Bio-inspired composite adherends: enhancing adhesive joint toughness under high-rate four-point bending

HMalekinejad (INEGI, Portugal) | RJC Carbas | EAS Marques | LFM da Silva

Introduction

Biostructures found in nature exhibit exceptional mechanical properties such as strength, toughness, and damage resistance. Despite attempts to replicate these properties in carbon fiber-reinforced laminate (CFRP) materials, mimicking the intricate structures of natural organisms remains a formidable challenge. This study explores bio-inspired Carbon Fiber Reinforced Plastic (CFRP) laminates as adherends in bonded single lap joints (SLJs), mimicking the helicoidal structure of the mantis shrimp's dactyl club.

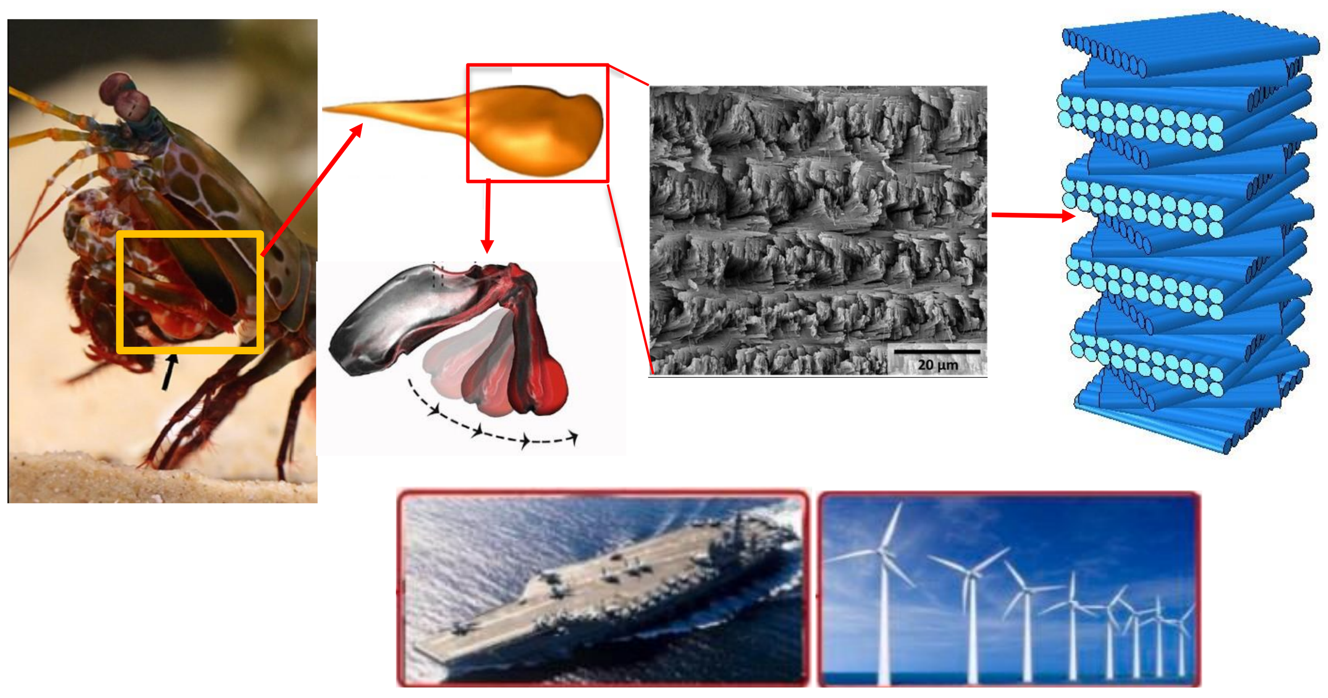


Figure 1 – Bio-inspired stacking sequence and its applications [1].

Experimental details

1. Adherends layup

- UD — Unidirectional (UD) $[0]_{20}$
- H — Helicoidal $[0/20/40/60/80/100/120/140/160/180]_s$
- G — Gradual $[0/5/15/60/90/90/60/15/5/0]_s$

