Patch Repair of Impact-Damaged CFRP: Effects of Patch Material and Laminate Thickness

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Abstract. Impact damage reduces the compressive strength of carbon fibre-reinforced polymer (CFRP) laminates. Adhesively bonded external patches are a common way to repair this damage without the stress concentrations caused by mechanical fasteners. Most existing studies test single-material carbon or glass patches on one parent laminate thickness. Hybrid carbon/glass patches, and the effect of parent laminate thickness on which patch material works best, have not been studied together before. This work tests carbon, glass, and hybrid carbon/glass patches on two parent laminate thicknesses under compression-after-impact (CAI) loading. The hybrid patch performed well on both thicknesses. Laminate thickness was also found to change the failure mode of the repaired specimen, from compressive fracture in the thick laminate to buckling in the thin laminate, and this changed which patch material gave the best result. Full data and analysis will be presented in a forthcoming journal paper.

Introduction

Barely visible impact damage (BVID) is a well-known threat to the compressive strength of CFRP laminates [1]. To restore load-bearing capacity, adhesively bonded patches are often preferred for repairs over mechanical fasteners, as they avoid introducing new stress concentrations into the composite. Design rules exist for patch sizing and thickness relative to a given parent laminate [2], and studies have compared single-material carbon or glass patches for specific structural cases. Hybrid carbon/glass patches have not been widely tested in this repair context, and it is not clear whether one patch material stays best across different laminate thicknesses. This work tests hybrid carbon/glass patches alongside carbon and glass on two parent laminate thicknesses, keeping fibre architecture, damage severity, and patch design rules consistent, to see how patch material and thickness together affect repair performance.

Materials and Methods

Two quasi-isotropic parent laminates were made with the same [0/45/90/−45] stacking sequence: an 8-ply thin laminate ($[0/45/90/-45]_s$, ~1.5–1.8 mm) and a 16-ply thick laminate ($[0/45/90/-45]_{2s}$, ~3.4–3.7 mm). Impact energies for each thickness were set using quasi-static indentation testing, giving 2.49 J for the thin laminate and 5.32 J for the thick laminate. Ultrasonic C-scan confirmed BVID at these energy levels. Damaged area's material was removed as an 8 mm diameter cutout and repaired with a pre-cured external patch (25 mm diameter, half the parent laminate thickness), following the design rule of Hu and Soutis [2]. Three repairing patch types were tested: carbon, glass, and a hybrid carbon/glass. Repaired and unrepaired specimens were then tested in compression-after-impact (CAI) per ASTM D7137 [3], using an anti-buckling support fixture as given in Fig. 1.

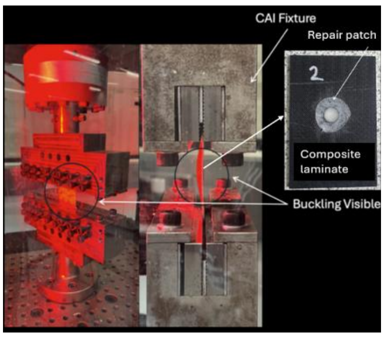

Fig. 1. Experimental setup, and a repaired sample demonstration

Results and Conclusion

The hybrid carbon/glass patch performed consistently well compared with the single-material carbon and glass patches. Specifically, the hybrid patch restored 87% of the undamaged baseline strength in the thick laminates (outperforming both carbon at 82% and glass at 81%) and 110% in the thin laminates (outperforming glass at 95% and performing comparably to carbon at 116%). Parent-laminate thickness influenced the dominant failure mode: thick specimens generally failed by compressive fracture through the damaged and repaired region, whereas thin specimens tended to fail by global panel buckling. As these failure modes load the patch and adhesive differently, the best-performing patch material varied with laminate thickness.

This is the first study to evaluate hybrid carbon/glass patches for the external repair of impact-damaged CFRP laminates. As shown in Fig. 2, the results demonstrate that patch selection should account for the expected failure mode of the parent structure rather than assume that one material will perform best in all cases. The consistently strong performance of the hybrid patch across both laminate thicknesses and failure modes indicates that it could provide a robust repair option.

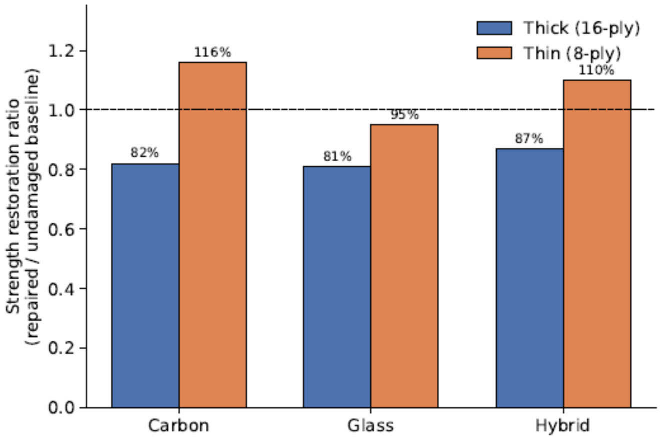

Fig. 2. Strength restoration ratios (repaired mean ÷ undamaged baseline mean) by patch type and laminate thickness. The dashed line indicates full restoration of the baseline strength.

References

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[2] F.Z. Hu and C. Soutis: Composites Science and Technology Vol. 60 (2000), p. 1103-1114.

[3] ASTM International: Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates, ASTM D7137/D7137M-17 (2017).