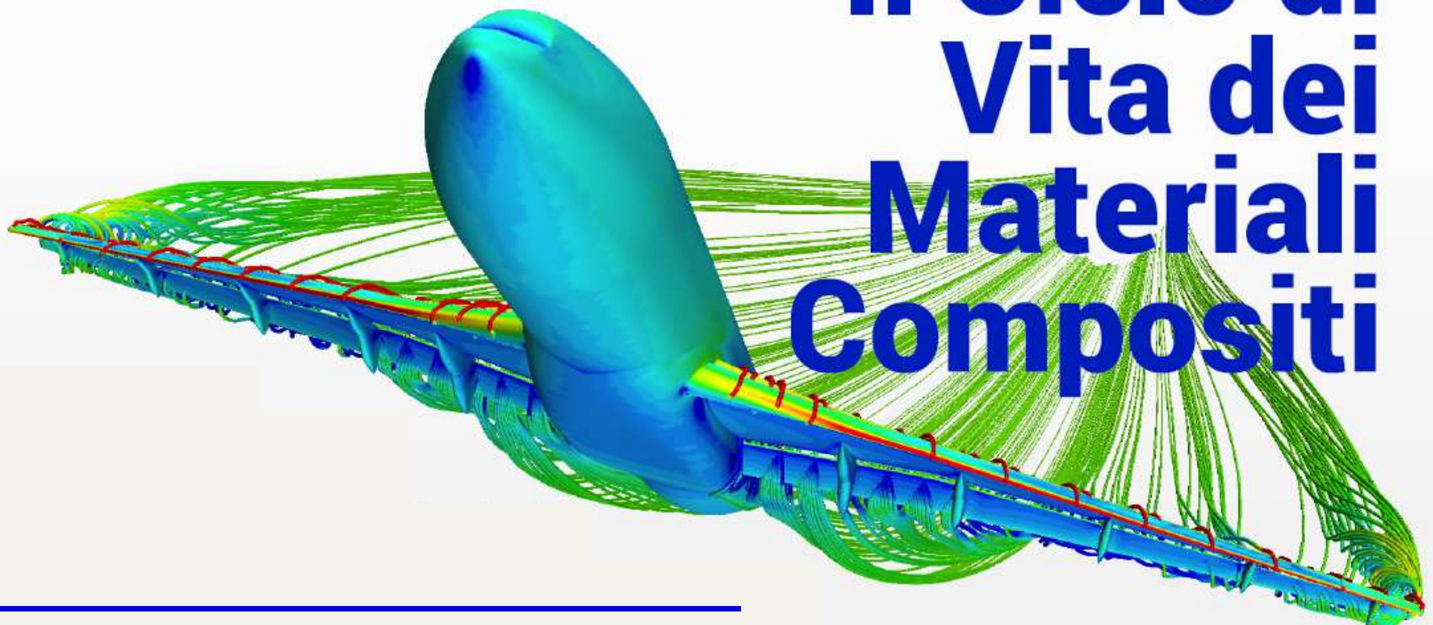
DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

