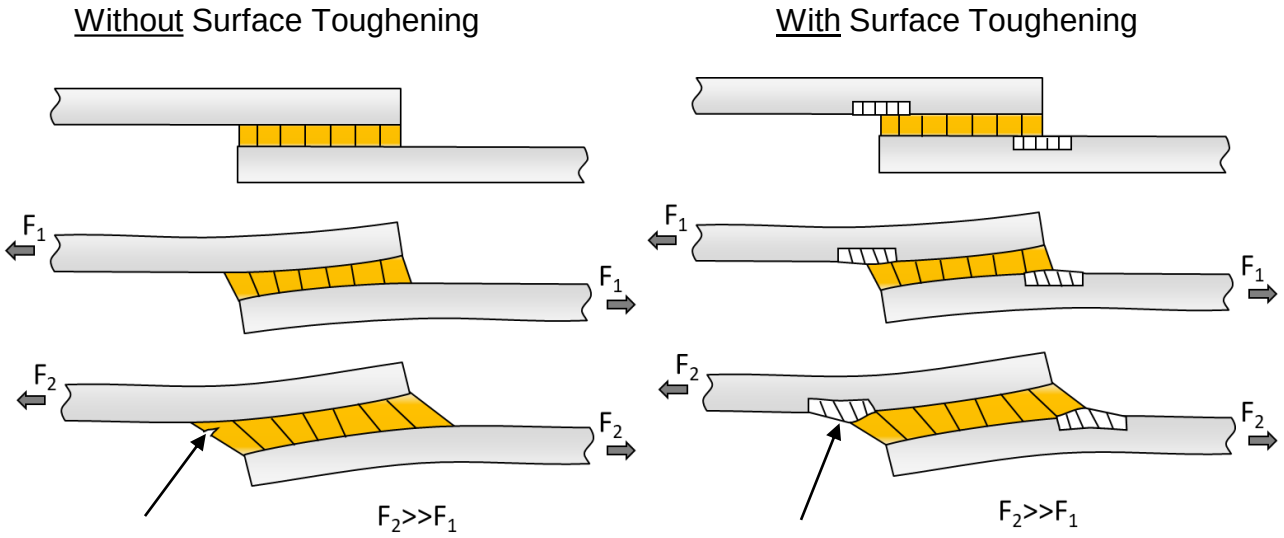
Surface Toughening



Surface Toughening

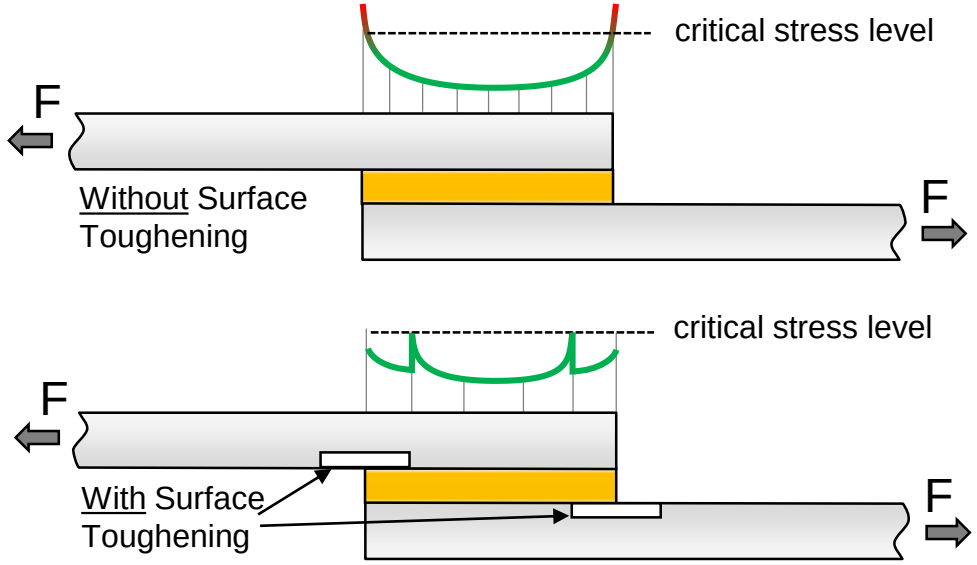
Mechanical Principle

What is Surface Toughening (ST)?
ST is a local surface toughening in the joining partner and reduces stress concentrations in the bonded joint.



stress concentration leads to a crack

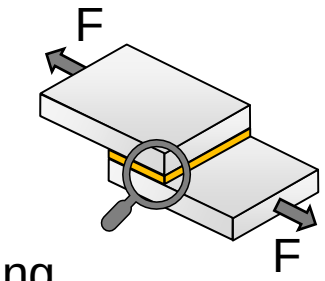
ductile material reduces the stress concentration → no crack



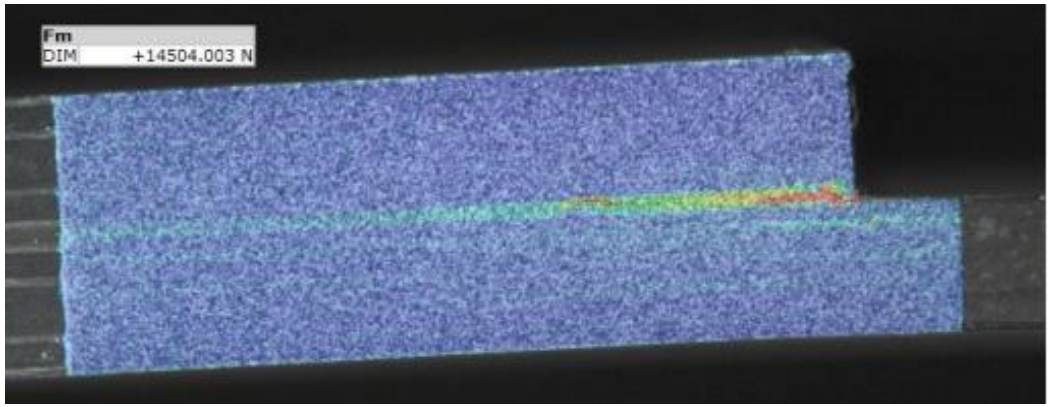
How does Surface Toughening work?
Stress concentrations always occur at overlap edges. Surface Toughening reduces the critical peel and shear stress and leads to a significantly more homogeneous stress distribution in the joint.

