THE INFLUENCE OF OPTIMIZED REPAIR PATCH GEOMETRY ON THE STRENGTH OF REPAIRED COMPOSITE STRUCTURES

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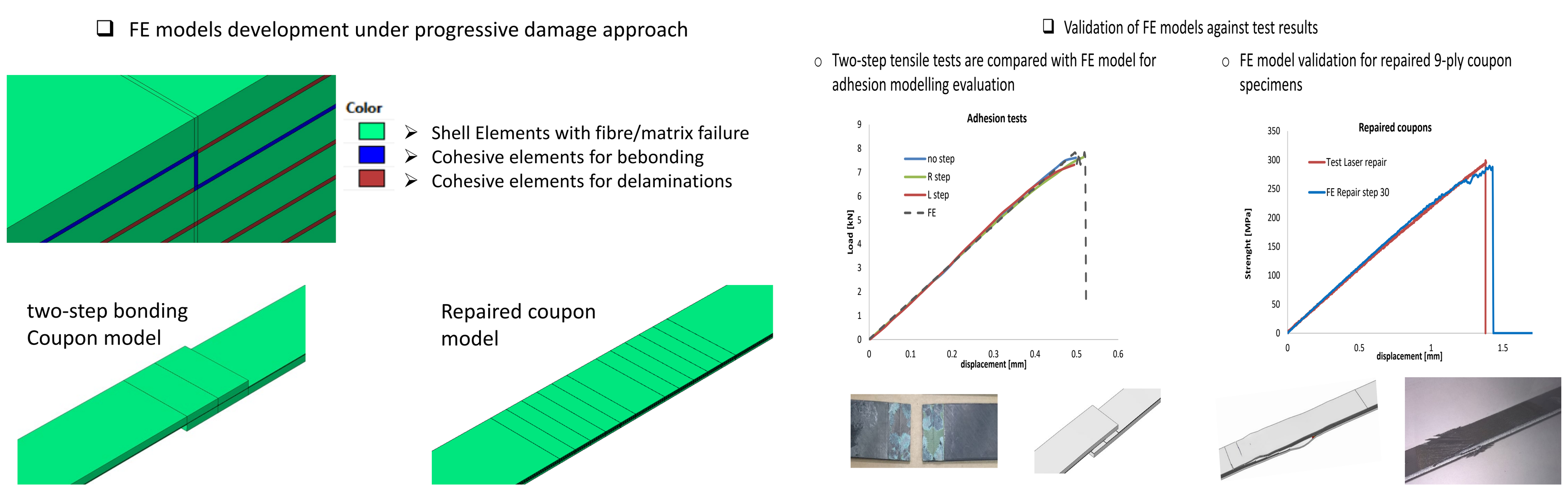
General Introduction

In this study the optimization of stepped scarf repair composite parts was investigated by using extensive test validated FE numerical modelling. The design of patch repair relies on stress concentration along the corner of the scarf surface; small scarf ratios mean high stress concentration [1, 2]. Low velocity impacts in CFRP's structures cause a variation of size, type and area of damages thus different types of repair methods have to take place [3]. For an ensured and controlled repair selection, numerical models have to be developed and verified against the acquired experimental results. So, a developed prediction tool for scarf repairs through the finite element modeling can lead to process automation, which is the final aim of repair researches, securing with that way the flight safety.

[1] C. H. Wang and C. N. Duong, "Chapter 8 - Design and optimization of scarf repairs," in Bonded Joints and Repairs to Composite Airframe Structures, C. H. Wang and C. N. Duong, Eds. Oxford: Academic Press, 2016, pp. 211-239.
[2] S. Psarras, T. Loutas, G. Galanopoulos, G. Karamadoukis, G. Sotiriadis, and V. Kostopoulos, "Evaluating experimentally and numerically different scarf-repair methodologies of composite structures," International Journal of Adhesion and Adhesives, pp. 102495, 2019.
[3] K. B. Katnam, L. F. M. Da Silva, and T. M. Young, "Bonded repair of composite aircraft structures: A review of scientific challenges and opportunities," Progress in Aerospace Sciences, vol. 61, pp. 26-42, 2013.

The Study

FE models have already been validated [2] and revealed the influence the scarf ratio played to the performance of the repaired composite parts.