SEMINARI INTERDISCIPLINARI DI CULTURA AERONAUTICA - III CICLO

Il Ciclo di Vita dei Materiali Compositi



1^ incontro

16 aprile 2016

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P.le Tecchio

Composite Structures: Essential of Repair Methods

Marco Barile

Contents

Why repairs are necessary …

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AEROSPACE SECTION

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

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

Boeing C-17 Tail Damage

Tug Racing

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

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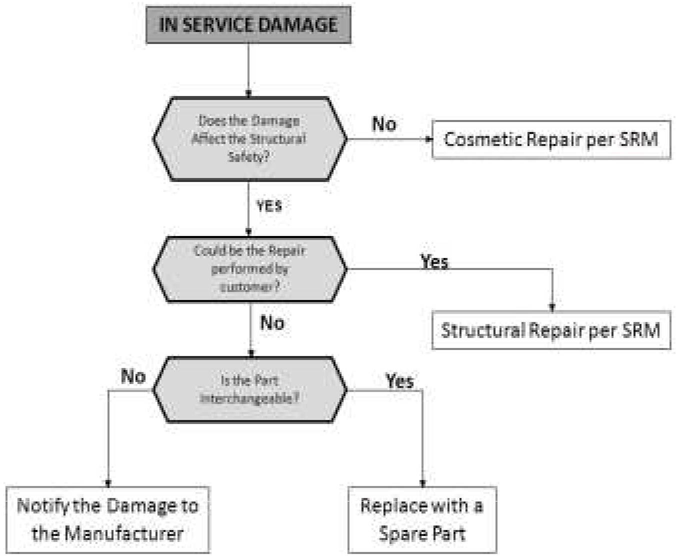
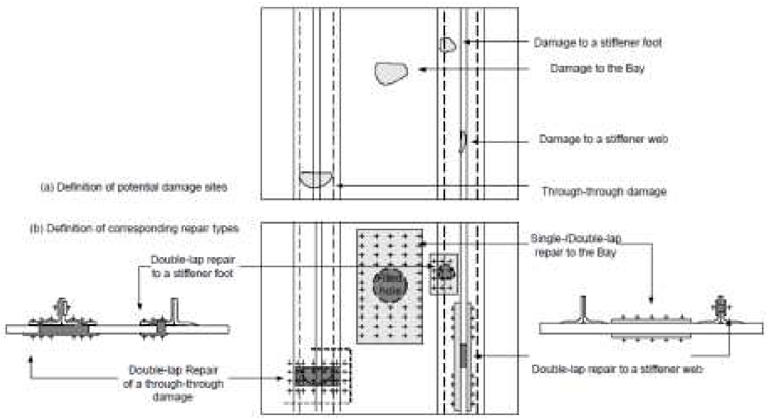
AEROSPACE SECTION

- ✓ 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.

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AEROSPACE SECTION

State-of-the-Art Bolted vs. CFRP Bonded Repair

Bolted Repair (Thick aircraft structures t>3mm)

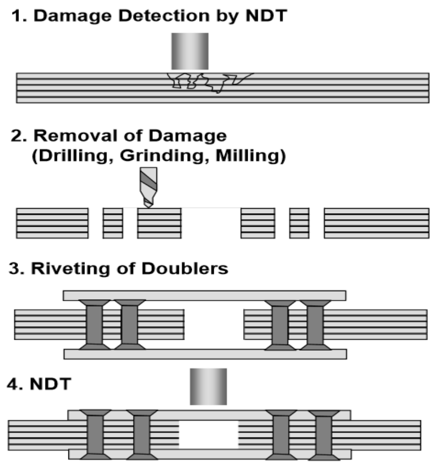
Bypass of original load path by riveting of one or two Doublers.

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)

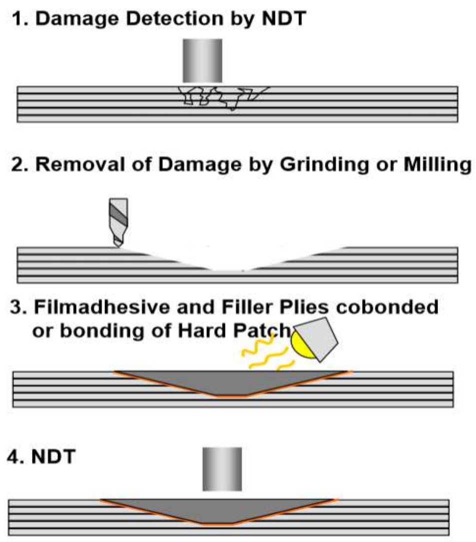
NDT, removal of damage, manual grinding of scarf, cocuring of wet prepreg layup or cobonding of hard patch (separate tooling necessary), Prepreg technology favoured. Ramp of Scarf 1:20-1:40

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

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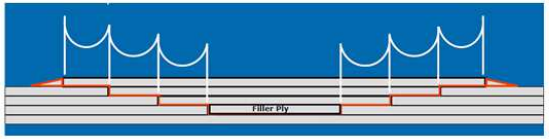
AEROSPACE SECTION