Surface Toughening

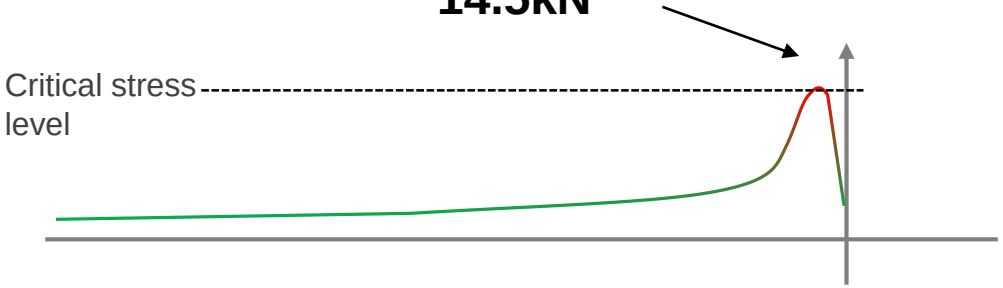
Static Strength Increase



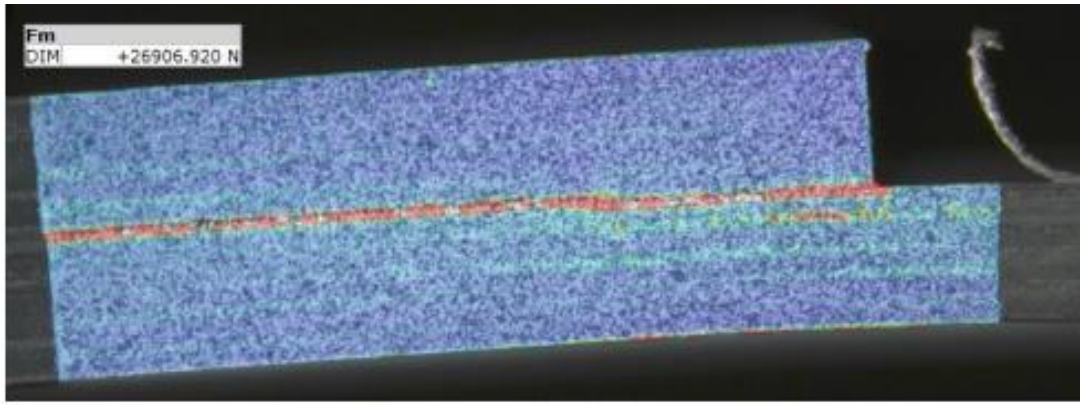
Without Surface Toughening



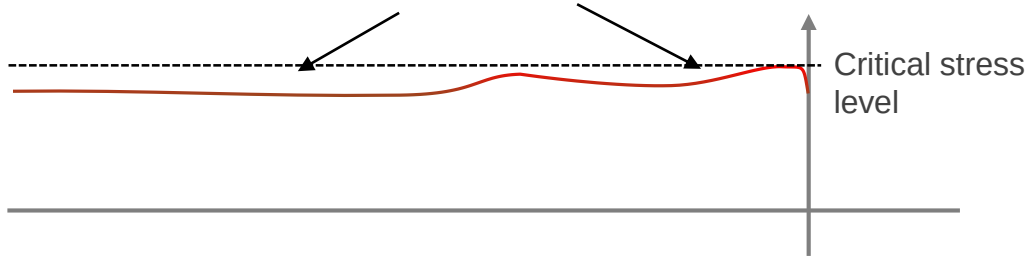
Stress concentration leads to failure at **14.5kN**



