E-LASS Seminar #15

18 Nov 2021

Nantes, France

Repairing with Composite Overlamination Applications on Steel and Composite Structures

AIMEN

Lourdes Blanco Salgado

Presentation Outline

- Brackground from AIMEN
- WP21 RAMSSES Overview
- Pre-Tests Procedure
- Description DC21.1
- Description DC21.2
- Description DC21.3
- Conclusions
- Q&A

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We are an **innovation** and **technology centre** specialized in **research** and in providing **technological services** in the field of **MATERIALS**, **ADVANCED MANUFACTURING PROCESS** and **INDUSTRY 4.0**

We are experts in

- Joining Technologies
- Laser Technologies applied to Materials Processing
- Industrial Robotics

690 R&D&i Projects In the last 10 years

8 Active Patents As of 31/12/2019

+500 Clients Annual average In the last 5 years

+250 Employees 37 PhDs 59% men 41% women

15,6 M€ Anual Income 2019

285.926 Technical Reports As of 31/12/2019

1967	1995	1998	2002	2004	2014	2017
Founding of AIMEN	Opening of the Armando Priegue building in O Porriño	Official recognition as a Innovation and Technology Centre	Creation of a Pilot Joining Technology Plant	Comissioning of the Laser Technologies Research Plant	Opening of the Laser Applications Centre	50th years associated with Innovation

Background for RAMSSES Project

FP7, H2020

Co-Patch

MOSAIC – Materials On-Board: Steel Advancements And Integrated Composites

SMARTYards

COMMUNION – JOINING OF 3D TPC/METAL MULTIMATERIAL COMPONENTS

National calls

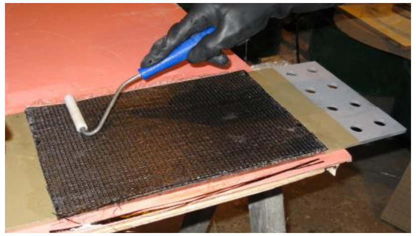
PARCHE

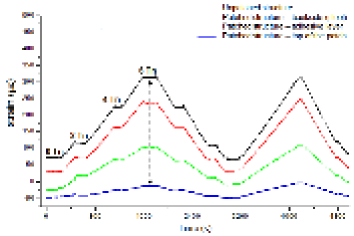
EMMA

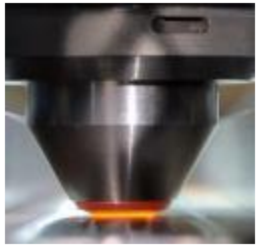
miami

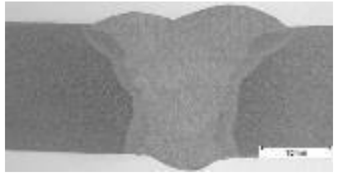
NAUTILUS – Nuevos materiales y sistemas automatizados para fabricación avanzada con aplicación en buques militares

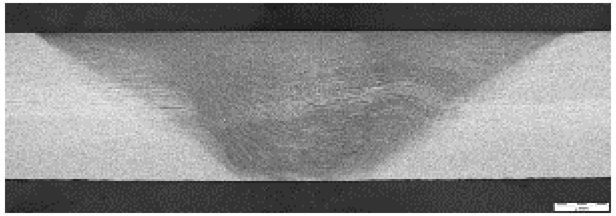
- ✓ Repair with composites
- ✓ Multi-material structures
- ✓ Welding procedures of HSLA (Laser and Hybrid)
- ✓ Friction Stir Welding and Processing
- ✓ Shipbuilding networking / technology transfer from&to other sectors











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WP21.- Composite Overlay to repair and improve metallic and non-metallic structures

Objective: demonstrate that composite overlaminating is suitable both as a repair technology for damaged structures in a marine environment as to improve the pristine properties of welded joints

DEMONSTRATORS LAYER

STEEL

COMPO-SITE

WELDS

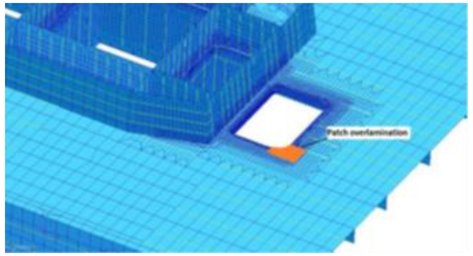
WP21
Steel cluster (WP19/WP20/ WP21): **repair**

WP21
"Ship integration: Composite" layer: **joint repair**

WP19,20
Steel Cluster: **reinforcement**

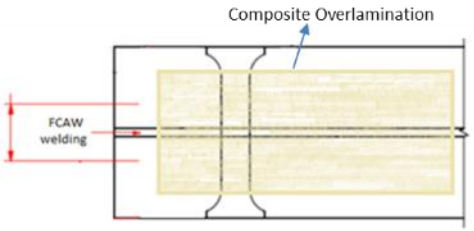
WP7
Standard testing

WP21 interaction within RAMSSES partners



DEMO CASE 21.1: crack arresting on a damaged structural detail on a deck opening of a cruise ship

DEMO CASE 21.2: composite joint repair by composite overlamination solutions.



DEMO CASE 21.3. reinforcement in way of structural details with external exposures. Improving fatigue behavior

WP21 DEMO CASES

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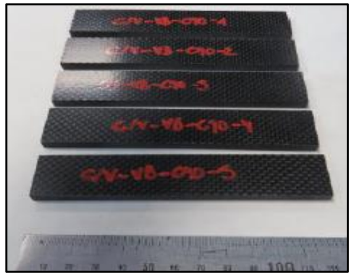
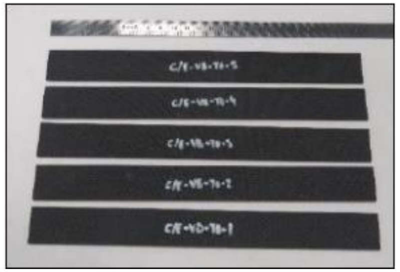
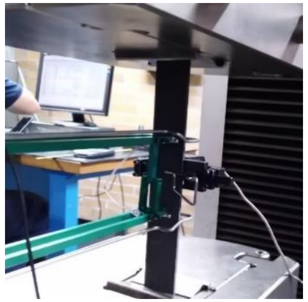
Pre - Tests

Composite Systems Characterization

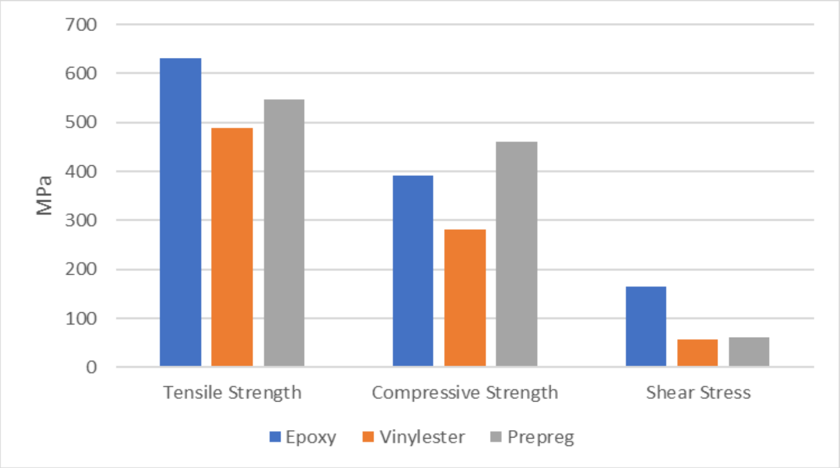
Composite System	Manufacturing Process	Carbon Fiber	Resin
CF/Epoxy	Vacuum Infusion	TOR000601, material designation: CC 200 P – 120 (KordCarbon), bidirectional plain weave, 200 g/m2, Toray 3K 200 tex carbon fibre	PRIMET 27 EPOXY INFUSION SYSTEM (Gurit)
CF/Vinylester			Epovia® Optimum KRF 4436 AI (Polynt Composites)
Prepreg CF/Epoxy	HLU + VB	VTM264/CF0302*-42%. CF0302 is a 2x2 twill, 199 g/m2 fabric with 3k FT300B 40B fibres.	







Test	Properties	VI-C/E	VI-C/V	PP-VB
Tensile (ASTM D3039/D3039M)	E_{1T} [GPa]	51,8 ± 1,4	49,4 ± 0,9	46,6±1,10
	E_{1T} [GPa]	52,1 ± 1,5	51,2 ± 1,1	46,8±1,22
	X_{1T} [MPa]	631,4 ± 48,9	489,4 ± 12,9	546±89
	X_{2T} [MPa]	588,6 ± 22,2	515,0 ± 28,0	544±48
	ν_{12}	0,32 ± 0,02	0,61 ± 0,07	0,06±0,025
	ν_{21}	0,42 ± 0,12	0,66 ± 0,06	0,06±0,014
Compression (UNE-EN ISO 14126: 2004)	E_{1C} [GPa]	44,0 ± 2,8	45,4 ± 1,9	42,8±3,36
	E_{2C} [GPa]	42,0 ± 1,2	46,2 ± 2,7	43,5±4,29
	X_{1C} [MPa]	391,0 ± 24,8	281,8 ± 30,8	461±54
	X_{2C} [MPa]	384,4 ± 336,5	241,8 ± 17,4	466±18
Shear (ASTM D3518-13)	S_1 [MPa]	165,1 ± 5,4	56,5 ± 3,2	61,98±0,45
	S_2 [MPa]	148,6 ± 6,3	63,1 ± 1,2	60,78±0,32