2. Manufactured Single Lap Joints (SLJs)

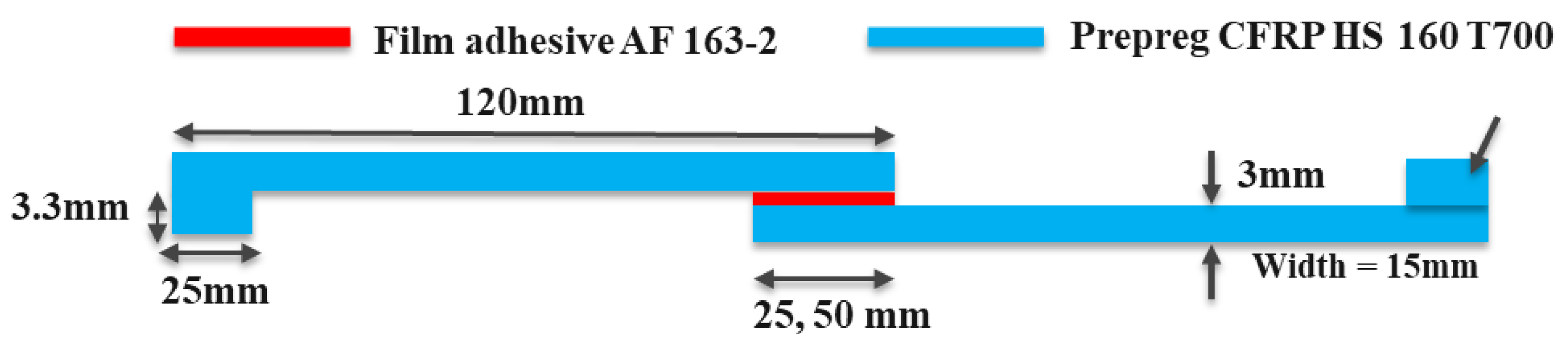


Figure 2 – Schematic of manufactured SLJs.

3. Testing method

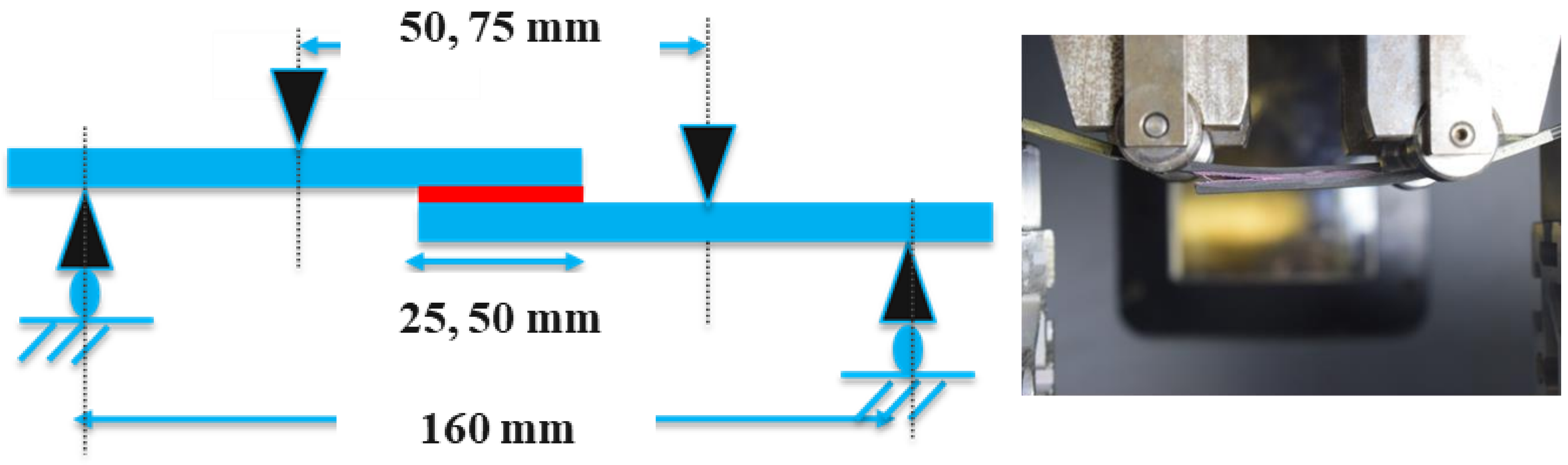


Figure 3 – Four-point bending test set-up.

Results and discussion

Figure 4 illustrates a 20% improvement in toughness for gradual helicoidal adherends compared to unidirectional references, while the maximum load achieved remains similar for both configurations. Additionally, the results highlight the advantages of the gradual helicoidal configuration over the conventional helicoidal design..