With Surface Toughening



ST homogenizes the stress and increases failure to **26.9kN**



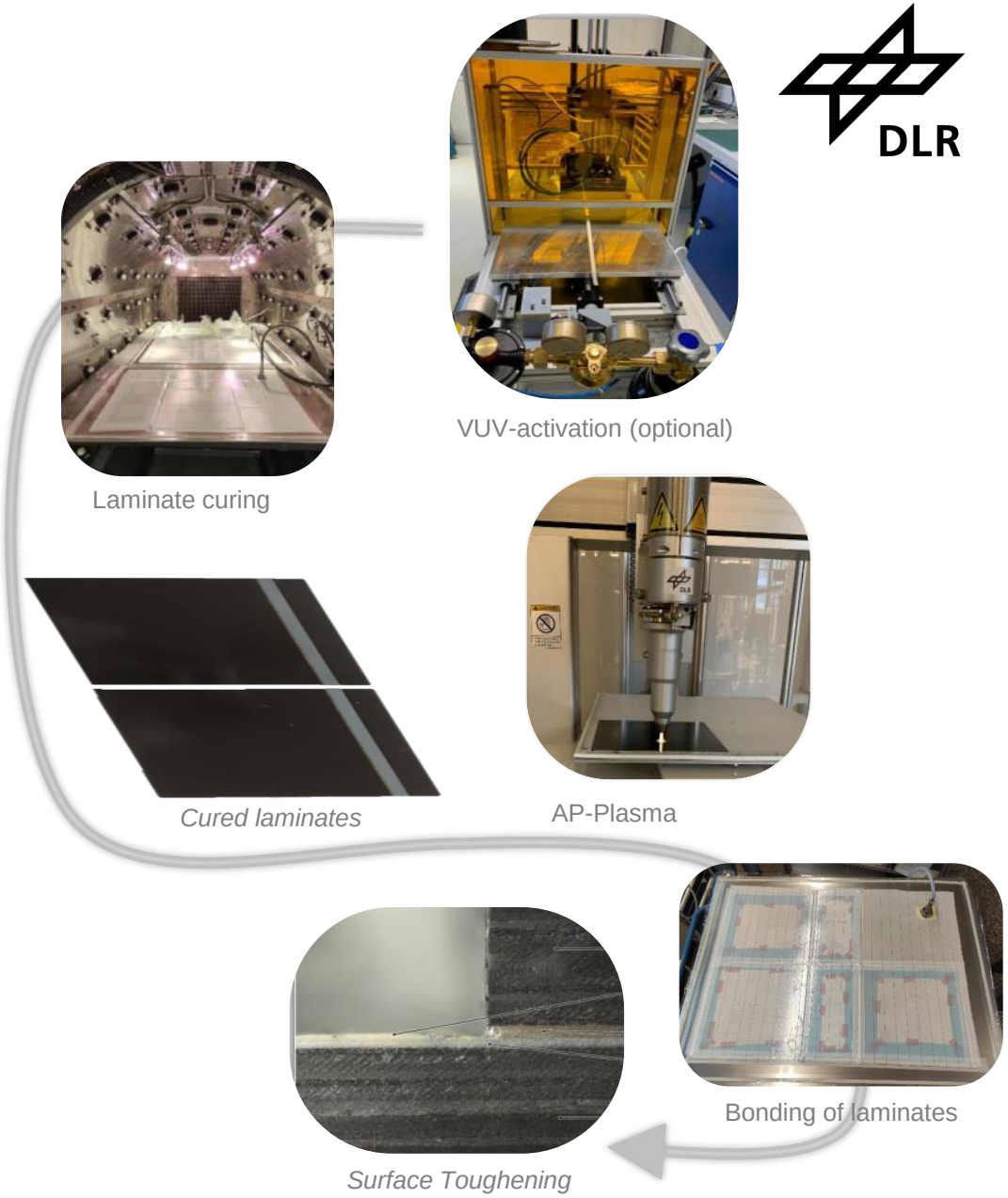
Surface Toughening

Manufacturing

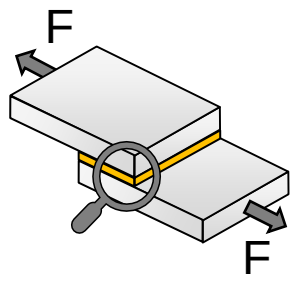
How is Surface Toughening (ST) produced?
The ST material is first cleaned and activated using vacuum UV radiation. It is then co-bonded in the laminate curing process. This creates a high adhesion between the ST material and the laminate. Very little, very thin material is required, so there is little additional effort or cost here. There are then various process options:

1. Secondary bonding with conventional epoxy film adhesive.
2. Secondary bonding with a pasty epoxy film adhesive.
3. CoCuring with conventional epoxy film adhesive.

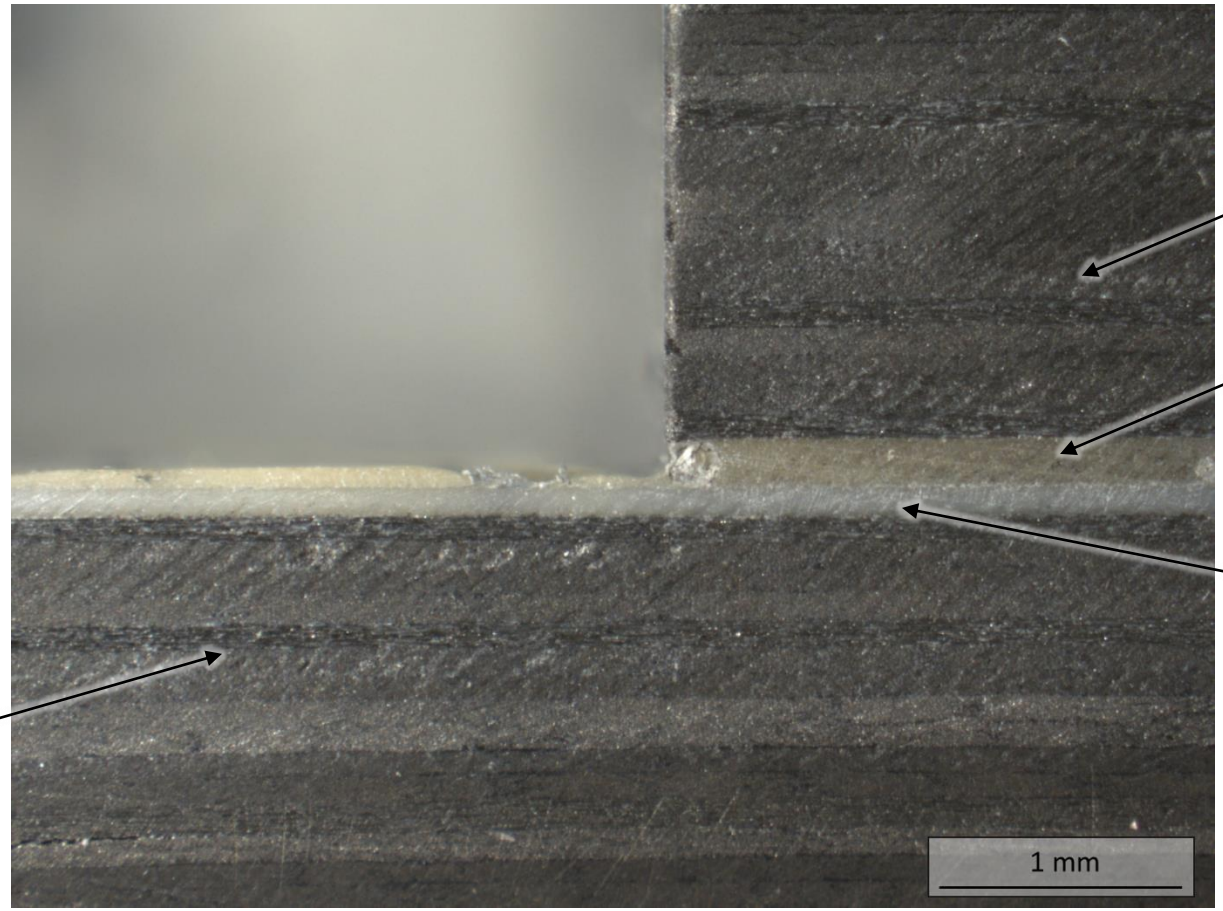
There is no single ST material. Currently, a film of polyvinyl diene fluoride is used (PVDF).