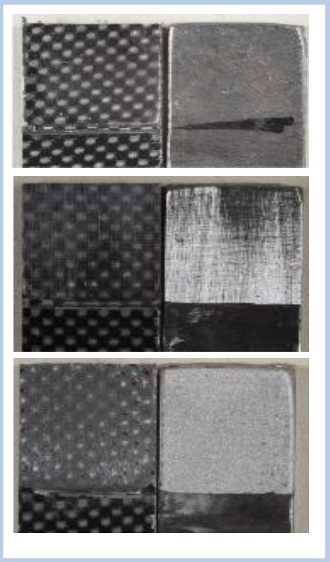
WP 21 - Composite Patches & Overlamination for Repairing

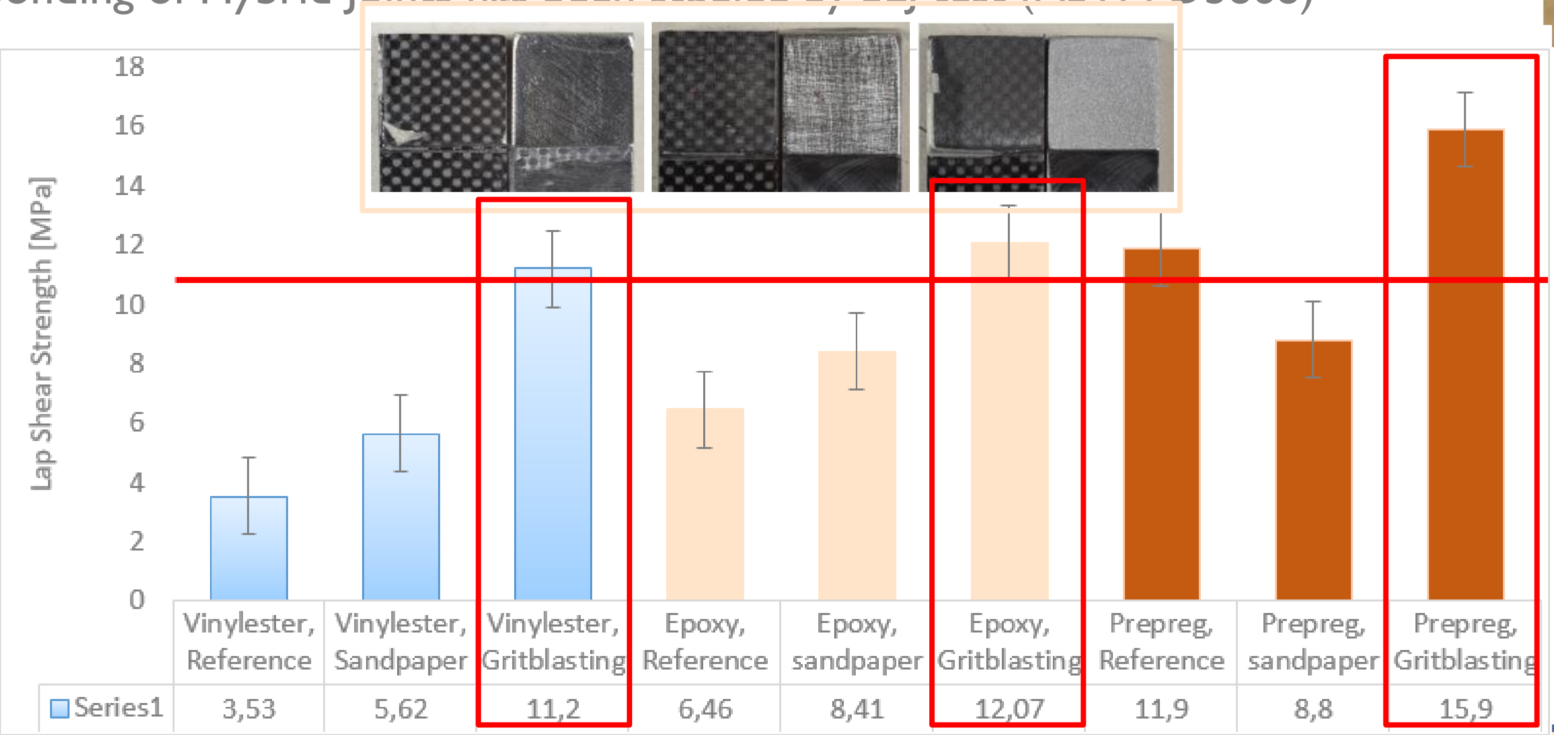
Pre - Tests

Metal Treatment & Dissimilar Joint Characterization

- Adherent 1: CFRP (3 CS)
- Adherent 2: Steel (AH36 6mm)

  Steel Surface Conditioning Treatments: Non treated (Ref), Sandpaper & Gritblasting
- Lamination was done directly on the steel surface.
- The Adhesive Bonding of Hybrid Joints has been studied by SLJ test (ASTM D5868)





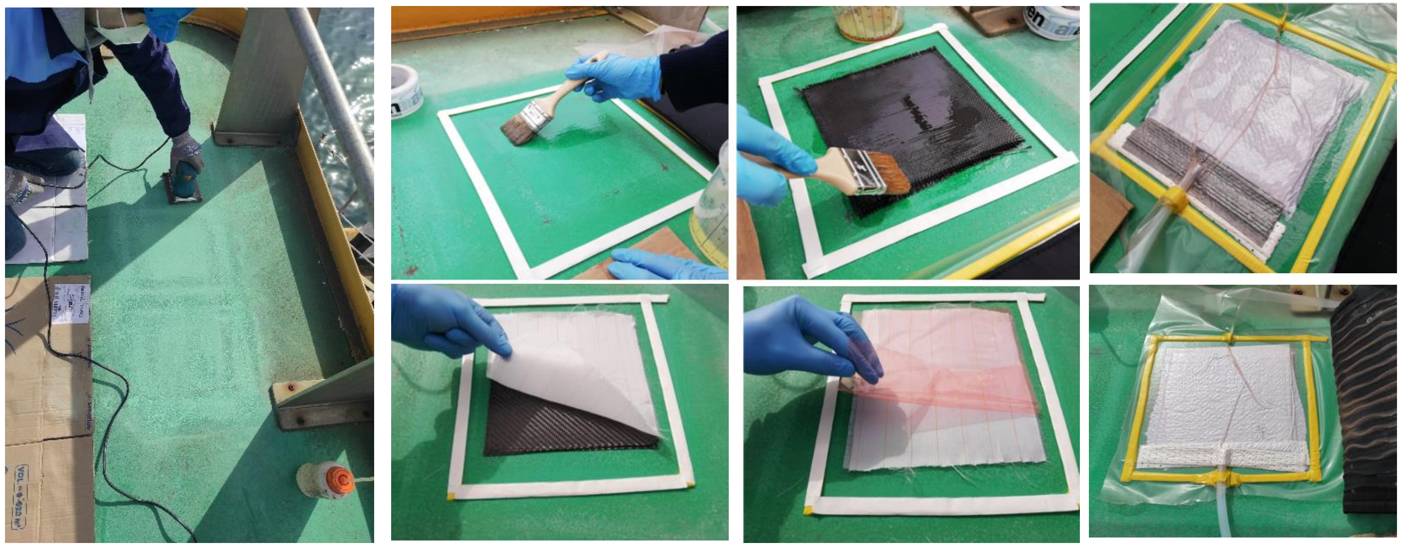
Pre - Tests

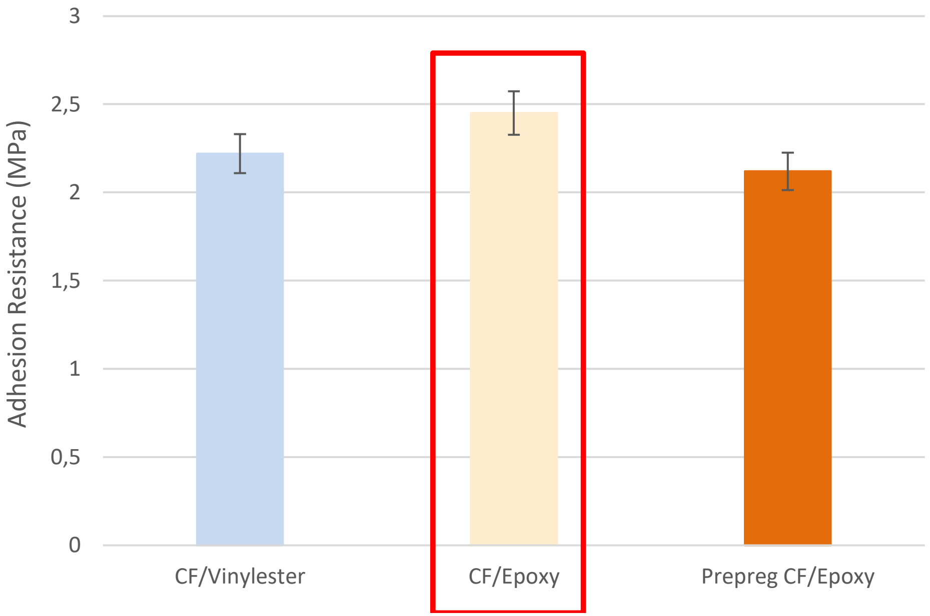
Composite Treatment & Dissimilar Joint Characterization

- Adherent 1: CFRP (3 CS)
- Adherent 2: GF/Polyester

    Composite Surface Conditioning Treatments: Sandpaper

- Lamination was done directly on the composite surface.
- The Adhesive Bonding of Hybrid Joints Composite-to-Composite has been studied by Pull-off test (ISO 4624)





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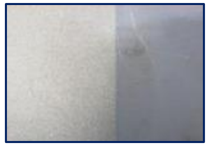
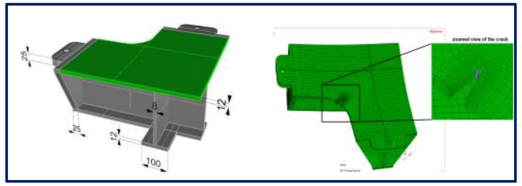
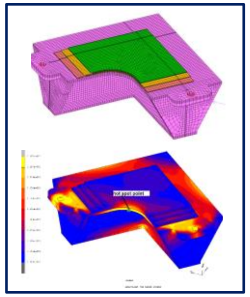
WP21 – DC 21. 1. Composite Overlamination to Repair on a Damaged Steel Structure



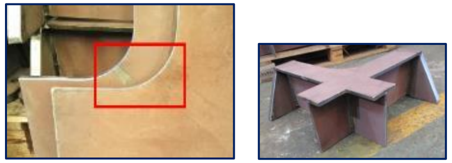
Steel selection and surface conditioning for patching



Demonstrator design & FEM calculations. Damage simulation.



