



TWENTY-THIRD INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS (ICCM23)



DAMAGE TOLERANCE OF DOUBLE- DOUBLE LAMINATES

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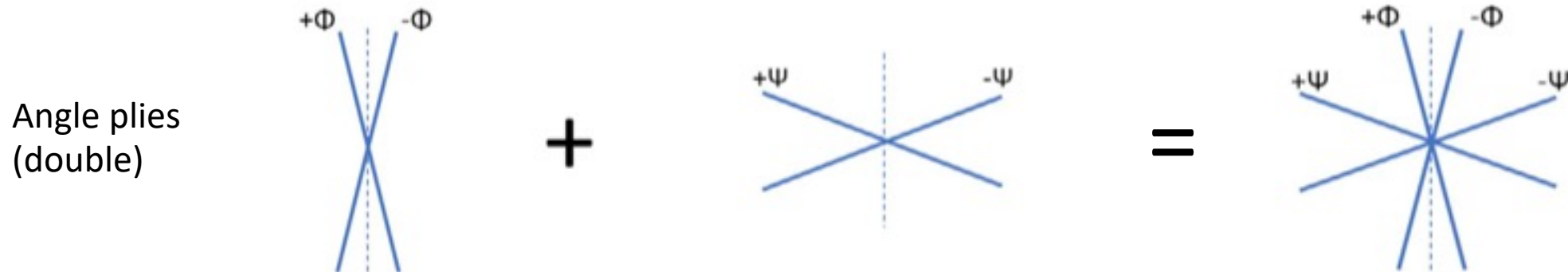
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OUTLINE

- Double-double (DD) vs. Quadriaxial laminates
- Experimental
 - Impact and CAI tests
 - Damage evaluation: CT Scan images after impact and after CAI tests
- Conclusions
 - Purpose is to contribute to the understanding of potential benefits of the double-double concept *w.r.t.* damage resistance and damage tolerance.

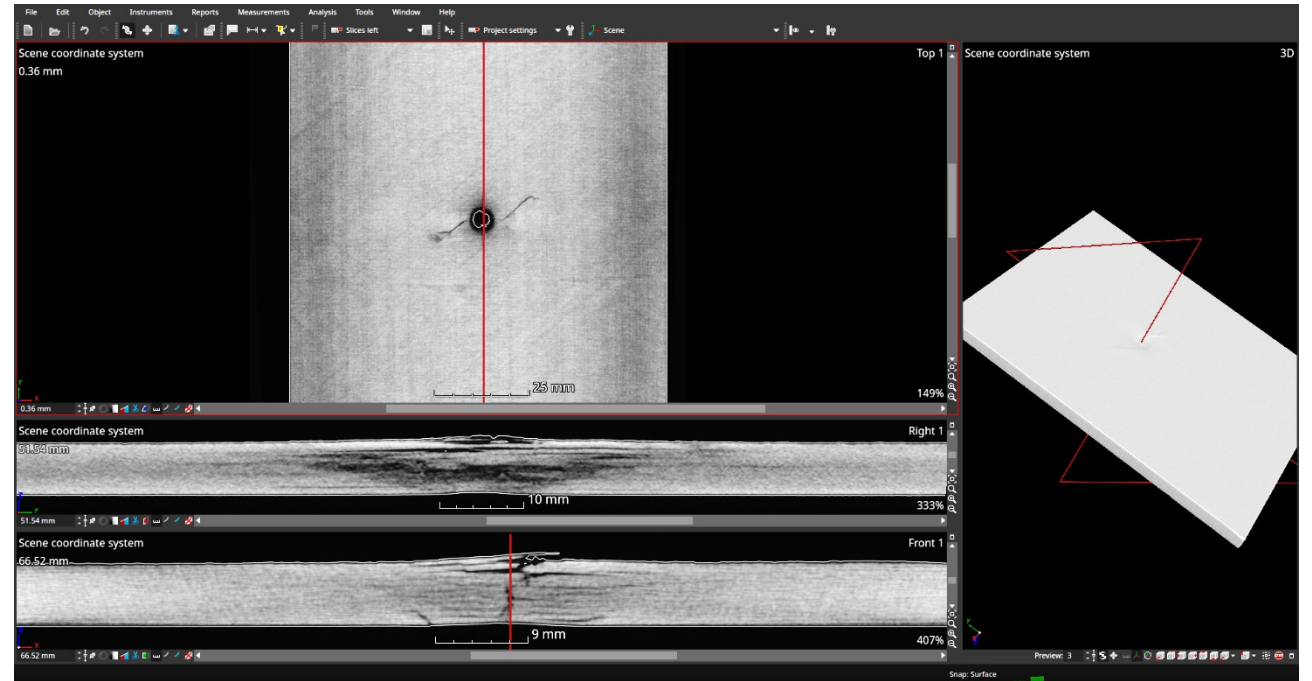
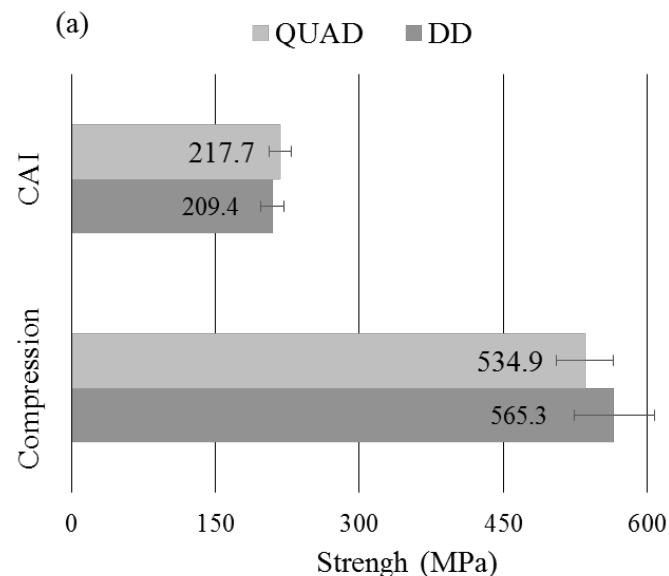
DD vs. QUADRIAXIAL