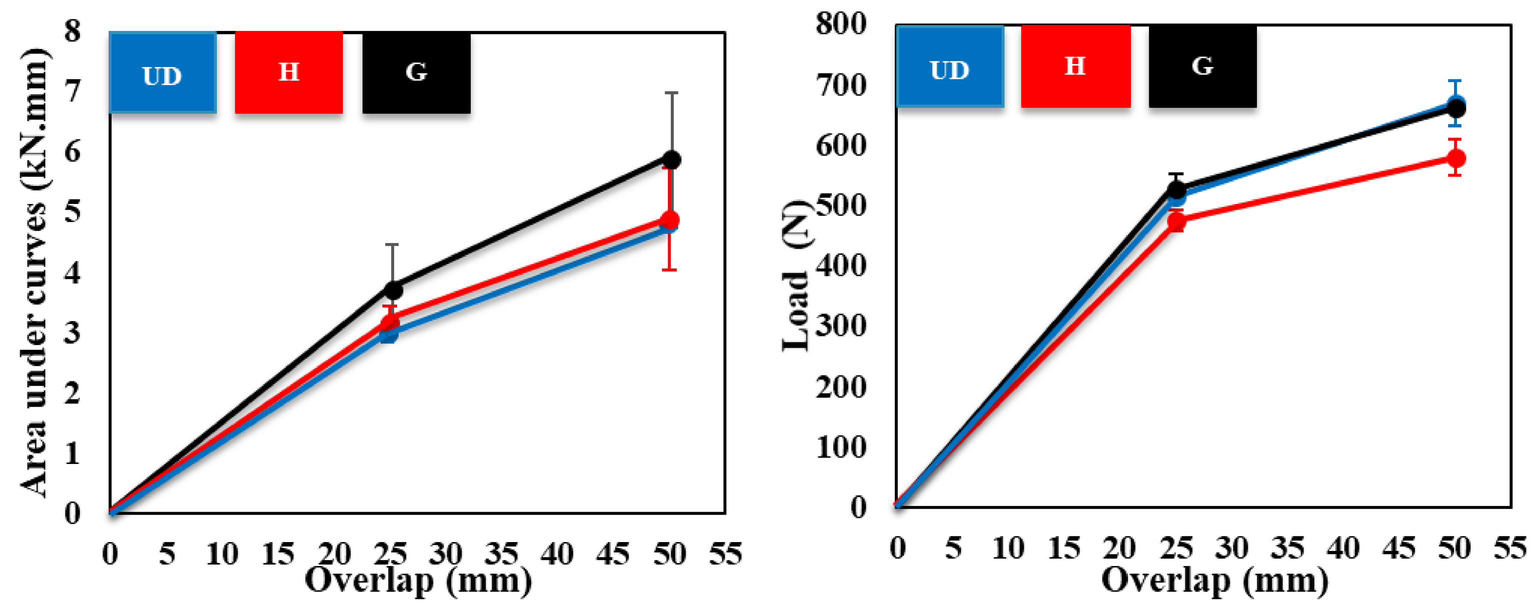
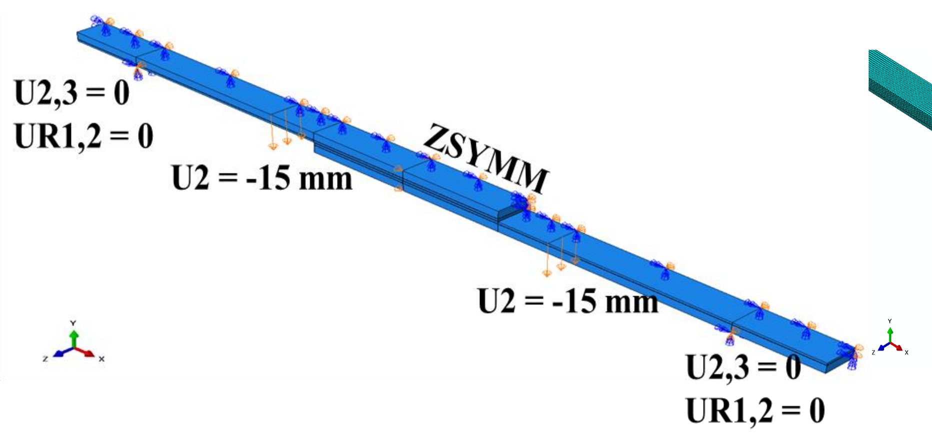


Figure 4 – Bio-inspired stacking sequence and its applications

Numerical details



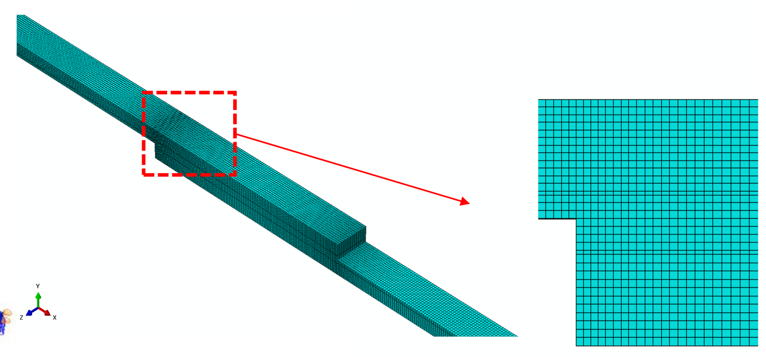


Figure 5 – Conducted 3D model, load and BC **Figure 6 –** Assigned elements.