Stepped Removal and Repair

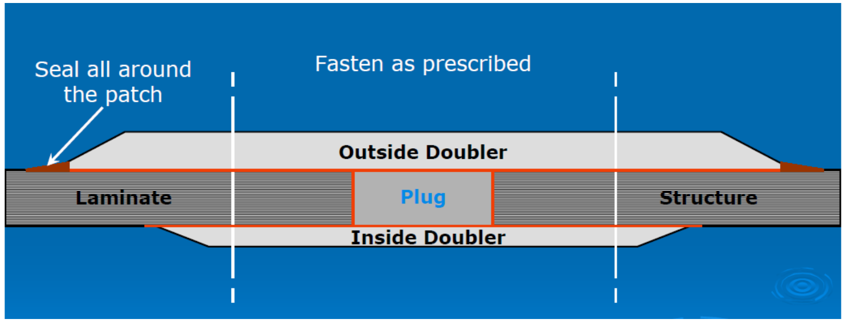
Loads are distributed through the repair via a lap joint into the underlying layers.

Shear stress distribution



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

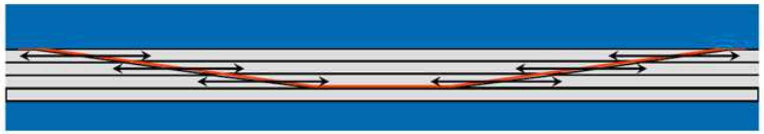
Bolted Doubler Repairs



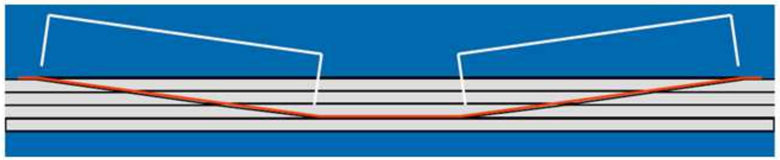
Tapered Scarf Removal and Repair

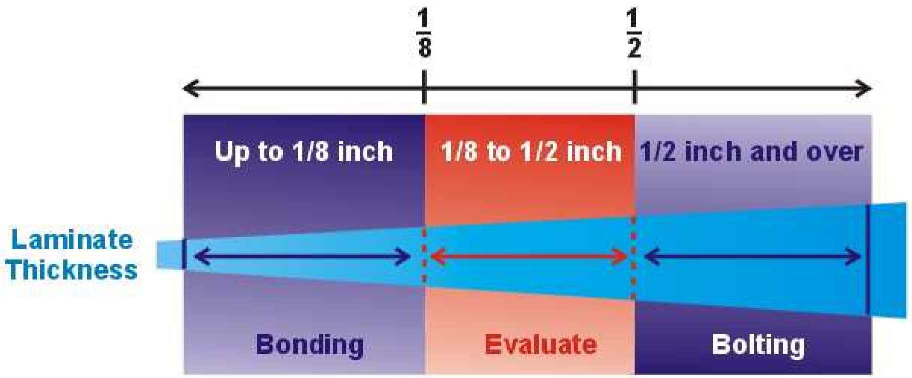
Loads are transferred directly through the edges of the repair plies, in plane, on axis, in shear, to the underlying structure