Surface Toughening



Manufacturing



Adherend 2
8552 IM7

Adhesive
EA9695
t_{Adh} ~0,15mm)

ST material
PVDF
t_{ST} ~0,1mm

Adherend 1
8552 IM7

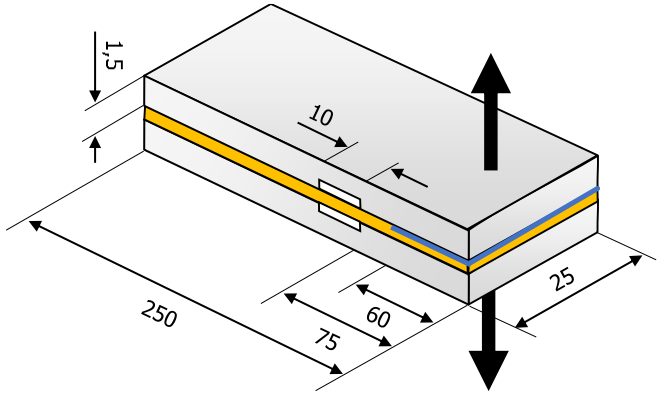
Surface Toughening Static Loading

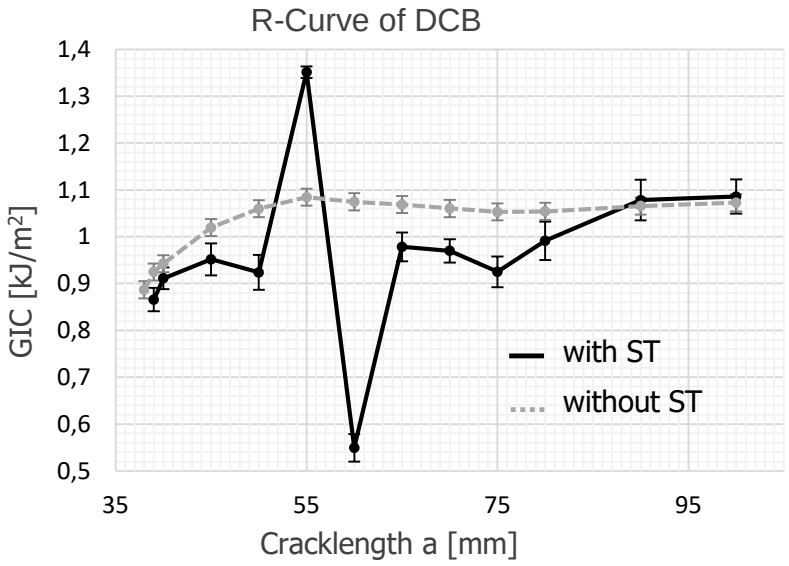
Double Cantilever Beam

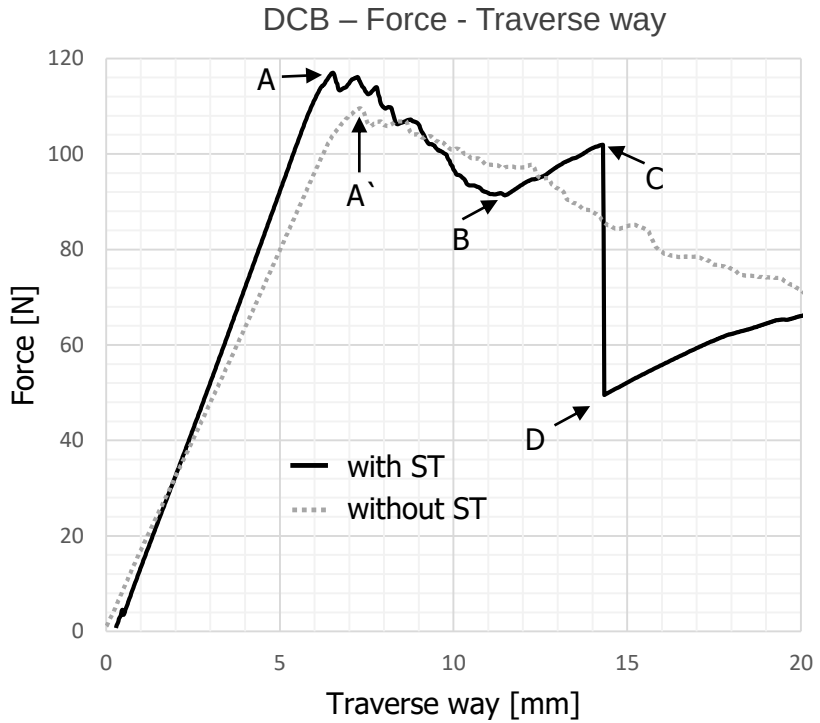
Effect of ST to Mode I?

After an initial crack (A→B), the crack stops at the ST (B) and the test load increases to (C). Then the crack jumps further

- Increase of G_{IC} by 25,1%



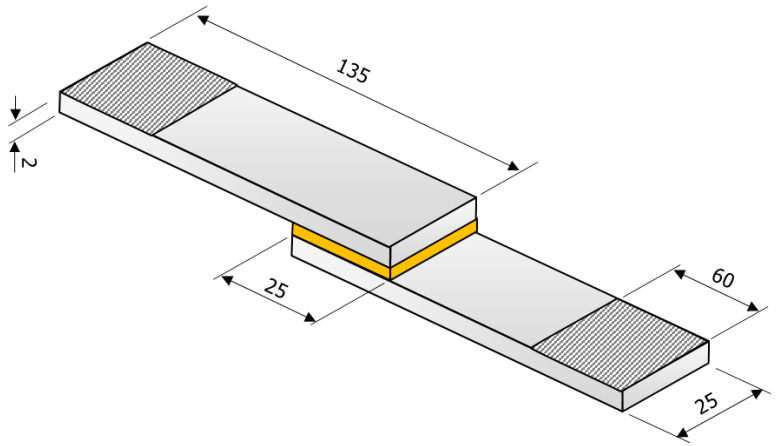




Surface Toughening Static Loading

Single Lap Joints

How strong is the effect to SLJ? Surface Toughening **increases the bond strength** of overlap bonds with film adhesives **by up to 84%.** When using pasty adhesive systems, by up to 122%. The geometry of the joint, as well as the bonding process, is not changed.