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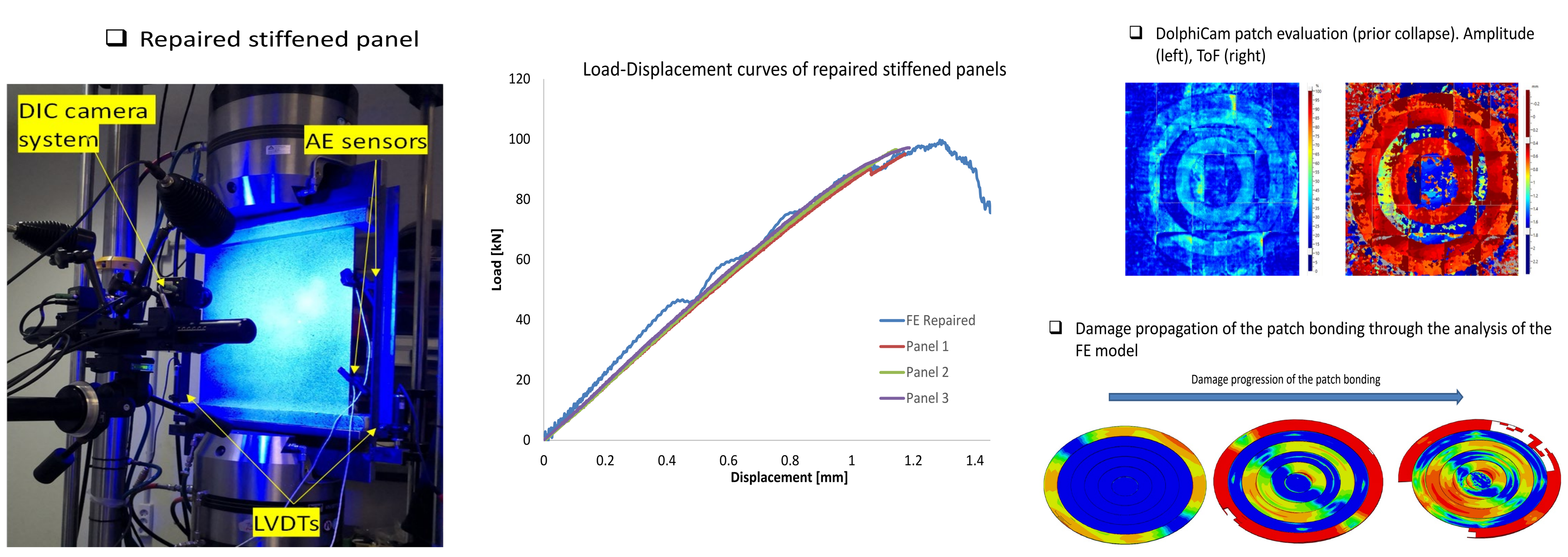
The next step that is investigated here is the importance of scarf shapes, not only to the surface plane but also through the thickness. In general, the challenge is not only to detect the failure, but also to repair it in a short time qualitatively in order to stop the damage propagation. For this reason, models with circular and elliptical, as this shape is similar to the peanut shape of delaminations when an impact takes place, shapes were optimized and investigated [4].

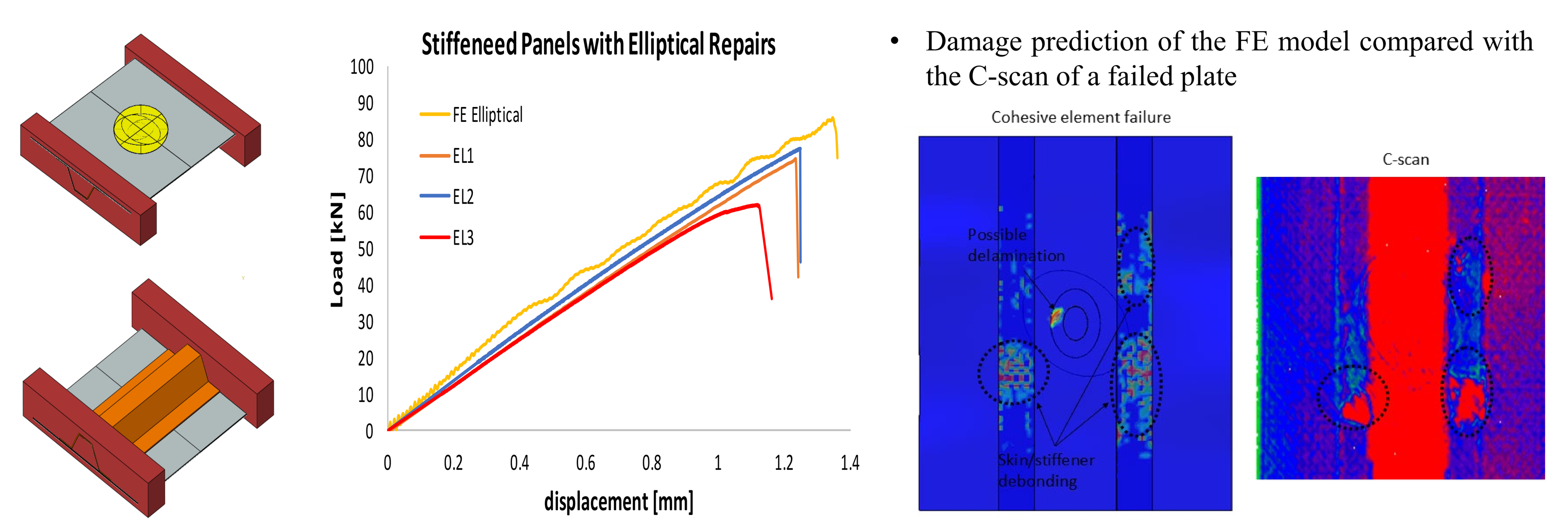
[4] S. Psarras, T. Loutas, M. Papanaoum, O. Triantopoulos and V. Kostopoulos, "Investigating the Effect of Stepped Scarf Repair Ratio in Repaired CFRP Laminates under Compressive Loading", J. Compos. Sci. 4(4), 153; 2020