The resulting repair is flush with the surface



Uniform shear stress distribution through a tapered scarf joint

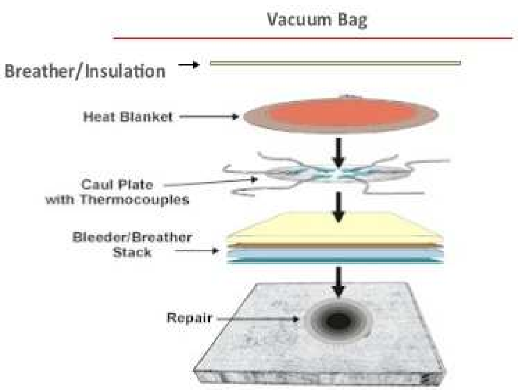




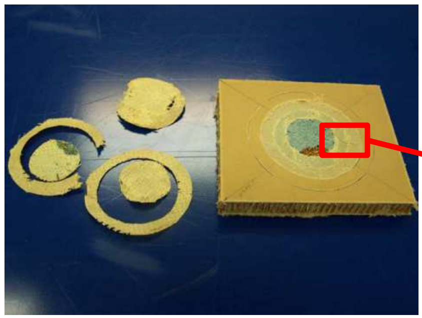
Typical Wet Layup Repair Process

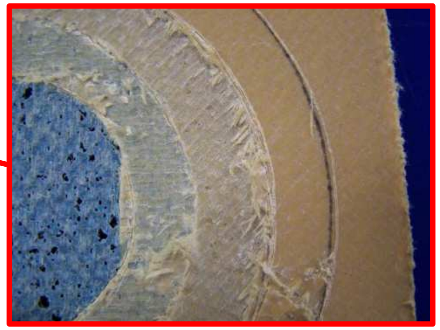
Prepreg Repairs follow a similar process and typically require an elevated temperature cure using portable Hot-Bond equipment

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.

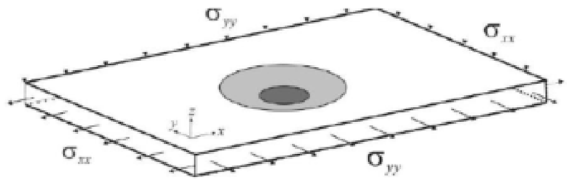
1 - LINEAR STATIC ANALYSIS OF A SCARF-REPAIRED COMPOSITE PANEL

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).

Geometry		
Ply thickness	0.13	mm
Adhesive t	0.13	mm
Model length	65	mm
Scarf angle	5	degree
Slice Model thickness tp/2	0.065	mm

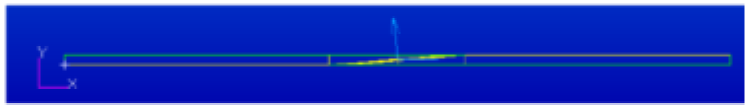
Model	Scarf length	Scarf length/2	
8 ply	11.89	5.94	mm
16 ply	23.77	11.89	mm
32 ply	47.55	23.77	mm

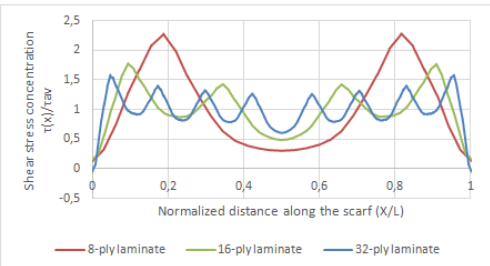
Data								
Material	Properties							
AS4-3501	E11	E22=E33	v12	v23	v13	v31	G12=G13	G23
	128	13	0.3	0.3	0.3	0.030	7.2	5
	GPa	GPa					GPa	GPa
Adhesive	E	G	v					
	1.014	0.39	0.3					
	GPa	GPa						



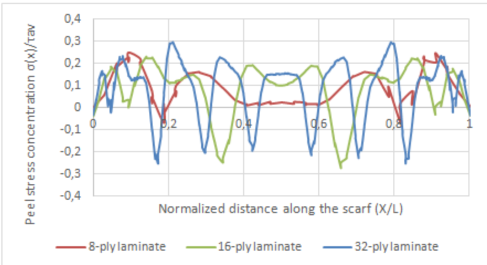
A scarf repair subjected to biaxial stresses

An equivalent scarf joint





Shear Stress concentrations in a scarf joint (θ = 5°) between quasi-isotropic composite laminates. Stacking sequences are respectively [45/0/-45/90]s, [45/0/-45/90]2s, [45/0/-45/90]4s.