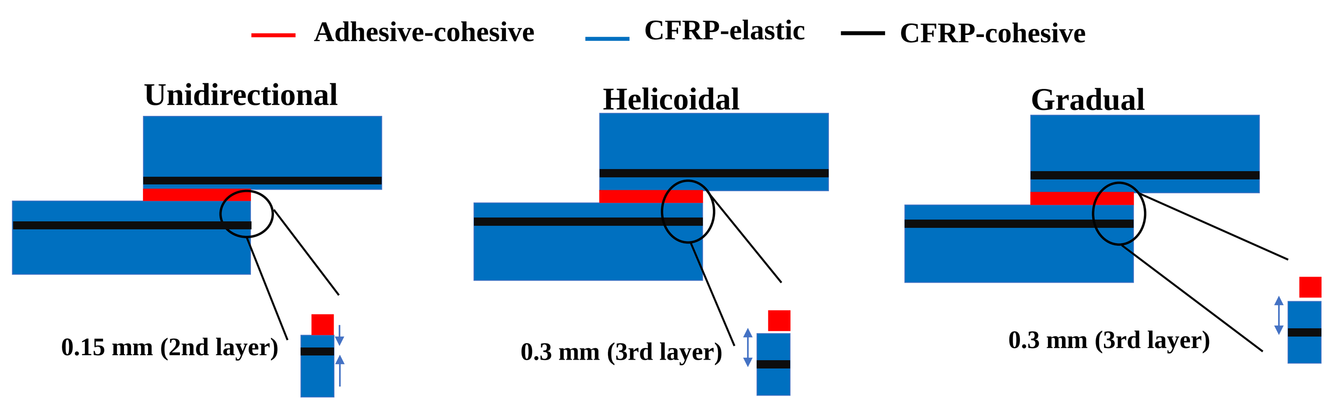


Figure 7 – Placing CFRP-cohesive in different locations.

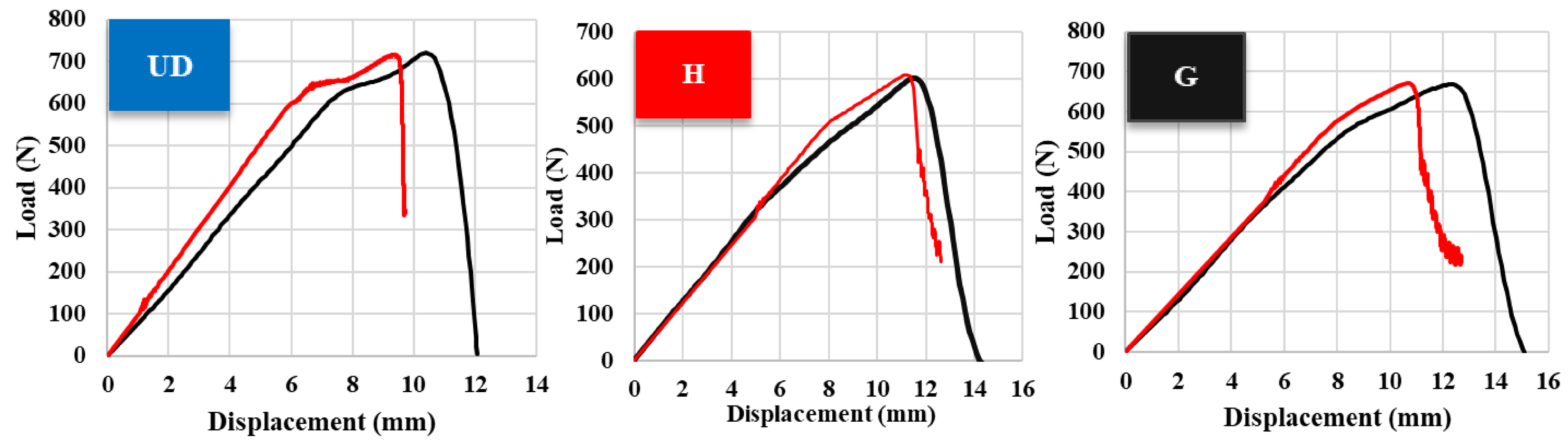


Figure 7 – Obtained experimental (black lines) and numerical (red lines) load-displacement curves.

CONCLUSION

- The proposed numerical Cohesive Zone Model (CZM) accurately captures the behaviour of all tested configurations.
- Gradual configurations improve the toughness of SLJs by approximately 20% compared to the reference unidirectional SLJs, while maintaining similar strength.

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[1] Malekinejad, H.; Carbas, R.J.C.; Akhavan-Safar, A.; Marques, E.A.S.; Ferreira, M.; da Silva, L.F.M. Bio-Inspired Helicoidal Composite Structure Featuring Graded Variable Ply Pitch under Transverse Tensile Loading. J. Compos. Sci.. 2024, 8, 228.

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