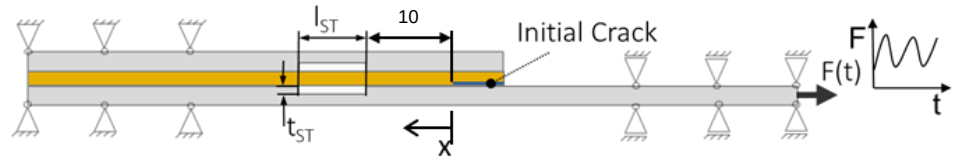
Surface Toughening Design Feature
Fatigue Loading

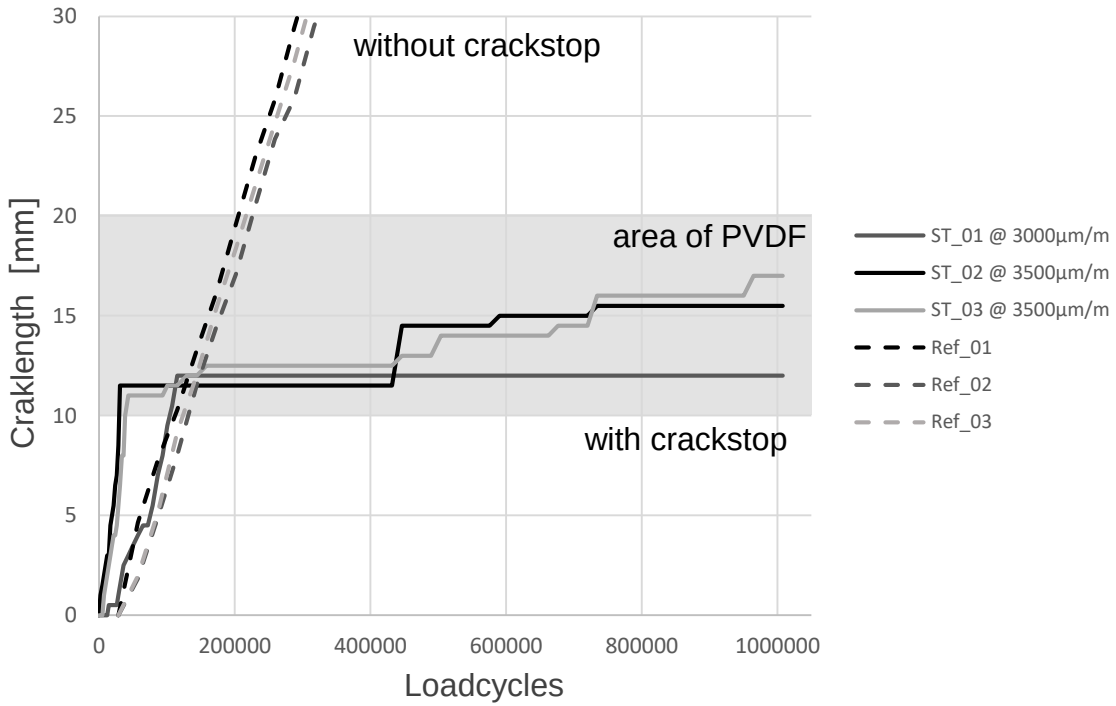
Crack Lap Shear

How strong is the effect to CLS? A crack grows stationary up to the ST crack stop element and is safely stopped.

Strain level [µm m^{-1}]	F_{min} [N]	F_{max} [N]	F_{mean} [N]	Amplitude [N]
3.000	928	9.280	5.104	4.176
3.500	1.086	10.860	5.973	4.887
4.000	1.243	12.430	6.837	5.594

- 3000µm m^{-1} ≙ LL of the bond (SLJ)
- ST works as a Crack Stop Element



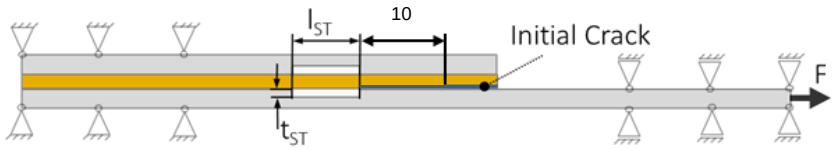


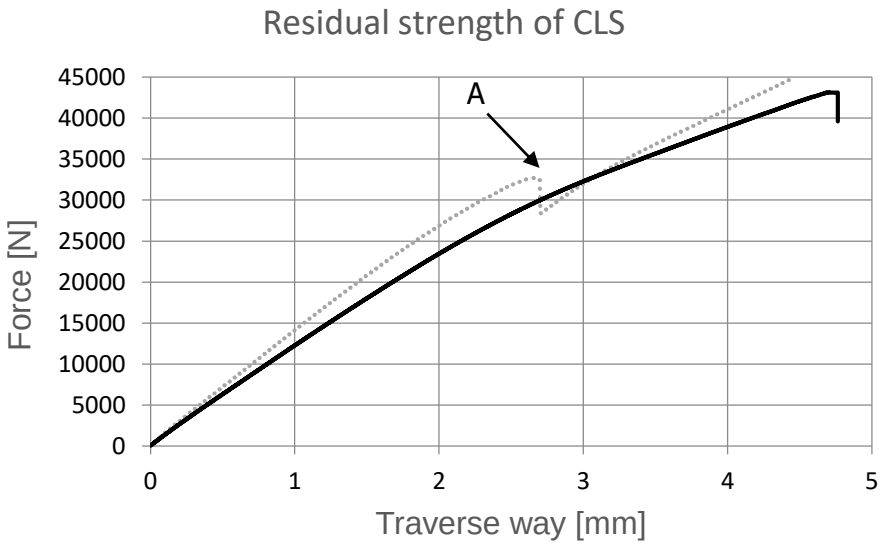
Surface Toughening Static Loading

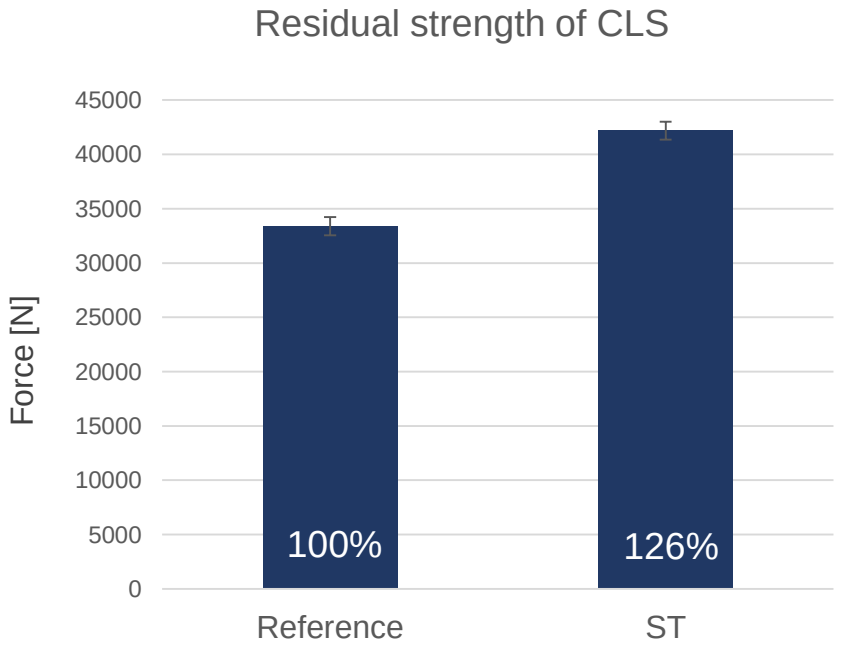
Crack Lap Shear

Is there an effect to the residual strength of CLS?