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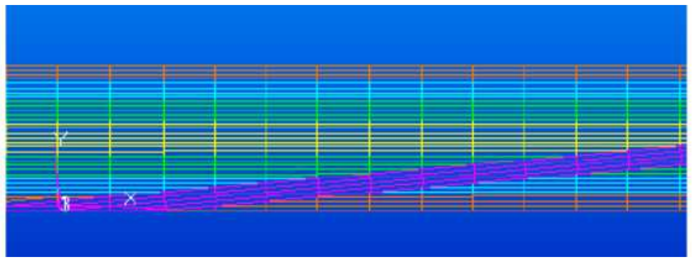

FE model of a 8 plies laminate: [45/0/-45/90]s

Case Study: FEA Investigations on Scarf Repairs

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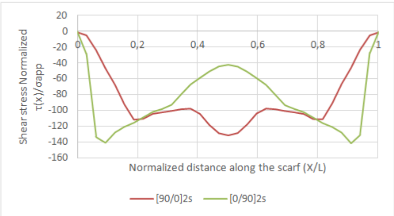
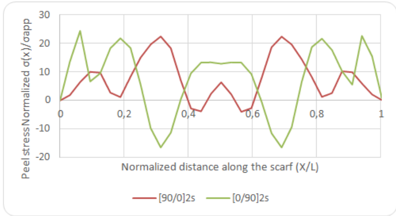
AEROSPACE SECTION

2 - PARAMETRIC STUDY ON SCARF-REPAIRED COMPOSITE PANELS

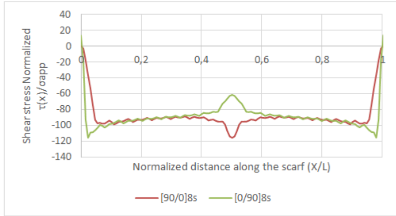
Objective: Investigation on stress distribution along the bondline of a scarf joint varying layup sequence, laminate thickness, adhesive thickness and scarf angle.



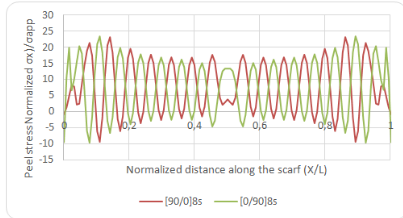
Normalized shear stresses along the adhesive bondline for $[0/90]_{2s}$ and $[90/0]_{2s}$ laminates



Normalized peel stresses along the adhesive bondline for $[0/90]_{2s}$ and $[90/0]_{2s}$ laminates

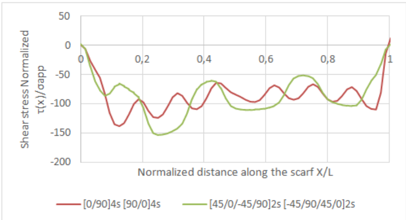


Normalized shear stresses along the adhesive bondline for $[0/90]_{8s}$ and $[90/0]_{8s}$ laminates

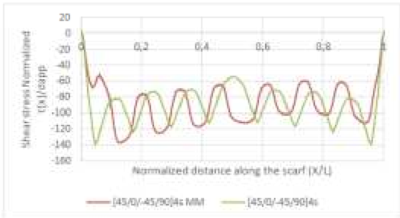


Normalized peel stresses along the adhesive bondline for $[0/90]_{8s}$ and $[90/0]_{8s}$ laminates.

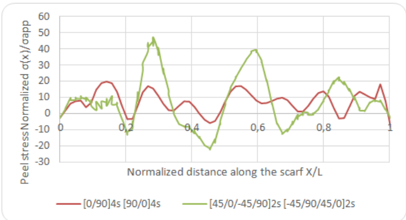
Stacking sequence



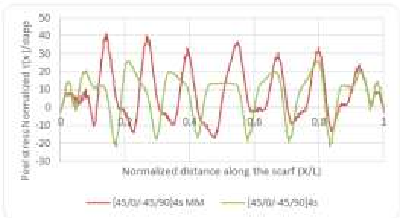
Normalized shear stresses along the adhesive bondline for mismatched (MM) adhered pairs; $[0/90]_{4s}$ with $[90/0]_{4s}$ and $[45/0/-45/90]_{2s}$ with $[-45/90/45/0]_{2s}$



Normalized shear stresses along the adhesive bondline for mismatched (MM) adhered pairs $[45/0/-45/90]_{4s}$ with $[-45/90/45/0]_{4s}$ and matched $[45/0/-45/90]_{4s}$.