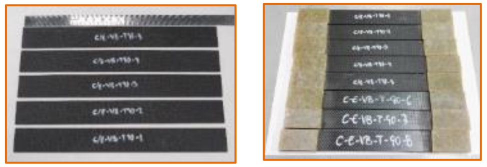
Patch repair design & modelling



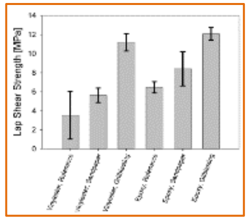
Demo cutting and welding. Crack manufacturing

Patch Manufacturing

Composite systems characterization & selection



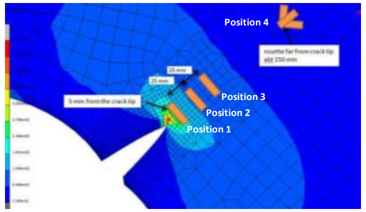
Dissimilar joint strength evaluation



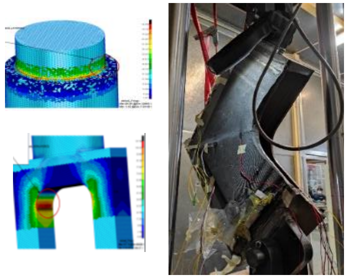
Sensors lay-out definition

Location	Distance from the crack tip [mm]
Position 1	5
Position 2	30
Position 3	55
Position 4	150

Location	Number and Type of sensor	Position and orientation
Plate p5 bottom side – steel (no patched, patched)	3 Strain gauges	**Position: 1 – 2 – 3** **Orientation:** SGs positioned perpendicular to the crack (parallel to the load)
	1 Rosette gauge	**Position: 4** **Orientation:** See a picture with a possible Rosette distribution.
Plate p5 – steel to patch interface (no patched, patched)	2 FBGs	**Position: 2 – 3** **Orientation:** FBGs positioned perpendicular to the crack (parallel to the load)
Patch intermediate layers (patched)	2 FBGs	**Position: 2 – 3** **Layer: mid layer** **Orientation:** FBGs positioned perpendicular to the crack (parallel to the load)
Upper layer of the patch (patched)	1 Strain gauge	**Position: 1** **Orientation:** SGs positioned perpendicular to the crack (parallel to the load)
	1 Rosette gauge	**Position: 4** **Orientation:** See a picture with a possible Rosette distribution.
	1 FBG	**Position: 2** **Orientation:** FBGs positioned perpendicular to the crack (parallel to the load)



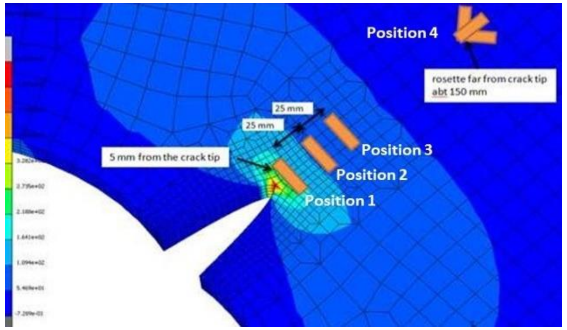
Testing:
Fixture design & Fatigue Test



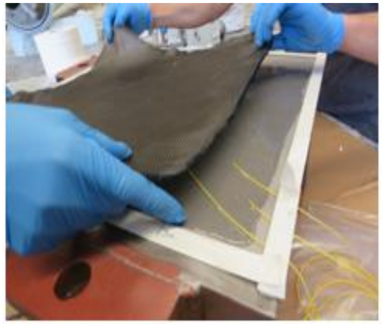
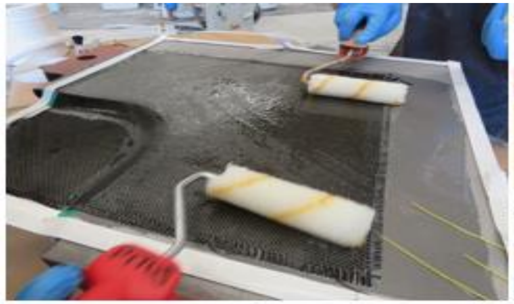
DC 21.1: Composite Overlamination for Crack Arresting – Metallic Structures Repair

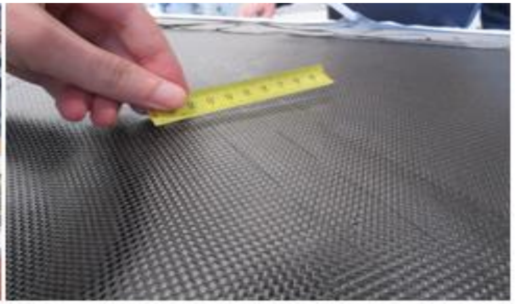
Objective: demonstrate that composite overlaminating is suitable as a repair technology for metallic damaged structures in a marine environment as to improve the pristine properties of welded joints

Manufacturing Process & Monitoring Systems :







DC 21.1: Composite Overlamination for Crack Arresting – Metallic Structures Repair

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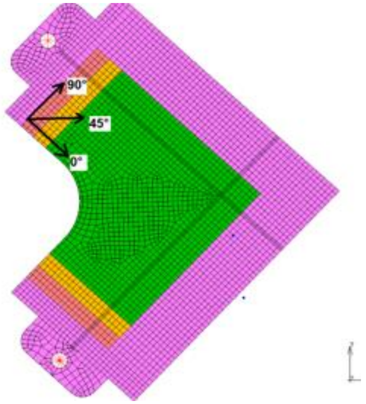
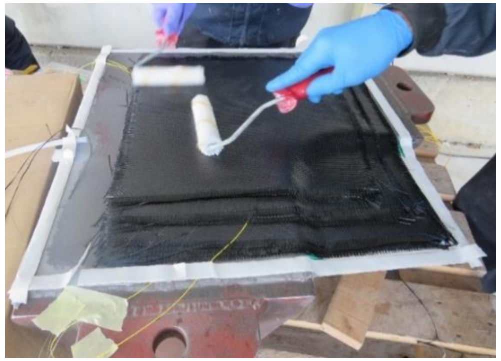
Set-up Fatigue Test :





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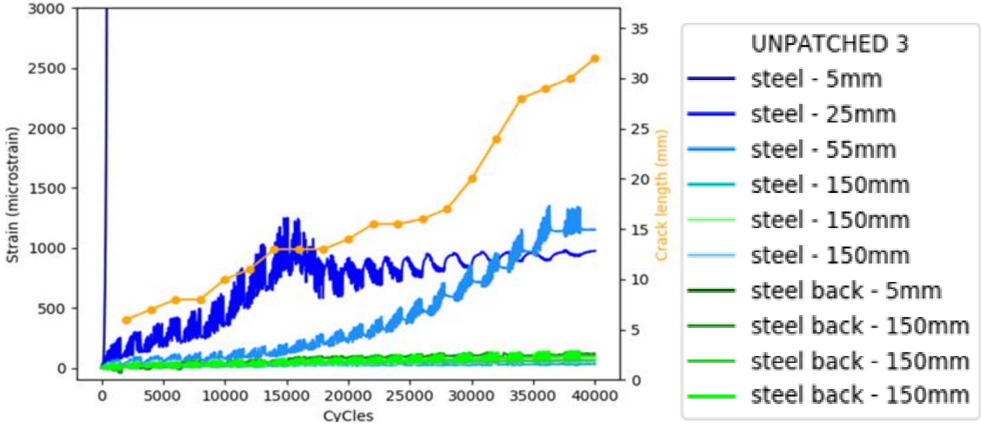
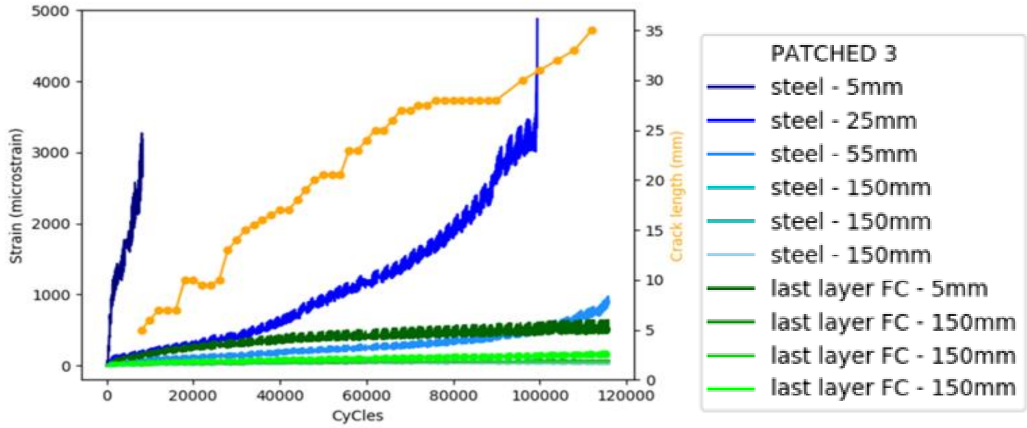
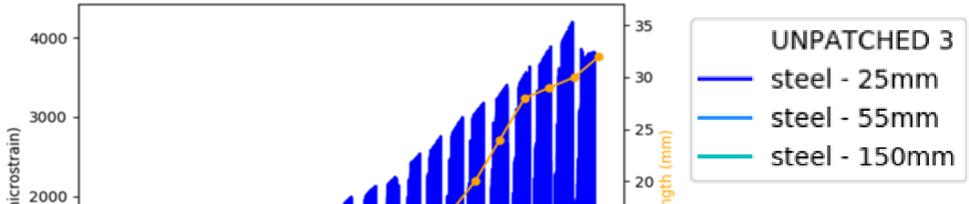
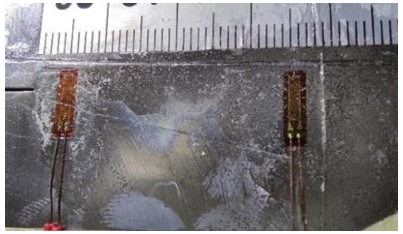
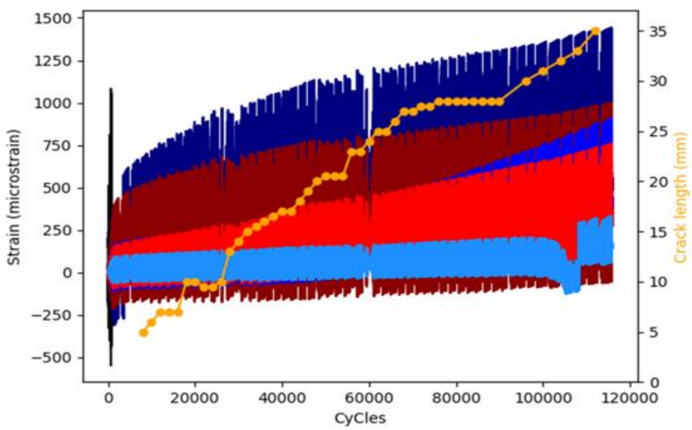
Fatigue Test Results:

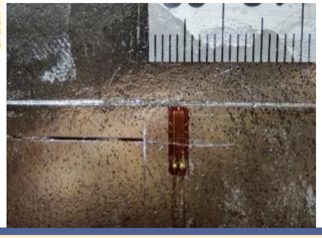












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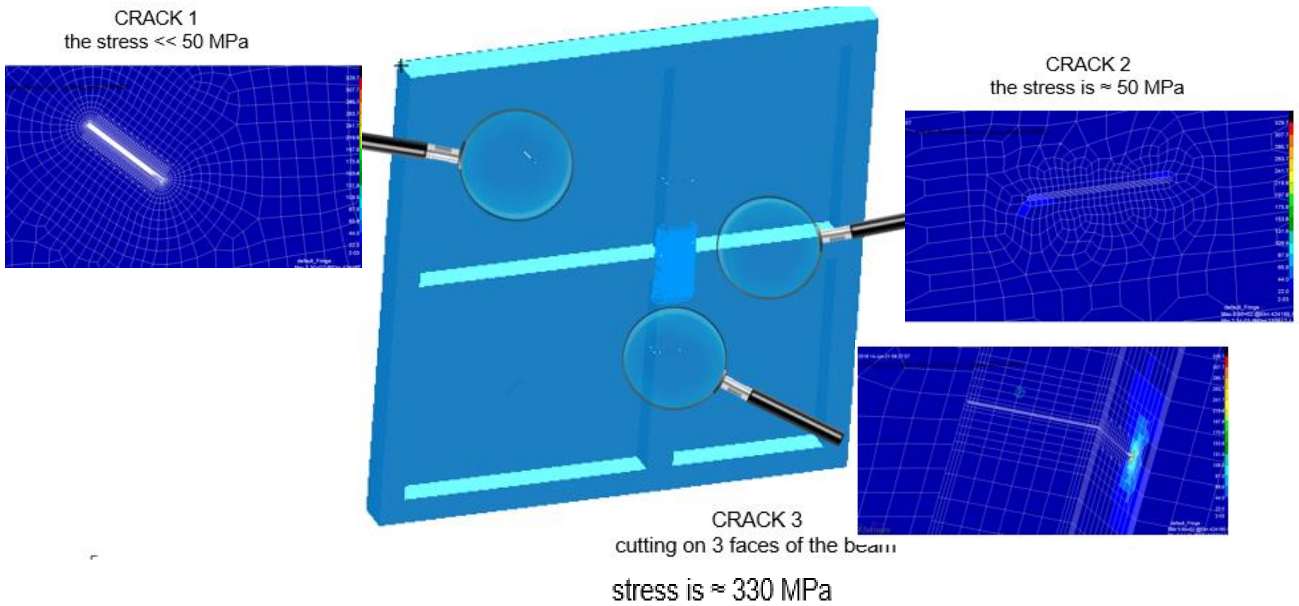
Questionnaires with all the partners involved in the composite layer

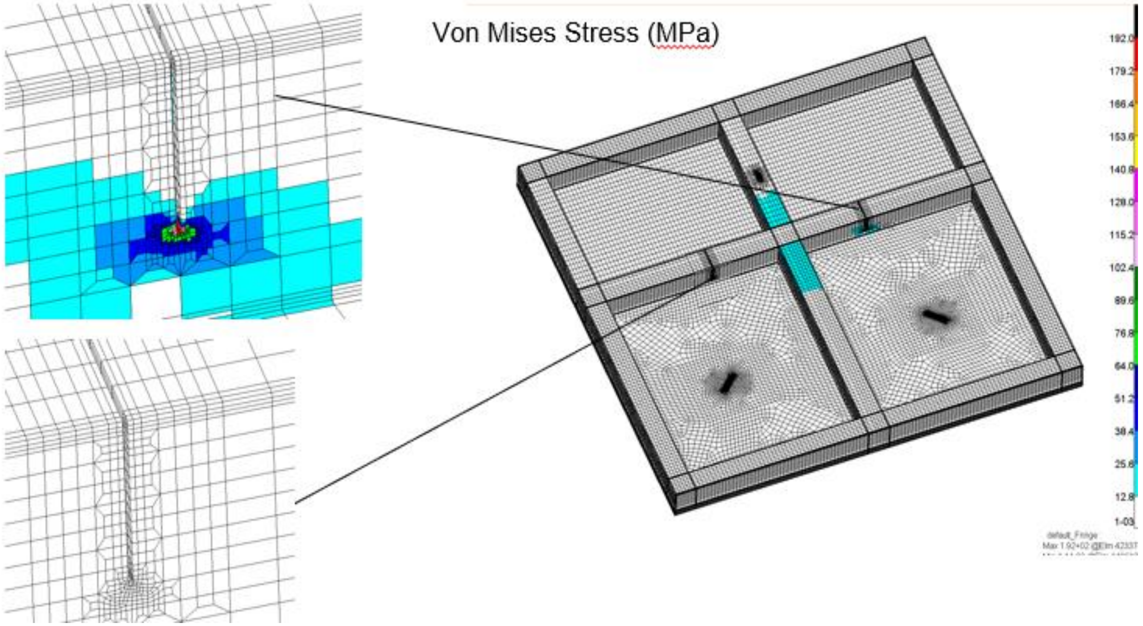
Selection of a type of repair to be studied: JOINT repair

Representative demo SMARTYards Project demo (CARDA)