- The reference specimens fail cohesively (A).
- The ST specimens break in the laminate between bonding and clamping to the testing machine



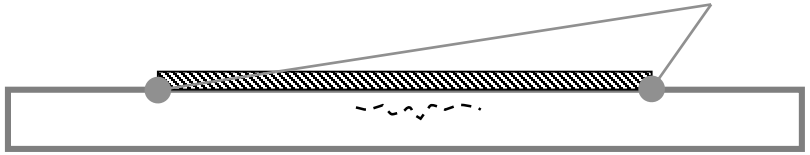




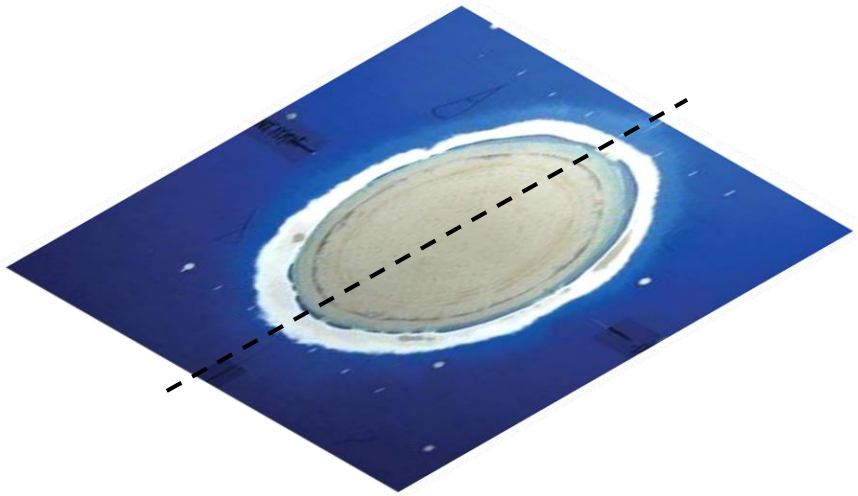
Surface Toughening Use Cases

Simplified Patch Repair

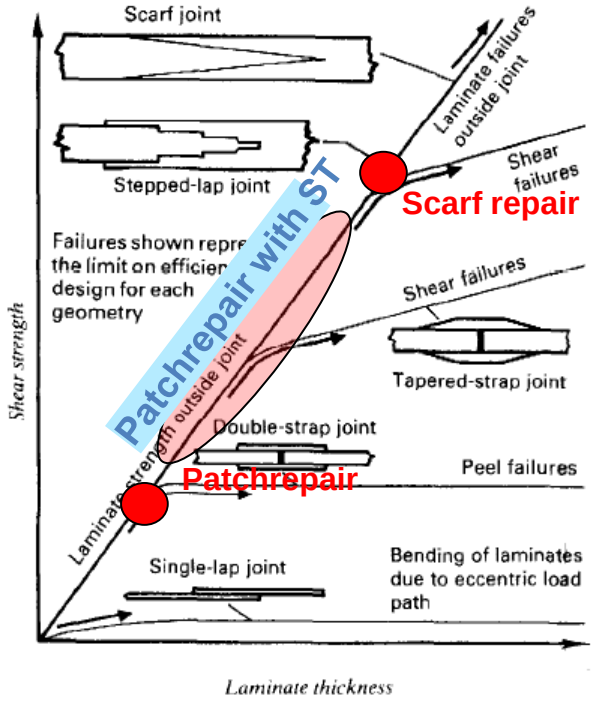
Scarf repair

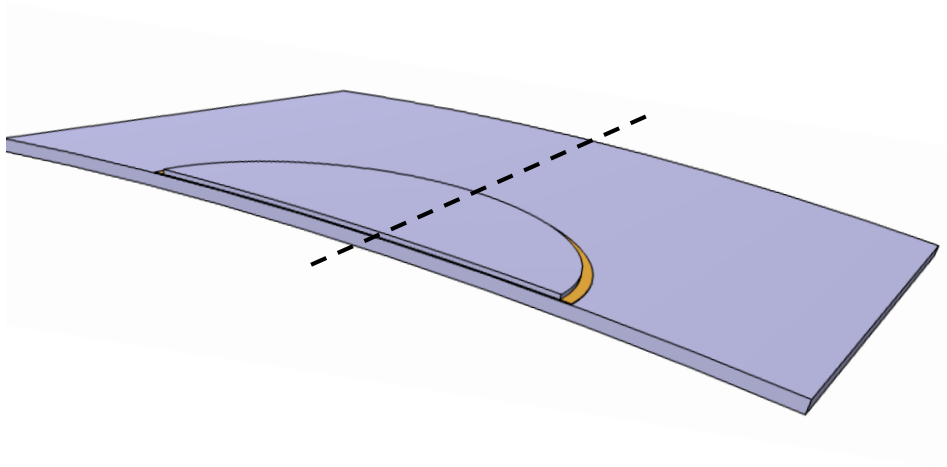


Patch repair



High Performance Repair

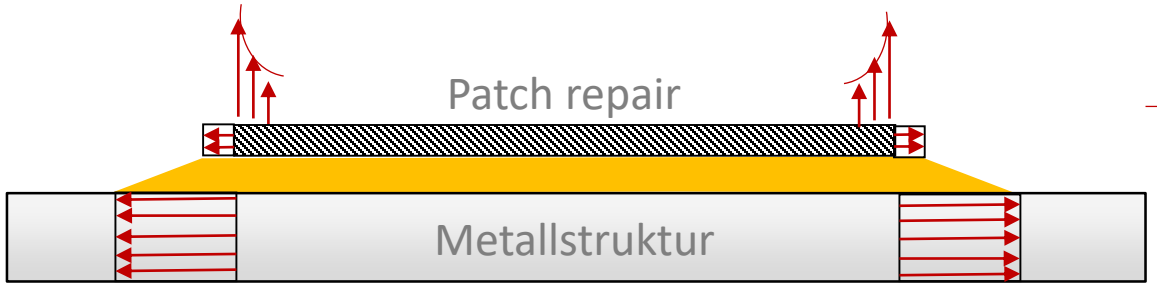


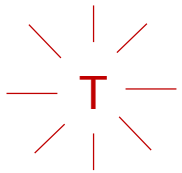


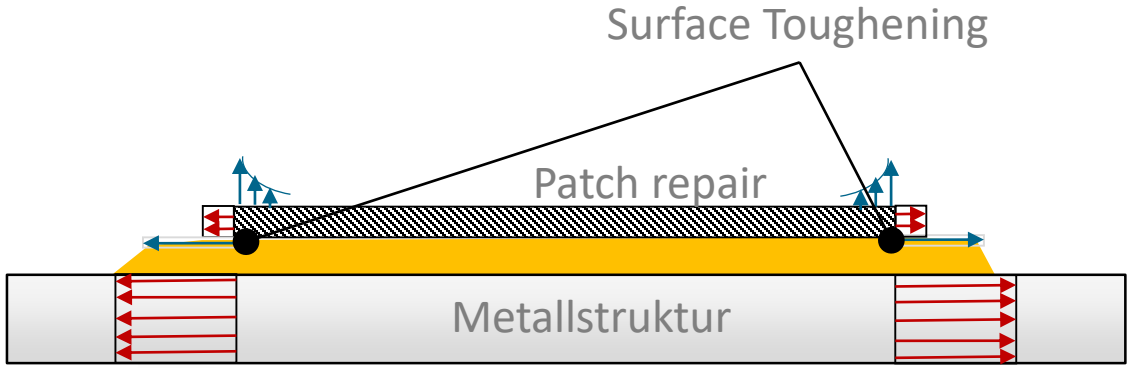
Low Perfomance Repair