Normalized peel stresses along the adhesive bondline for mismatched (MM) adhered pairs; $[0/90]_{4s}$ with $[90/0]_{4s}$ and $[45/0/-45/90]_{2s}$ with $[-45/90/45/0]_{2s}$.

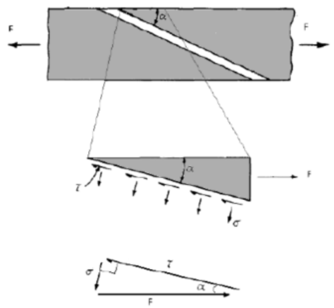


Normalized peel stresses along the adhesive bondline for mismatched (MM) adhered pairs $[45/0/-45/90]_{4s}$ with $[-45/90/45/0]_{4s}$ and matched $[45/0/-45/90]_{4s}$.

Mismatched Adherends Layup

Gunnion and Herszberg (2006) investigated the stress distribution along the bondline varying the scarf angle (α) between 3 and 15 degrees for a cross ply layup $[0/90]_{2s}$.
Lower scarf angles lead higher joint strengths due to greater adhesive joint area of action.

$$\frac{\sigma_{yav}}{\tau_{yxav}} = \tan[\alpha]$$



Separation of Applied Axial Force into Shear and Normal Force Components

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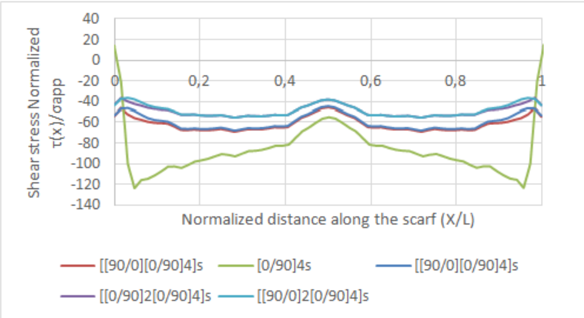
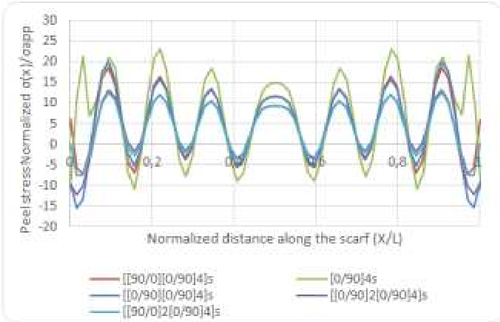
AEROSPACE SECTION

3 - OVER LAMINATE

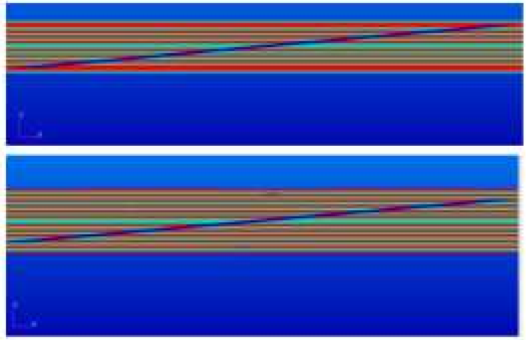
Adding over laminate plies to the scarf joint a relevant decrease of peak peel and shear stresses is obtained.



Normalized shear stress along the adhesive bondline for [0/90]4s laminates with 4 and 8 ply over laminate of [0/90] and [90/0].



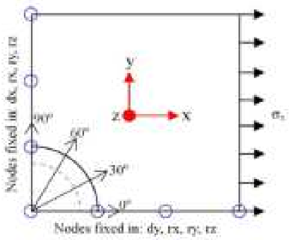
Normalized peel stress along the adhesive bondline for [0/90]4s laminates with 4 and 8 ply over laminate of [0/90] and [90/0].