JOINT REPAIR STRATEGIES

Design of the test

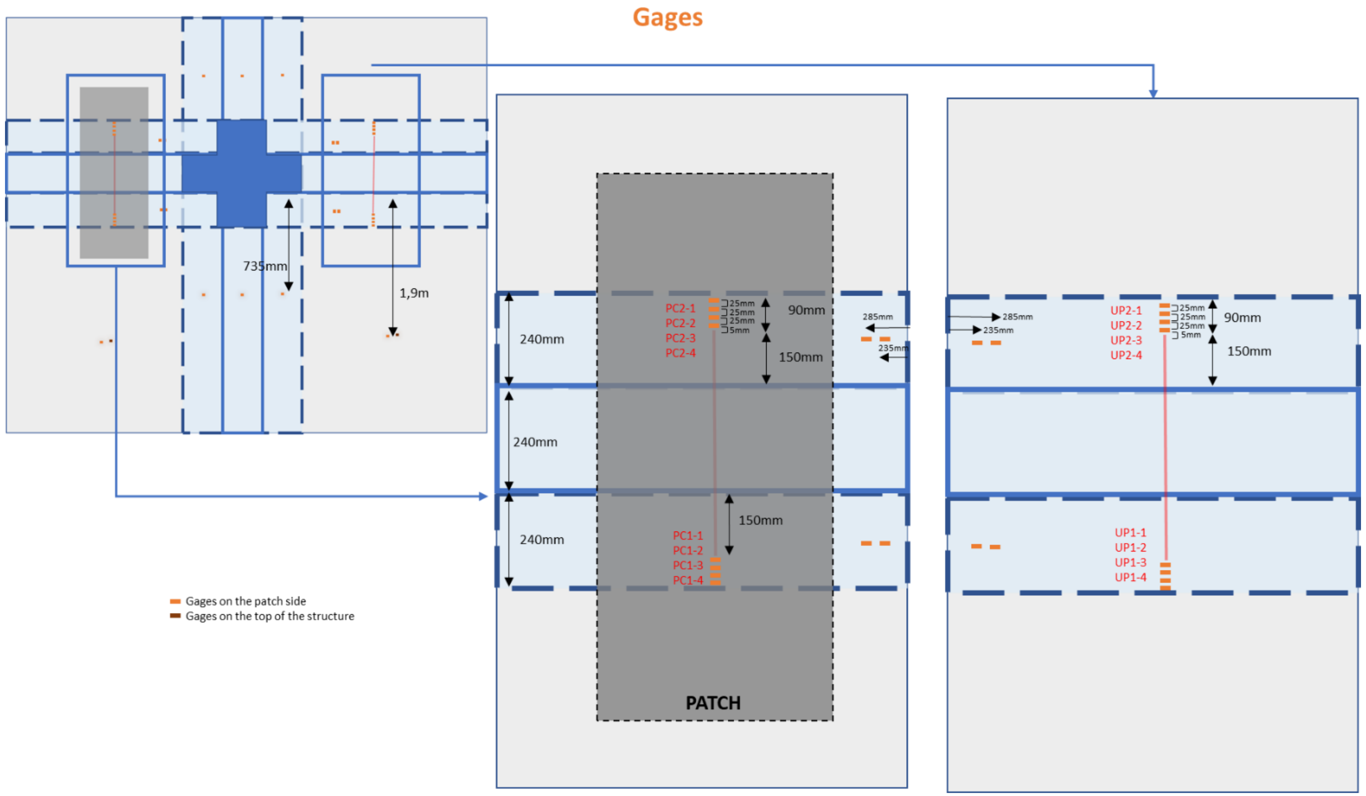


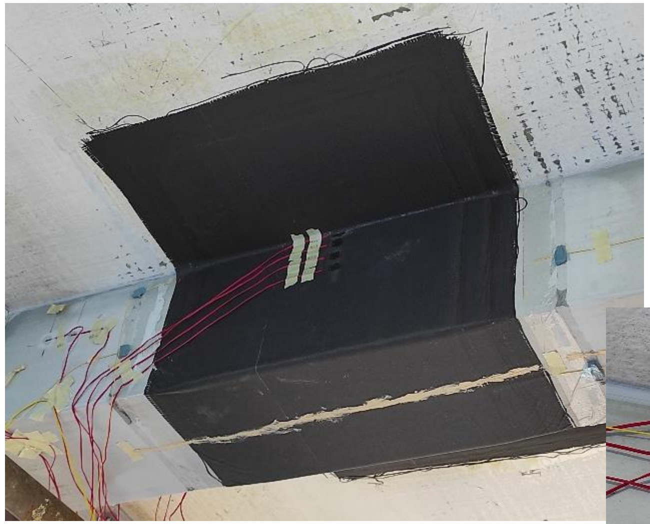


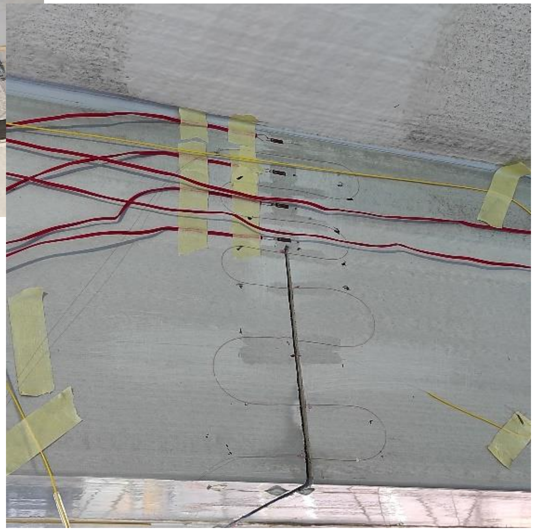
DC 21.2: Composite Overlamination for Crack Arresting – Non-Metallic Structures Repair

Objective: demonstrate that composite overlaminating is suitable as a repair technology for non-metallic damaged structures in a marine environment as to improve the pristine properties of welded joints

Monitoring Systems:







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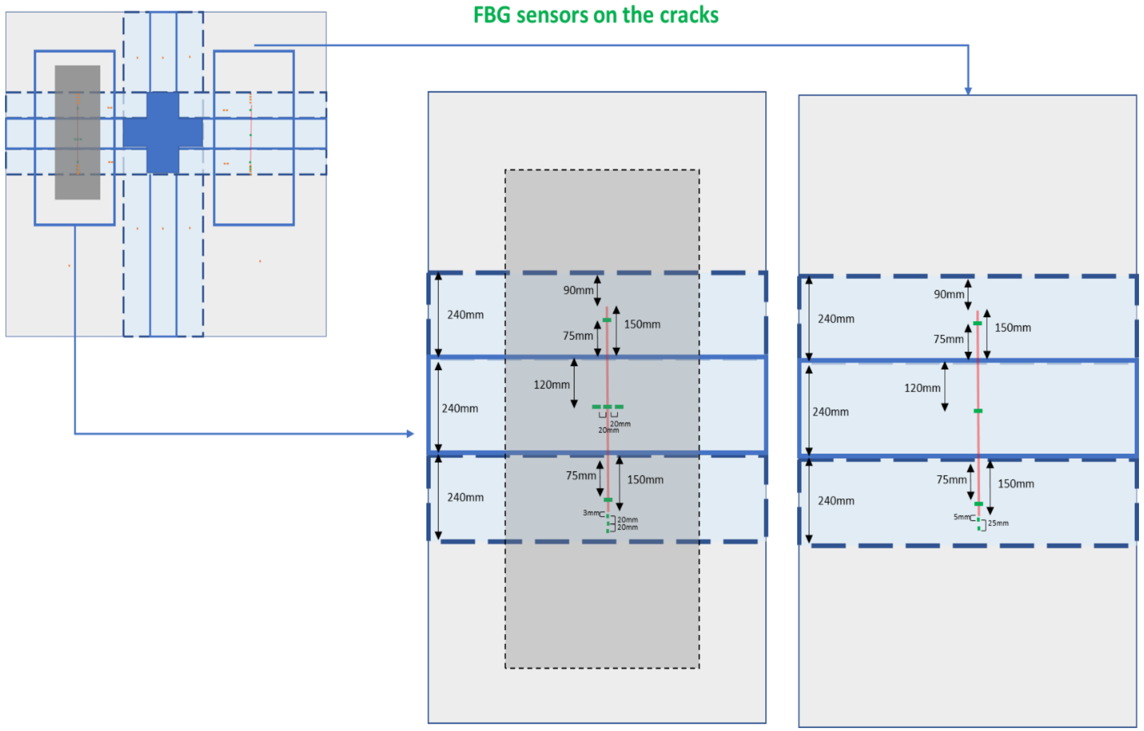