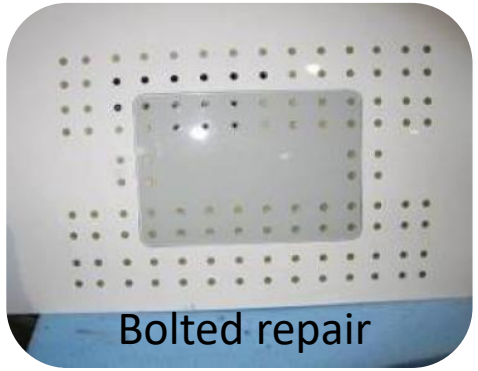
Surface Toughening Use Cases

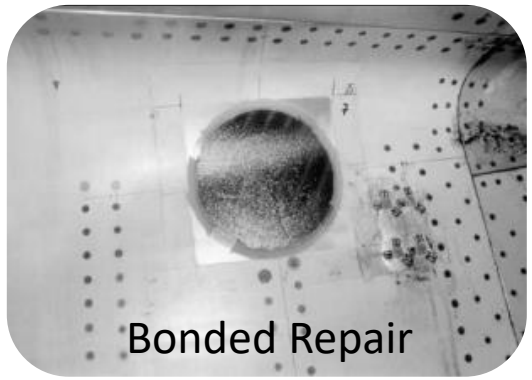
Thermoelastic Tolerant Repair



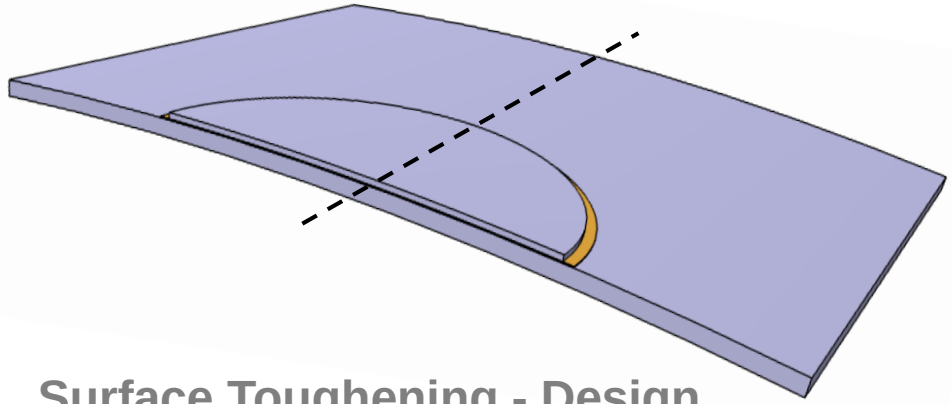








Composite Repair of Metallic Structures



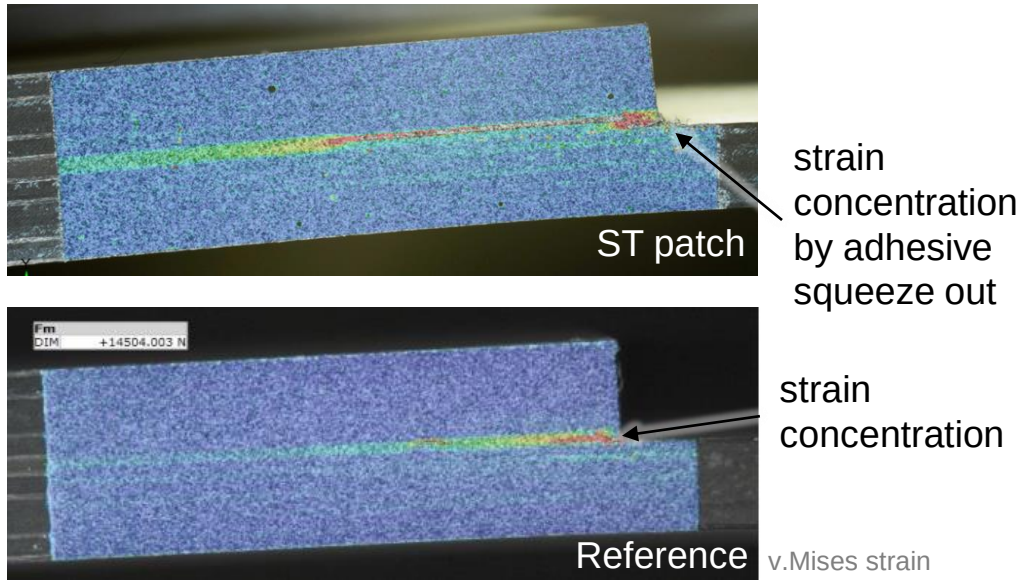
Surface Toughening - Design

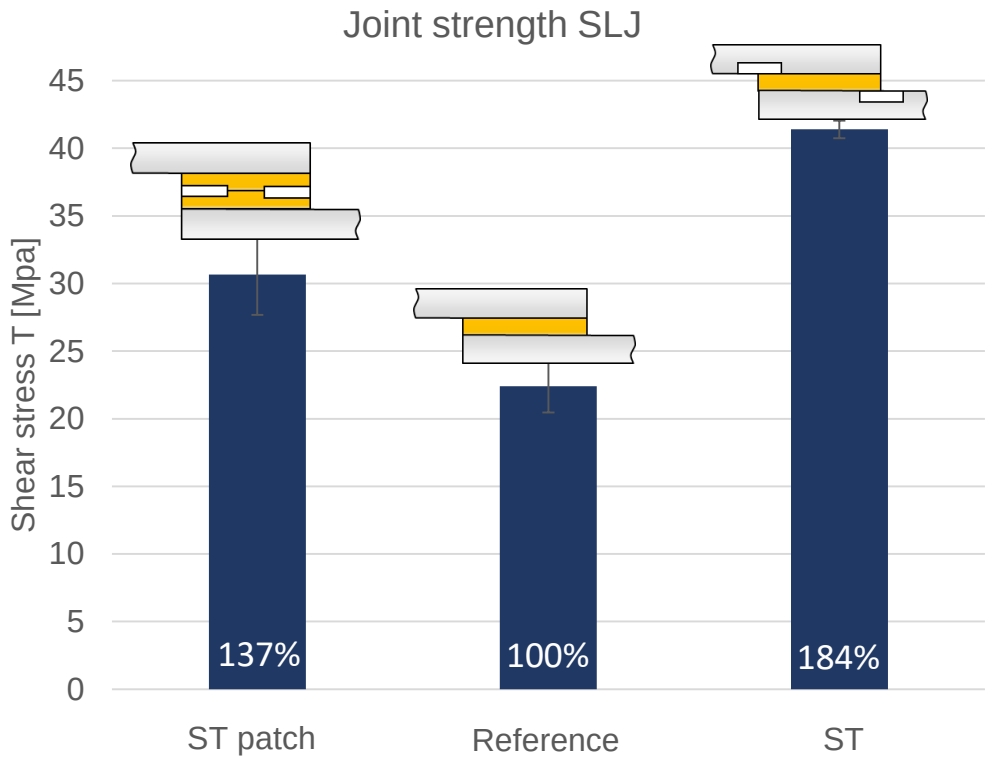
Surface Toughening Design Feature
Static Loading

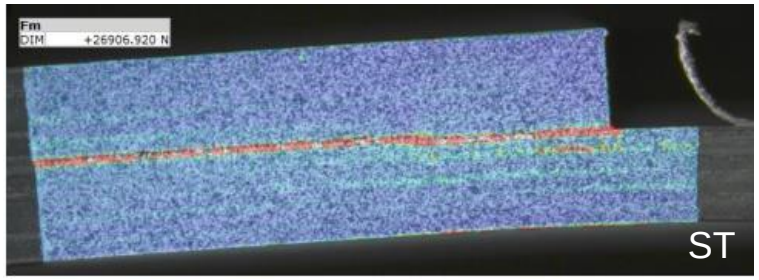
Repair Configuration

How can we use ST in a patch?

- ST material secondary bonded between the adhesive
- Joint strength with ST patch is 37% higher than the Reference