The FE models were capable to predict the failure load of the panels in compression as well as the way they failed. Also, the comparison of the Acoustic Emission (AE) data Digital Image Correlation (DIC) and the Phase Array (PA) images with the FE models gave a clear insight of the loads and the way the patch debonds during compression. An example is shown in the figure where on the left the Load-Displacement curves of tested repaired stiffened panels are compared with the FE model predictions and on the right the patch debonding is evaluated.



*S. Psarras, T. Loutas, G. Sotiriadis, and V. Kostopoulos, "Evaluating the compressive strength of stepped scarf repaired single stiffener composite panels" Journal of Composite Materials, JCM 1178684, 2023

By using the optimum scarf repair shapes of FE model predictions, stiffened composite panels were repaired and tested and the capabilities of the FE models were evaluated.



In order to optimize further the repair procedure a design methodology was implemented based on four axis :

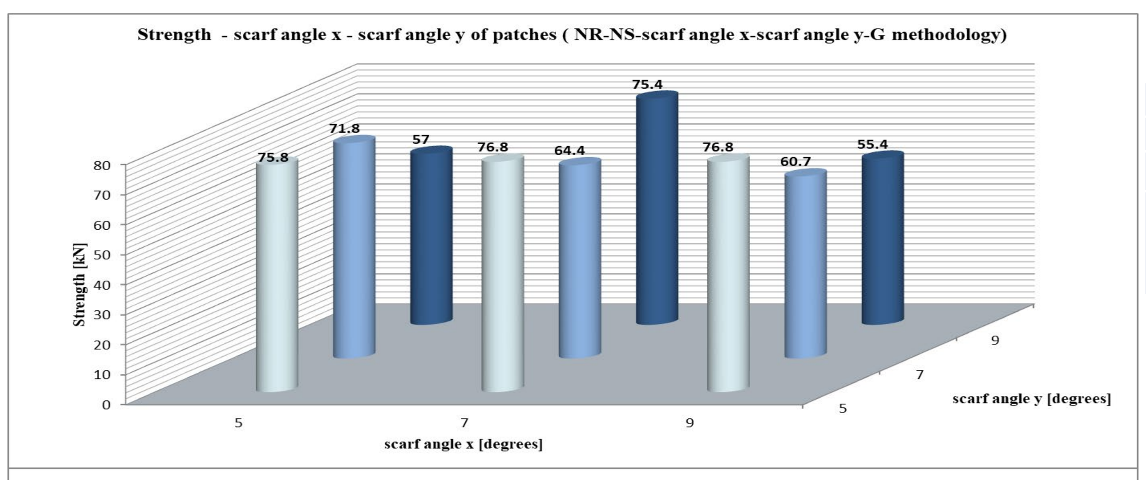
- Orientation of patch's ellipses
- Design load under which the repair must exhibit sufficient strength
- Method of scarf angle calculation
- Method of step calculation

This was achieved by using ABAQUS in combination with Python programming. The target values were:

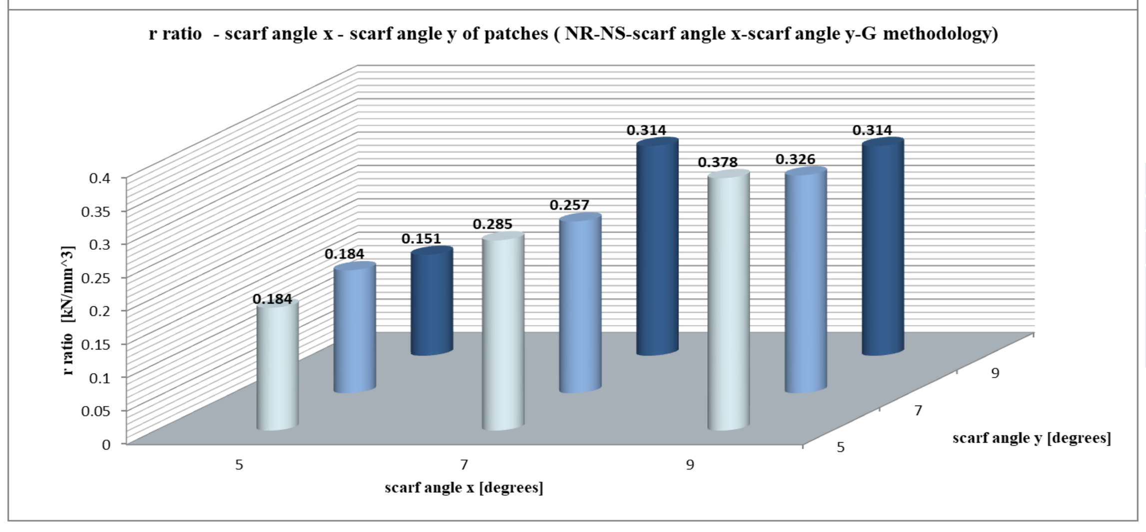
1. F = Maximum strength
2. $r = \frac{maximum\ load}{removed\ material\ volume}$

Compared to a circular patch repair, optimized designs can be generated and the optimum can be selected as can be seen below.

		COMPRESSION						TENSION					
		Loading in 0°		Loading in 45°		Loading in 90°		Loading in 0°		Loading in 45°		Loading in 90°	
		Deviation F_0	Deviation r_0	Deviation F_{45}	Deviation r_{45}	Deviation F_{90}	Deviation r_{90}	Deviation F_0	Deviation r_0	Deviation F_{45}	Deviation r_{45}	Deviation F_{90}	Deviation r_{90}
(I)	NR-XP-NC-AD	10.5 %	893.5 %	-7.4 %	730.1 %	-56.4 %	287 %	-20.3 %	605.9 %	-77.3 %	103.4 %	-65.3 %	207.7 %
(II)	NR-XYP-KT-G	-4.8 %	-1.6 %	-13.3 %	-9.6 %	6.7 %	8.7 %	3.7 %	5.9 %	-12.3 %	-8.6 %	22.7 %	25 %
(III)	NR-XYP-KT-FD	-8.1 %	82.3 %	-14.2 %	69.9 %	4.1 %	104.3 %	-46.1 %	5.9 %	-65.7 %	-32.8 %	6.8 %	107.7 %
(IV)	NR-12L-MS-G	8.9 %	171 %	-6.4 %	131.5 %	12.3 %	175.4 %	-13.7 %	111.8 %	-23.5 %	89.7 %	7 %	161.5 %
(V)	NR-XYP-MS-G	10.5 %	391.9 %	-5.9 %	317.8 %	11.8 %	392.8 %	-50.5 %	117.6 %	-12.7 %	287.9 %	-46.6 %	134.6 %



		STRENGTH DEVIATION		
		scarf angle y [degrees]		
		5	7	9
scarf angle x [degrees]	5	9.2%	10.7%	10.7%
	7	3.5%	-7.2%	-12.5%
	9	-17.9%	8.6%	-20.2%



		R RATIO DEVIATION		
		scarf angle y [degrees]		
		5	7	9
scarf angle x [degrees]	5	196.8%	359.7%	509.7%
	7	196.8%	314.5%	425.8%
	9	143.5%	406.5%	406.5%

The Outcome

The outcome was that the optimized stepped scarf repair increases the strength of the damaged panel with main advantage the decreased material removal during the repair process, which relates to saving time, material and cost in comparison with the conventional repair shapes. Care should be taken to the necessity of parametric analysis before carrying out the repair for the optimal geometry, combining the recovered strength with small volume of removable material. Clearly these models can be used for further repair studies.