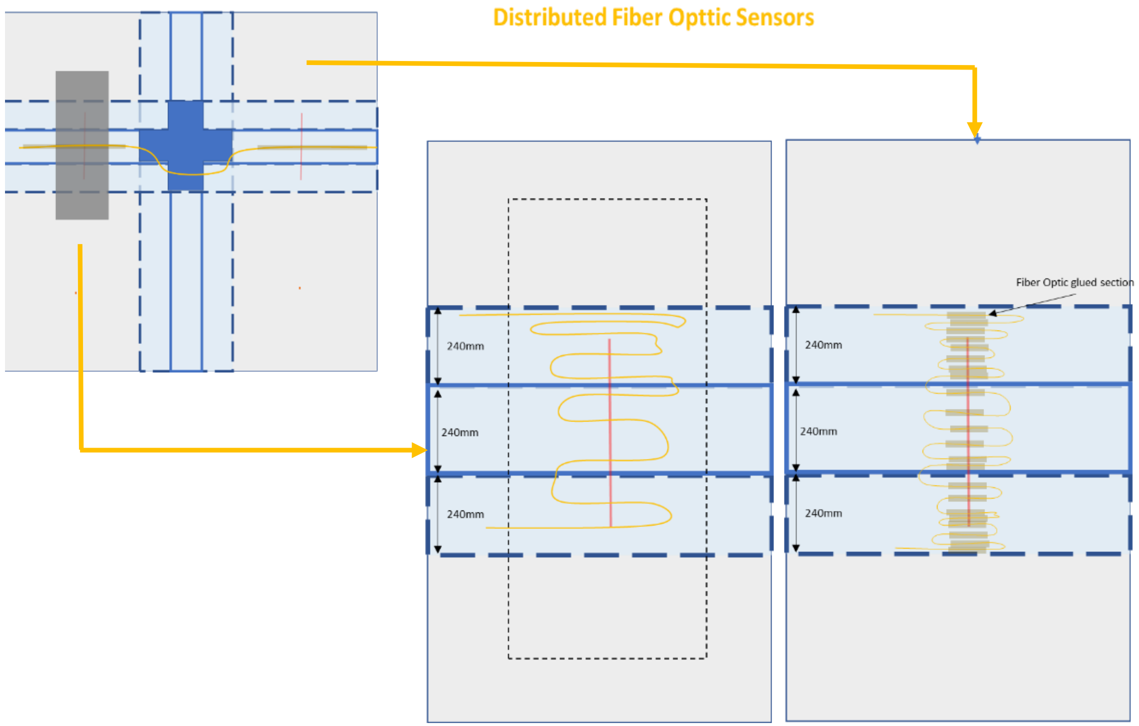

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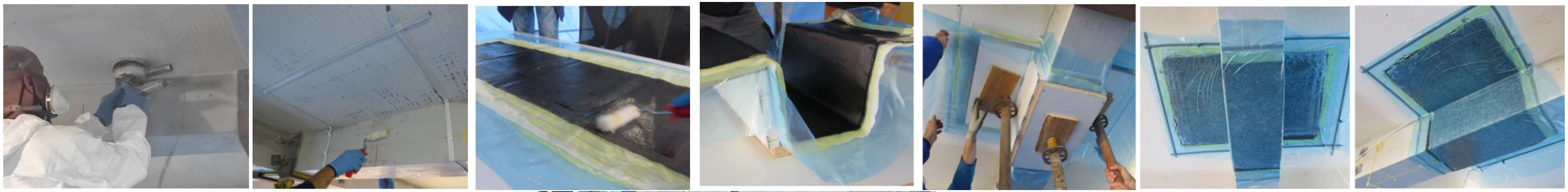
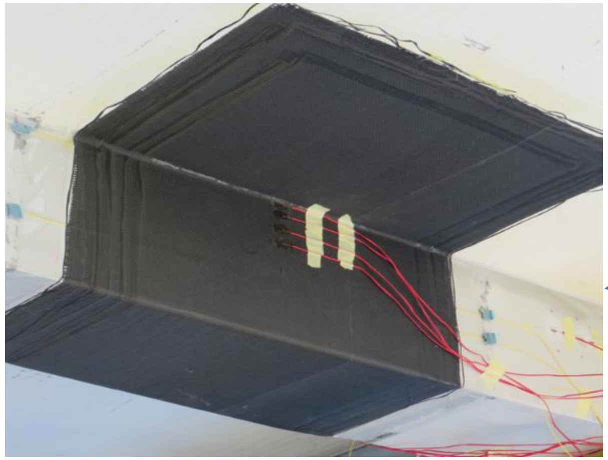
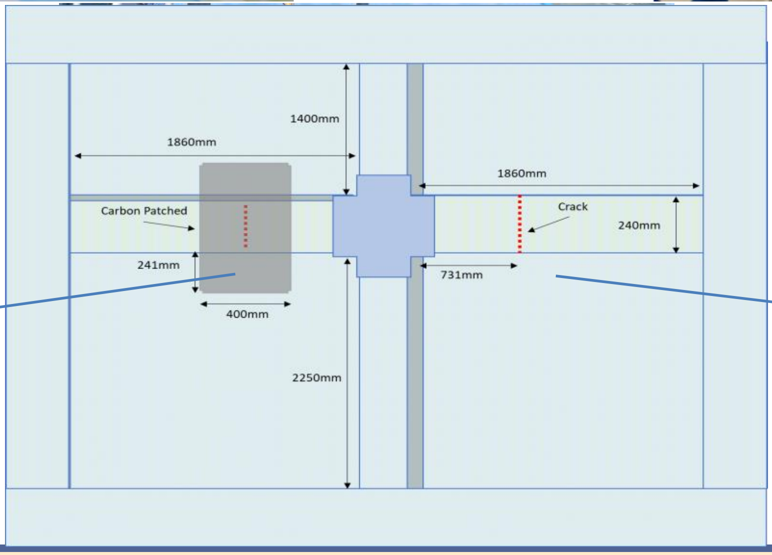
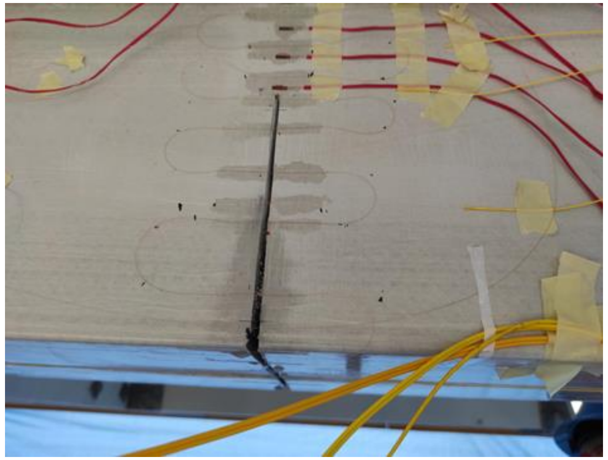
Manufacturing Process & Set-up Test :









DC 21.2: Composite Overlamination for Crack Arresting – Non-Metallic Structures Repair

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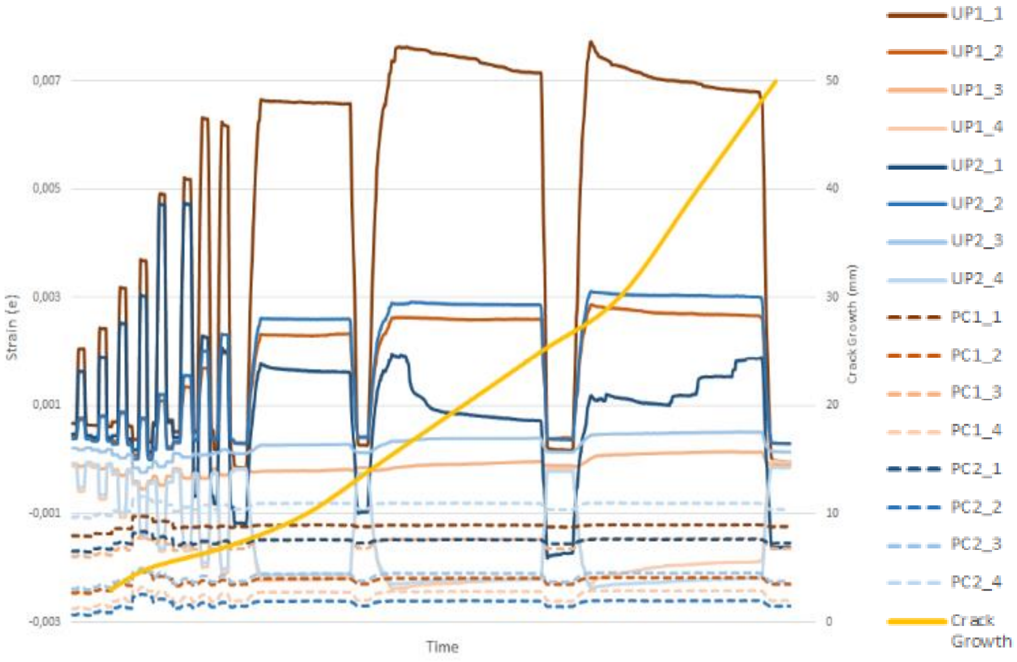
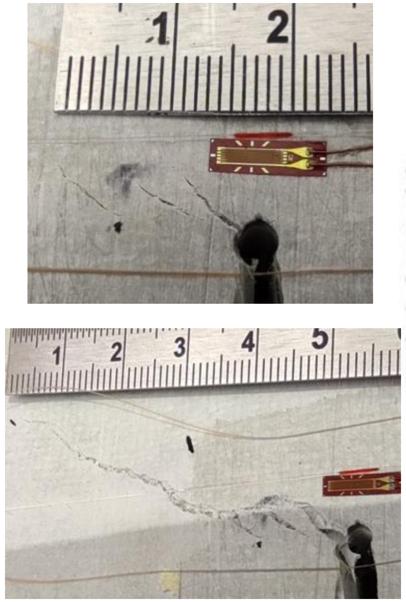
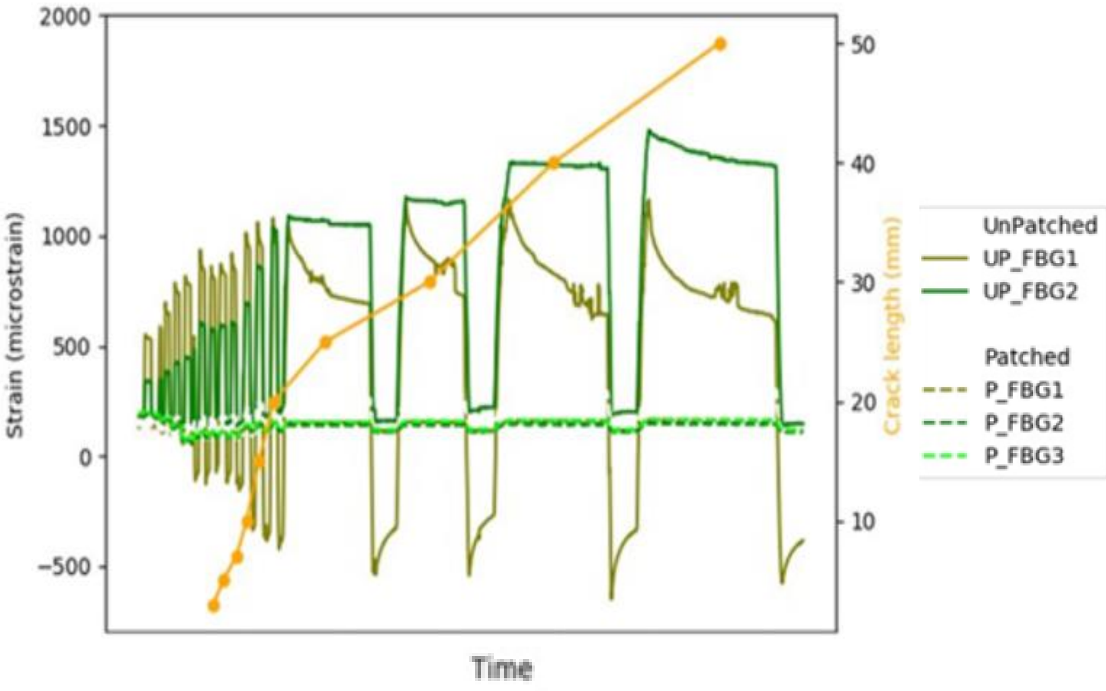
Dynamic and Static Test Results:







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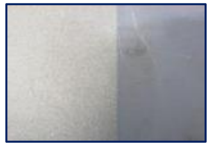
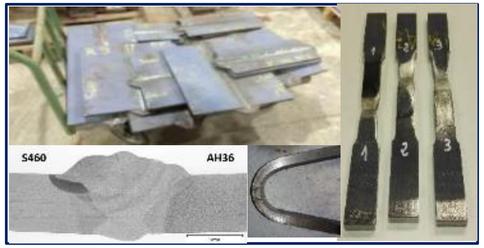
- Q&A

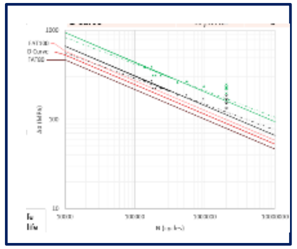
WP21 – DC 21.3. Composite Overlamination to Reinforce HSLA welded joints to Improve their Fatigue behaviour



HSLA Steel selection: 4 combinations

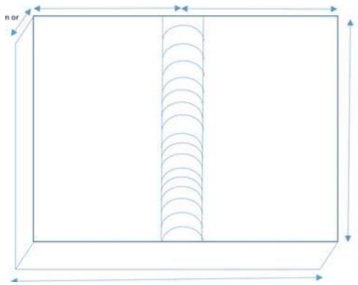


HSLA Steel welding optimization & Qualification tests

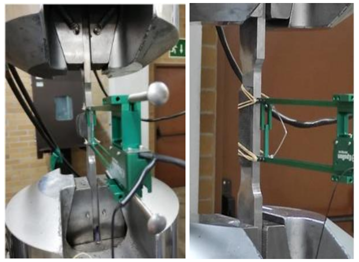


HSLA welded steels: fatigue testing campaign

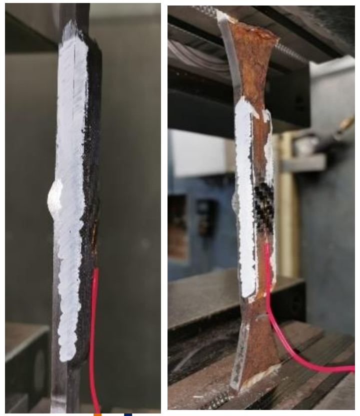
1 material combination



S460-S460 combination

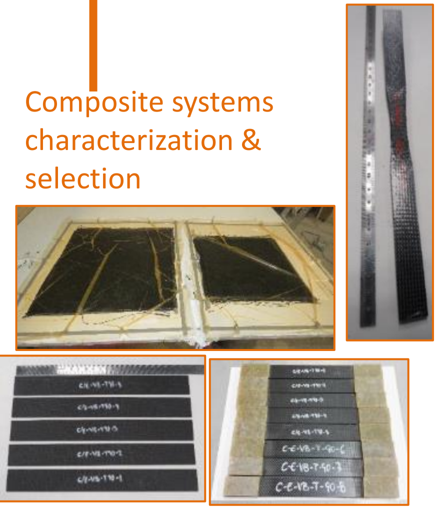


1st Phase:
DoE
Tensile Test

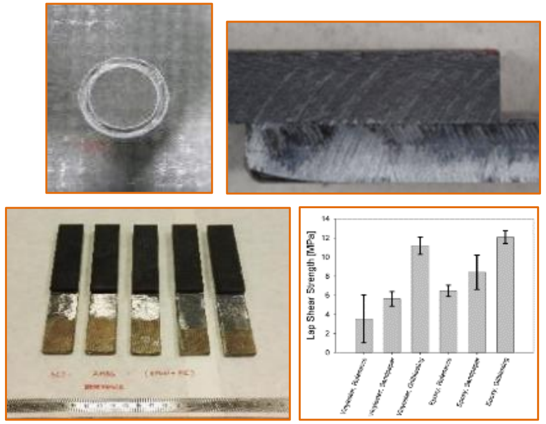


2nd Phase:
FATIGUE TESTING OF REINFORCED WELDS

Composite systems characterization & selection

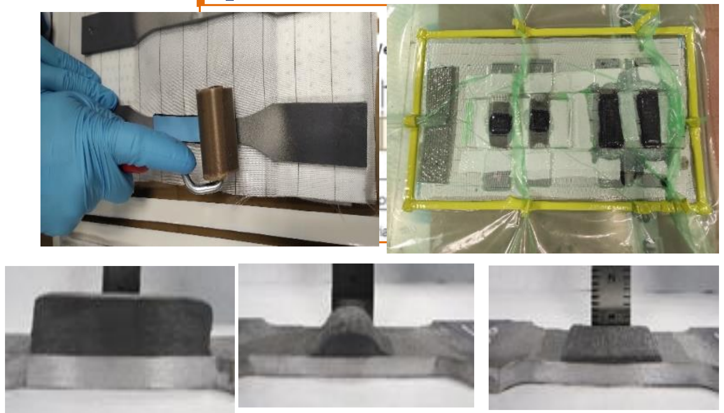


Dissimilar joint evaluation



DoE design:
Definition 36 specimens testing campaing

Patch reinforcement manufacturing
(lab scale specimens)

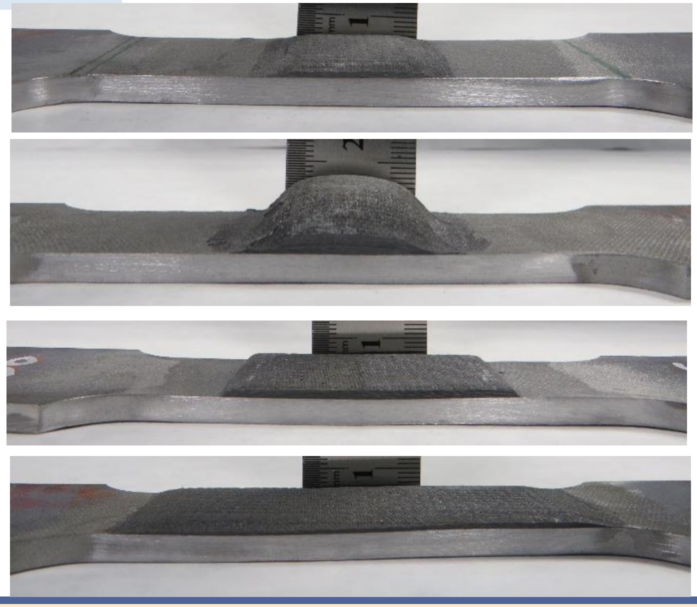


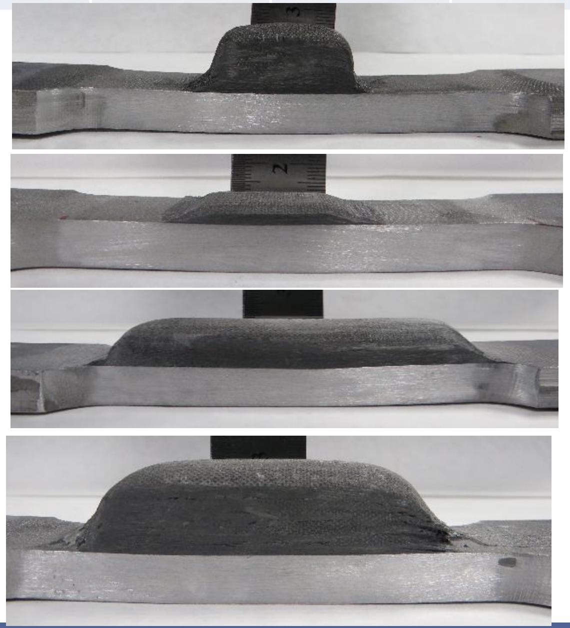
Post Treatment: Composite Overlamination – 1st Phase Study: DoE

36 Composite overlamination specimens were manufactured under the DoE selected conditions (SR, wp/ww)

D	D_{-1}= 5mm			D_1 = 10mm		
SR Value (A)	0.1 (A_{-1})	0.30 (A_0)	0.5 (A_1)	0.1 (A_{-1})	0.30 (A_0)	0.5 (A_1)
CS	tp	tp	tp	tp	tp	tp
CS $_{-1}$ CS $_0$	2	6.1	10.2	4	10.2	20.4
CS $_1$	1.7	5.2	8.7	3.5	10.4	17.3

Thickness Steel (D)	D_{-1}= 5mm ww =20mm Lc= 85mm			D_1 = 10mm ww= 27mm Lc= 95mm		
wp/ww (B)	1.25 (B-1)	2.5 (B0)	3.5 (B1)	1.25 (B-1)	2.5 (B0)	3.5 (B1)
wp (mm)	25	50	80	34	67	94.5