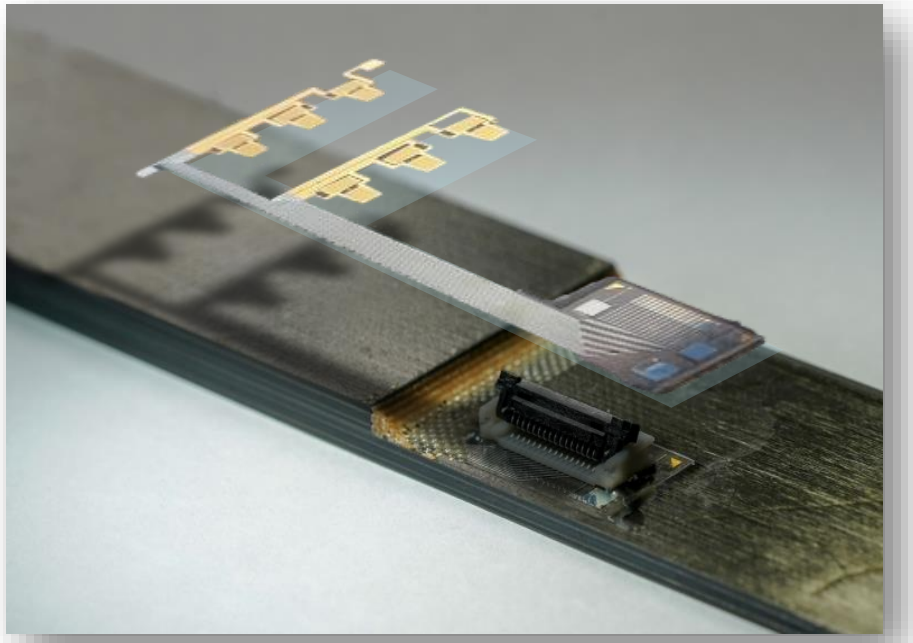
Outlook

Sensed Repair

Ensure the repair during operation?

It makes sense to monitor the adhesive layer in order to be able to react early.

- Two sensors measuring the strain in bondline
- Strain level has to be equal far away from crack
- Deviates the strain level from each other, a crack occurs
- Sensor is implemented to the PVDF ST crack stopper
- Crack is safely stopped for repair



Impressum

Thema:	Robust Bonded Joints with Surface Toughening design feature
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Bildcredits:	DLR