Surface Toughening – An industrial Approach to increase the Robustness of pure adhesive Joints with film adhesives

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Overview

Introduction & Motivation
Surface Toughening
Benefit for Joint Strength
Benefit for Fatigue Strength
Manufacturing and Results
Conclusions and Outlook
Introduction to the Background

Horizon 2020 Project: Manufacturing of a HLFC-Leading Edge Demonstrator for A350 HTP

Where is the POI? Bonding!

Perforated Titanium Skin

CFRP-Structure

Horizontal Tail-Plane Leading Edge (A320)

Conventional airfoil

NLF

LFC

HLFC

Hybrid Laminar Flow Control [1]
Motivation for Surface Toughening

Loads:
- Thermal loads by different CTE
- Aerodynamic loads
- Impacts

Diagram:
- HLFC-Leading Edge
- Titanium Skin
- CFRP-Omega-Stringer
- CFRP
- Adhesive
- Foam-Core
- Bondline
- Max stress of adhesive
- Stress
- Shear
- Peel

DLR.de • Chart 4
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Surface Toughening (ST)

Ductile material is implemented into the surface of adherends

- homogeneous load transfer in joint
- load rearrangement to the middle of joint
- decreasing of stress peaks
- increase in joint-strength
Benefit for Joint Strength (SLS)

Requirements for ST:

$E_{\text{Adherend}} >> E_{\text{Adhesive}} > E_{\text{ST}}$

$\varepsilon_{\text{br, ST}} >> \varepsilon_{\text{br, Adhesive}}$

Stress concentrations lead to crack formation

Reference

Surface Toughening
### Material properties used in the Tests

#### Adherend:
Hexcel HexPly® 8552 IM7 Laminate  
\([0/+45/90/-45/0/+45/90/-45]_s\), 16 ply, 2mm

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Young’s Modulus [MPa]</td>
<td>65020</td>
<td>Curing at 180°C</td>
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<td>Poisson’s ratio:</td>
<td>0.31</td>
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</table>

#### Adhesive [2],[3]:
Hysol® EA 9695 0.05 NW AERO

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<td>Poisson’s ratio:</td>
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<td>Tensile strength [MPa]</td>
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<td>Global elongation at yield [%]</td>
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<td>Tensile Yield strength [MPa]</td>
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<td>Shear yield strength [MPa]</td>
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<td>Shear failure strength [MPa]</td>
<td>51.94</td>
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#### Ductile material [2],[4]:
Kynar® 740, PVDF

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<td>Young’s Modulus [MPa]</td>
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<td>Tensile strength [MPa]</td>
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<td>Global elongation at yield [%]</td>
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<td>Global elongation at break [%]</td>
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<tr>
<td>Tensile Yield strength [MPa]</td>
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#### Requirements for ST:
- \( E_{\text{Adherend}} > E_{\text{Adhesive}} > E_{\text{ST}} \)
- \( \varepsilon_{br, \text{ST}} > \varepsilon_{br, \text{Adhesive}} \)
Benefit for Joint Strength

Surface Toughening

- Increase in joint strength up to 84% (SLS ASTM D 5868)
- Increase in strength depends on geometry of ST
- Increase in strength higher than without ST
- Manufacturing and testing details →
- No crack growth with ST

Results of SLS-tests
Difference in Failure

Video of static failure of SLS-specimen

without Surface Toughening

with Surface Toughening
Benefit for Fatigue Strength (CLS)

Reference

500k Cycles
100k Cycles

Surface Toughening

Ductile material
Crack arrest

500k Cycles = 600k Cycles

Adherend
Adhesive

500k Cycles
100k Cycles
Benefit for Fatigue Strength

Surface Toughening

- Tested on Cracked lap shear specimens
- Crack arrest up to 3000µm/mm tested (9,28kN)
- 8Hz, 25.4mm width
- $t_{ST}=0.1$mm, $l_{ST}=10$mm
- Tests are still ongoing
Surface Toughening in a Small Scale Demonstrator

- Flat small scale demonstrator
- FEA analysis of bondline shear stress
- Cooldown from 120°C to 23°C

Surface Toughening

Adhesive

Ti - skin

CFRP

Foam

Stress concentrations

with ST

without ST

\( \tau \) in MPa

\( \tau_{UL} \)

\( \tau_{LL} \)
Manufacturing of a Small Scale Demonstrator

- **Preforming of G0926 fibers**
  - 100°C, 1bar
  - Flat structure

- **Application of PVDF**
  - Usage of binder fleece for fixation
  - Melting by soldering iron

- **Infusion with RTM6**
  - 180°C cure of resin
  - Smooth surface
  - No air inclusion
Manufacturing of a Small Scale Demonstrator

Surface Toughening Feasibility Demonstrator
Testing under thermal environments

PVDF strip as Surface Toughening material

Design demonstrator
to show the Surface Toughening in Structure
Transfer to an industrial Part

Stringer are supported with Surface Toughening

Edges are supported with Surface Toughening

-2000mm

-800mm
Results of industrial Application

- Application takes longer than expected for a curved geometry >>1h
- Misalignment due to the too flexible ST-strips (fixed)
- After curing, the PVDF shrinks and does not have a smooth surface
- No misalignment by the resin of infusion process
- Good adhesion to the CFRP
- First trial successful
- Easy application for worker by an illustrated manual

→ Successful demonstration
Conclusion and Outlook

Surface Toughening...
- ...was presented with **good benefits for the joint strength** (SLS) and the **fatigue strength** (CLS) of bonded joints
- ...was proved in a **prepreg** and **infusion system** successfully
- ... is **easy to apply** and does not change the manufacturing process
- ... is a **cheap technique** to reduce stress concentrations in bondline
- ...was **successful demonstrated** in an industrial application

Outlook
- Identification of low temperature influence for the ductile thermoplastic material
- Identify more materials: PEI, PES, PA6, PEEK...
- Integration of a sensor to Surface Toughening for bondline monitoring
Thank You!

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Literature


