Composite Structures: Essential of Repair Methods

Marco Barile
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Why repairs are necessary …

41 ft high tail Vs. 38 ft tall hangar door opening

Boeing C-17 Tail Damage

Tug Racing

737-800 is 4 feet taller than older 737-400 model

Formula 1 Racing

Speed-Boat Racing

One approach does not fit all types of damage.

Repair technicians have to know their materials and processes in order to accomplish good quality repairs.
Goal of Composite Repair Design

- the repair should restore the structure to original design strength and stiffness;
- the repair must restore the functional requirements (i.e. aerodynamics);
- the repair must have negligible weight penalty;
- time and equipment (ER);

Trade-offs:
- To match strength, repair is stiffer & heavier
- To match stiffness, repair is weaker & heavier
- Cannot match all original properties

Repairs to aircraft structures are controlled and should be carried out according to the Aircraft SRM.
State-of-the-Art Bolted vs. CFRP Bonded Repair

Bolted Repair (Thick aircraft structures t>3mm)
Bypass of original load path by riveting of one or two Doublers.

Advantages:
- Good Recovery of strength
- Fast Application
- Easy Certification because of Fail-Safe-Concept

Disadvantages:
- Minimum skin thickness necessary
- Steps in aerodynamic shape
- Complex at edges and pressure vessels
- High weight
- Two sided Access recommended

Scarf Repair (i.e. repair of flaps - A320)
NDT, removal of damage, manual grinding of scarf, cocuring of wet prepreg layup or cobonding of hard patch (separate tooling necessary), Prepreg technology favoured. Ramp of Scarf 1:20-1:40

Advantages:
- Original Structural behaviour nearly restored
- Flush repair
- Good mechanical performance

Disadvantages:
- Extremely complex and time consuming
- High skilled technicians for scarfing phase
- A lot of healthy material has to be removed by the scarf -> Weakening of structure?
**State-of-the-Art Bolted vs. CFRP Bonded Repair**

**Stepped Removal and Repair**
Loads are distributed through the repair via a lap joint into the underlying layers.

Shear stress distribution

Note peak stress concentrations at edges of each step within the repair.

**Tapered Scarf Removal and Repair**

Loads are transferred directly through the edges of the repair plies, in plane, on axis, in shear, to the underlying structure.

The resulting repair is flush with the surface.

Uniform shear stress distribution through a tapered scarf joint.

**Bolted Doubler Repairs**

Seal all around the patch.

Fasten as prescribed.

**Composite Structures: Essentials of Repair Methods**

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Typical Wet Layup Repair Process

Prepreg Repairs follow a similar process and typically require an elevated temperature cure using portable Hot-Bond equipment.

Typical Heat Blanket Layup Scheme

Briskheat Corporation – ACR 3 Dual Zone Hot Bonder portable kit
Case Study: FEA Investigations on Scarf Repairs

Numerical investigation aimed to characterize the variation of adhesive stresses in a scarf joint between orthotropic composite laminates was carried out.

1 - LINEAR STATIC ANALYSIS OF A SCARF-REPAIRED COMPOSITE PANEL

Objective: Study of the adhesive normal (peel) and shear stress distributions along the bondline of the scarf joint for 3 different laminates (8, 16 and 32 plies).

A scarf repair subjected to biaxial stresses

An equivalent scarf joint

FE model of a 8 plies laminate: [45/0/-45/90]s
**2 - PARAMETRIC STUDY ON SCARF-REPAIRED COMPOSITE PANELS**

**Objective:** Investigation on stress distribution along the bondline of a scarf joint varying layup sequence, laminate thickness, adhesive thickness and scarf angle.

Gunnion and Herszberg (2006) investigated the stress distribution along the bondline varying the scarf angle ($\alpha$) between 3 and 15 degrees for a cross ply layup [0/90]$_2$s. Lower scarf angles lead higher joint strengths due to greater adhesive joint area of action.

\[
\frac{\sigma_{yy}}{\tau_{yy}} = \tan[\alpha]
\]

Separation of Applied Axial Force into Shear and Normal Force Components
Case Study: FEA Investigations on Scarf Repairs

3 - OVER LAMINATE

Adding over laminate plies to the scarf joint a relevant decrease of peak peel and shear stresses is obtained.

4 - CIRCULAR PATCH - LINEAR ANALYSIS

A FE model was developed to characterize the variation of the adhesive stresses in a 3D scarf repair.
Case Study: FEA Investigations on Scarf Repairs

5 - ELASTIC PLASTIC ANALYSIS

2D SCARF JOINT

Elastic-plastic FEA was performed to quantify the resulting stress redistribution as the adhesive reached plastic yielding.

CIRCULAR PATCH - NONLINEAR ANALYSIS

Variation of adhesive stresses in a 3D scarf repaired composite panel with an elastic-plastic adhesive, a FE model was developed following the same procedure and same materials used for the linear analysis of the circular patch.
### 6 - RESULTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average peel</th>
<th>Peak peel</th>
<th>Average shear</th>
<th>Peak shear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacking sequence</td>
<td>No</td>
<td>Increases when $0^\circ$ plies are on the outer surfaces</td>
<td>No</td>
<td>Decreases with more $0^\circ$ plies. Increases with increasing distance between $0^\circ$ plies across the scarf.</td>
</tr>
<tr>
<td>Laminate thickness</td>
<td>No</td>
<td>Decreases with increasing laminate thickness</td>
<td>No</td>
<td>Decreases with increasing laminate thickness</td>
</tr>
<tr>
<td>Mismatched adherends</td>
<td>No</td>
<td>Slight increase or decrease depending on lay-up</td>
<td>No</td>
<td>Slight increase or decrease depending on lay-up</td>
</tr>
<tr>
<td>Over laminate</td>
<td>No</td>
<td>Slight decrease with increasing over laminate number of plies</td>
<td>Decreases with increasing over laminate number of plies</td>
<td>Slight decrease with increasing over laminate number of plies</td>
</tr>
<tr>
<td>Scarf angle</td>
<td>Increases with increasing scarf angle</td>
<td>Strongly decreases with increasing scarf angle</td>
<td>Decreases with increasing scarf</td>
<td>Slightly decreases with increasing scarf angle</td>
</tr>
<tr>
<td>Allowing load by-pass of patch</td>
<td>Decreases if there is an alternate load path</td>
<td>Decreases if there is an alternate load path</td>
<td>Decreases if there is an alternate load path</td>
<td>Decreases if there is an alternate load path</td>
</tr>
<tr>
<td>Angle to loading direction for a 3D circular patch</td>
<td>Decreases with increasing angle from loading direction</td>
<td>Decreases with increasing angle from loading direction</td>
<td>Decreases with increasing angle from loading direction</td>
<td>Decreases with increasing angle from loading direction</td>
</tr>
</tbody>
</table>
Automated, on-aircraft bonded patch prep.
DMG MORI (Germany) and SAUER (Germany) have co-developed this ULTRASONIC mobileBLOCK 5-axis milling unit, which attaches to aircraft surfaces via 12 vacuum feet and provides multiple functions, including laser surface scanning, ultrasonic milling and plasma surface treatment.

Saving time/labor in complex repairs. Lufthansa Technik’s (Hamburg, Germany) mobile robotic repair system reportedly cuts repair time by 60% while enabling bonded patch repairs previously not possible or simply too time-consuming and expensive to attempt with conventional manual methods.
Thank you for your attention

Let’s go to repair!