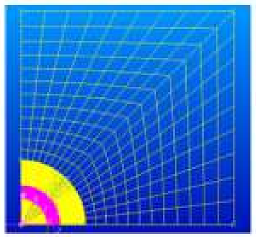
Models with 4 and 8 plies over laminate

4 - CIRCULAR PATCH - LINEAR ANALYSIS

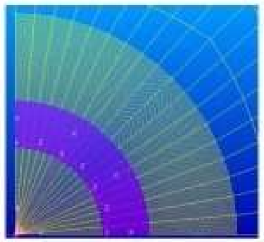
A FE model was developed to characterize the variation of the adhesive stresses in a 3D scarf repair.



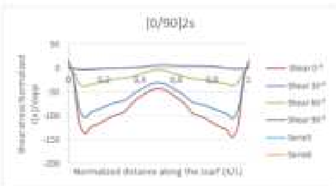
Boundary conditions



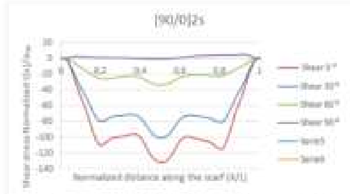
One quarter panel mesh



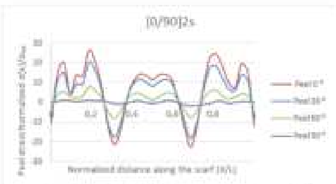
Refined region



Normalized shear stresses along the bondline for [0/90]2s laminate at 30° intervals around a 3D circular scarf joint



Normalized shear stresses along the bondline for [90/0]2s laminate at 30° intervals around a 3D circular scarf joint



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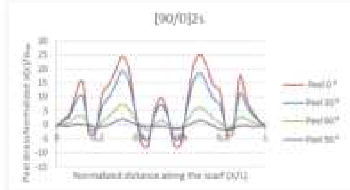

Normalized peel stresses along the bondline for [90/0]2s laminate at 30° intervals around a 3D circular scarf joint

3D circular patch geometric data

Geometry	quarter model panel	
half-width	215	mm
lower radii	25	mm
upper radii	39	mm
Loaded Area	223.6	mm^2

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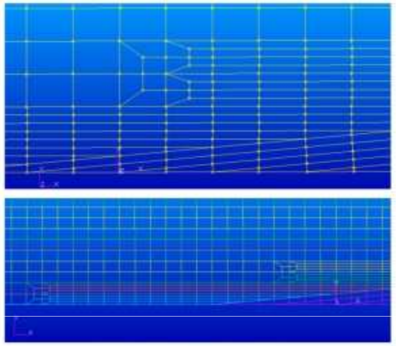
AEROSPACE SECTION

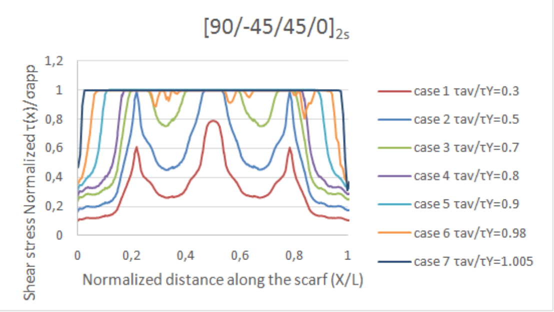
5 - ELASTIC PLASTIC ANALYSIS

➢ 2D SCARF JOINT

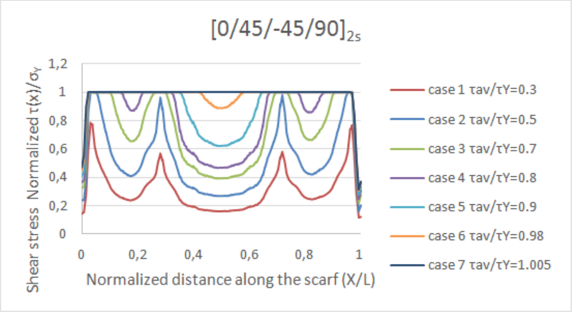
Elastic-plastic FEA was performed to quantify the resulting stress redistribution as the adhesive reached plastic yielding.