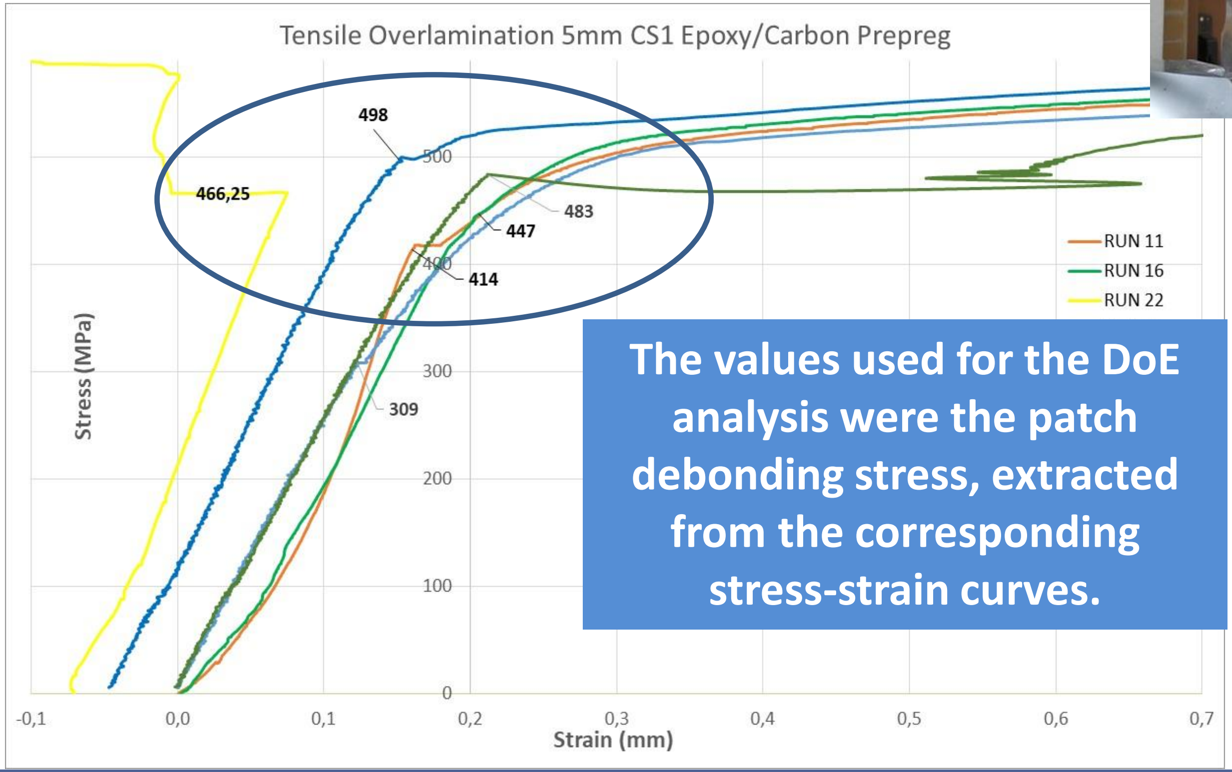


Post Treatment: Composite Overlamination – 1st Phase Study: DoE

36 Composite overlamination specimens were performed by Tensile Test (ISO 4136) for DoE analysis

Patch debonding stress were used:

- to select the most efficient patch configuration
- to perform the fatigue tests



The values used for the DoE analysis were the patch debonding stress, extracted from the corresponding stress-strain curves.

D	D_{-1}= 5mm		
SR Value (A)	0.1 (A_{-1})	0.30 (A_0)	0.5 (A_1)
CS	tp	tp	tp
CS_{-1} CS_0	2	6.1	10.2
CS_1	1.7	5.2	8.7

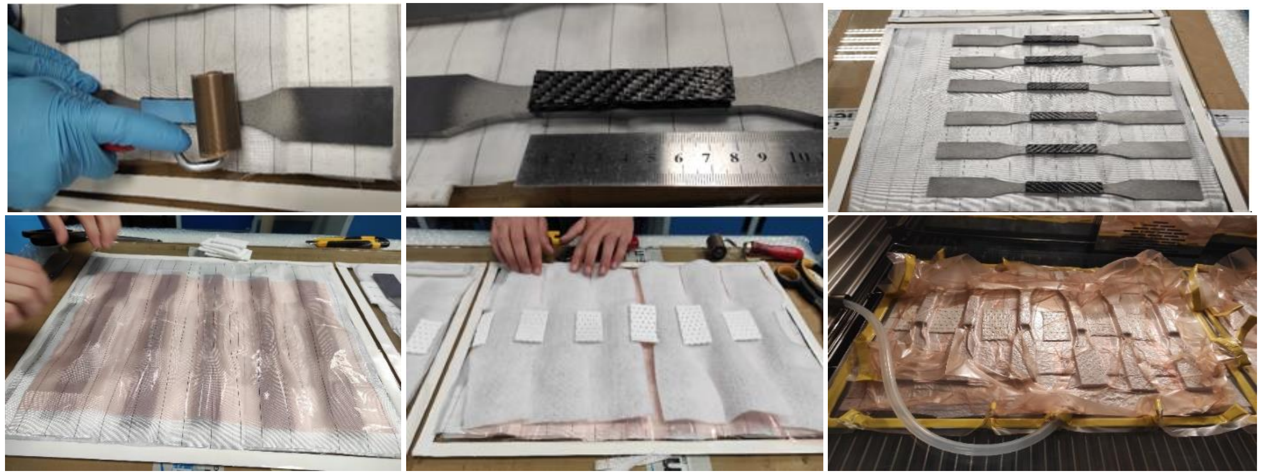
Thickness Steel (D)	D_{-1}= 5mm ww =20mm Lc= 85mm		
B	1.25 (B-1)	2.5 (B0)	3.5 (B1)
wp (mm)	25	50	80

DC 21.3: Improving fatigue behaviour of welded HSLA by Composite Overlamination

Objective: demonstrate that composite overlaminating is suitable as a technology for improving the fatigue behaviour in a marine environment as to improve the pristine properties of welded joints

After DoE: selected the best combination for Patch configuration

Manufacturing Process



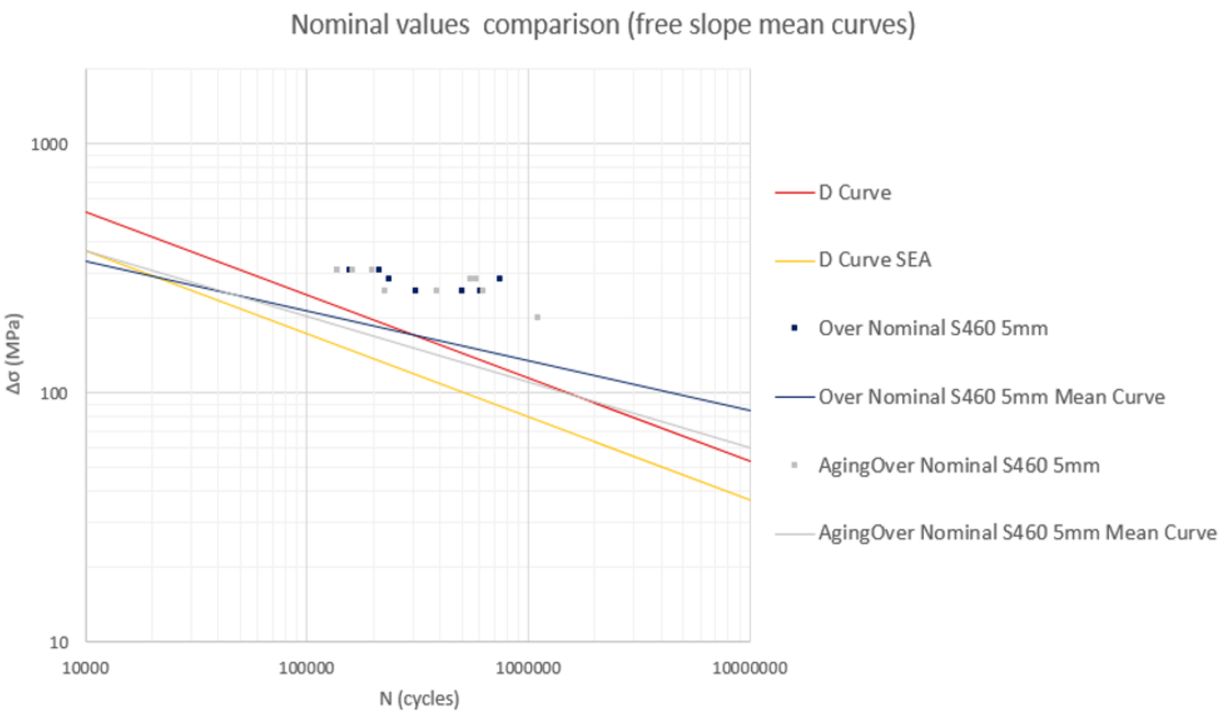
Aging Test

Set-up Fatigue Test

DC 21.3: Improving fatigue behaviour of welded HSLA by Composite Overlamination

Objective: demonstrate that composite overlaminating is suitable as a technology for improving the fatigue behaviour in a marine environment as to improve the pristine properties of welded joints

Fatigue Test Results:



Survival Probability Level of 97,7%			
	logC	m	FAT
Overlamination	16,60211671	4,9873	116,27
Overlamination + Aging	13,7810799	3,8082	92,09
D curve in seawater without corrosion protection	11,7	3	63,27
D curve in air	12,1818	3	91,25

- Overlamination has a better FAT than D curve in air (according to Ni611).
- Aging exposure has caused a worst fatigue behaviour than without aging. Instead of that, it had a better FAT than D curve in seawater without corrosion protection (according to Ni611).

Presentation Outline

- Brackground from AIMEN
- WP21 RAMSSES Overview
- Pre-Tests Procedure
- Description DC21.1
- Description DC21.2
- Description DC21.3
- **Conclusions**
- Q&A

Conclusions

DC21.1

Composite patch works as crack arrested. So this behaviour represent an **improvement of the 2.6 times** of the fatigue life comparing UnPatched and Patched damaged steel.

DC21.2:

At the end of the tests on the cracked UnPatched side, the crack increased its length by 50 mm. On the other hand, regarding the cracked Patched side, the patch arrested the crack completely, so this behaviour shows that the **composite repair works properly and the structure maintains its stiffness.**

DC21.3:

Overlamination without and with Aging tests **combinations have an acceptable fatigue behaviour.**

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AIMEN

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