Finite element mesh near the scarf region.



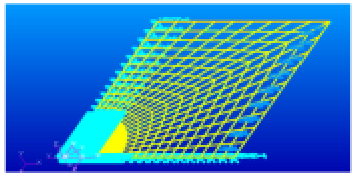
Shear stress distribution for [90/-45/45/0]s.



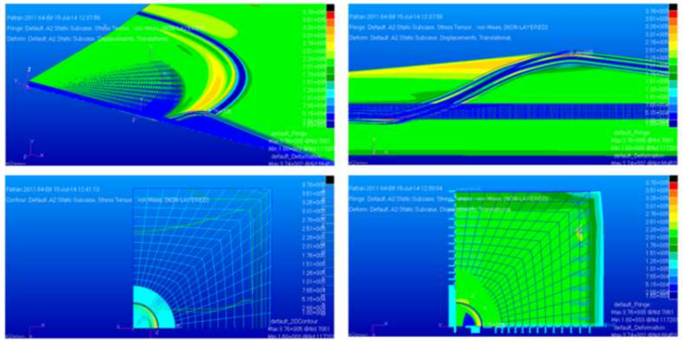
Shear stress distribution for [0/45/-45/90]s.

➢ CIRCULAR PATCH - NONLINEAR ANALYSIS

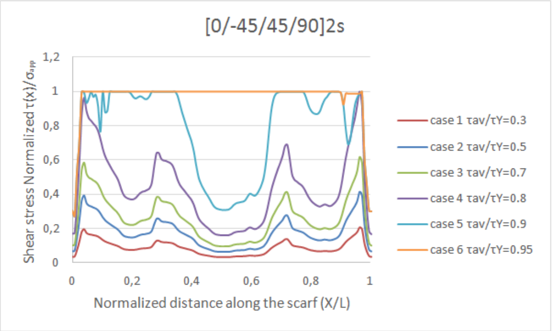
<u>Variation of adhesive stresses in a 3D scarf repaired composite panel with an elastic-plastic adhesive</u>, a FE model was developed following the same procedure and same materials used for the linear analysis of the circular patch.



3D Circular patch model with LBCs



3D Scarf Repair – Results of the Elastic Analysis (Deformation and Stress)



Shear stress distribution along 3-D scarf (shear stress normalized by yield stress for [0/-45/45/90]2s.

6 - RESULTS

Effect of scarf joint parameters on bondline average and peak stresses				
Parameter	**Average peel**	**Peak peel**	**Average shear**	**Peak shear**
Stacking sequence	No	Increases when 0^0 plies are on the outer surfaces	No	Decreases with more 0^0 plies. Increases with increasing distancebetween 0^0 plies across the scarf.
Laminate thickness	No	Decreases with increasing laminate thickness	No	Decreases with increasing laminate thickness
Mismatched adherends	No	Slight increase or decrease depending on lay-up	No	Slight increase or decrease, deponding on lay-up
Over laminate	Decreases with increasing over laminate number of plies	Slight decrease with increasing over laminate number of plies	Decreases with increasing over laminate number of plies	Slight decrease with increasing over laminate number of plies
Scarf angle	Increases with increasing scarf angle	Strongly decreases with increasing scarf angle	Decreases with increasing scarf	Slightly decreases with increasing scarf angle
Allowing load by-pass of patch	Decreases if there is an alternate load paths	Decreases if there is an alternate load paths	Decreases if there is an alternate load paths	Decreases if there is an alternate load paths
Angle to loading direction for a 3D circular patch	Decreases with increasing angle from loading direction	Decreases with increasing angle from loading direction	Decreases with increasing angle from loading direction	Decreases with increasing angle from loading direction

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AEROSPACE SECTION

Automation in Composite Repairs

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!