- Double-double (DD) laminates
 - New configuration strategy for the design of composite laminates
 - Double helix angle laminates $[\pm\phi/\pm\psi]$
 - Simplified stacking sequences
 - Improved manufacturability
 - Design optimization facilitated
 - Facilitates through-the-thickness homogenization using thinner sub-laminates
 - Mid-plane symmetry no longer necessary
 - Profile optimization through thickness tapering becomes possible
- Mechanical properties? Impact? Fatigue?



EXPERIMENTAL

- Material: T700G/G94 UD carbon/epoxy prepreg - Toray Composite Materials America
- Hard conventional laminate: $(0_3/90/\pm 45/0_2/\pm 45)_{2S}$
- Double-double laminate of equivalent in-plane stiffness: $(+50/0/-50/0)_{10}$
- Impact tests (74 J) and CAI
- CT Scan images
 - Damage after impact
 - Damage after CAI tests.



Ref. Cunha et al. Low velocity impact response of non-traditional double-double laminates. Journal of Composite Materials 2023, Vol. 57(10) 1807–1817.

DAMAGE AFTER IMPACT

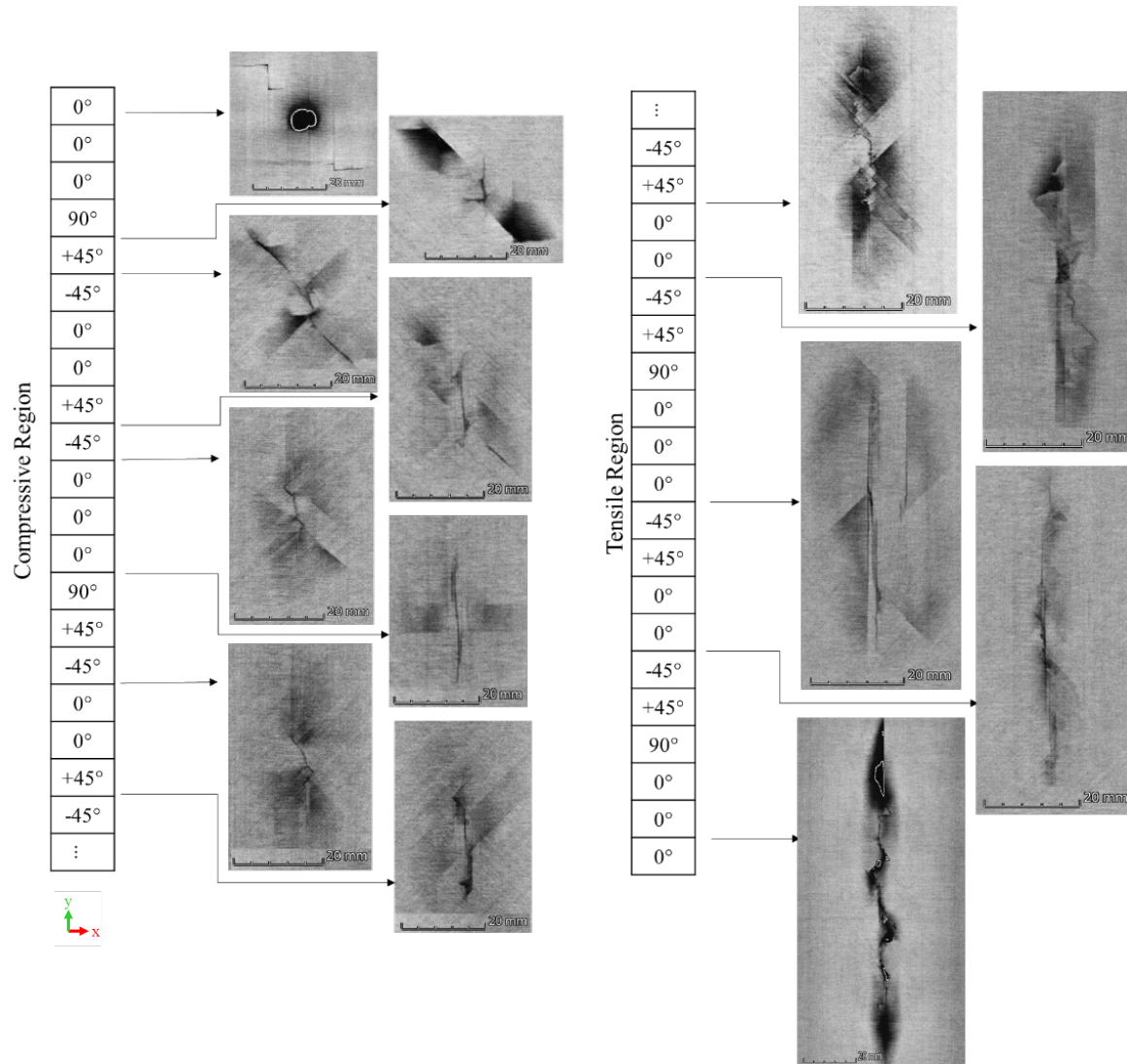


Figure 1: CT Scan images of typical delaminations and cracks in quad laminates after impact.

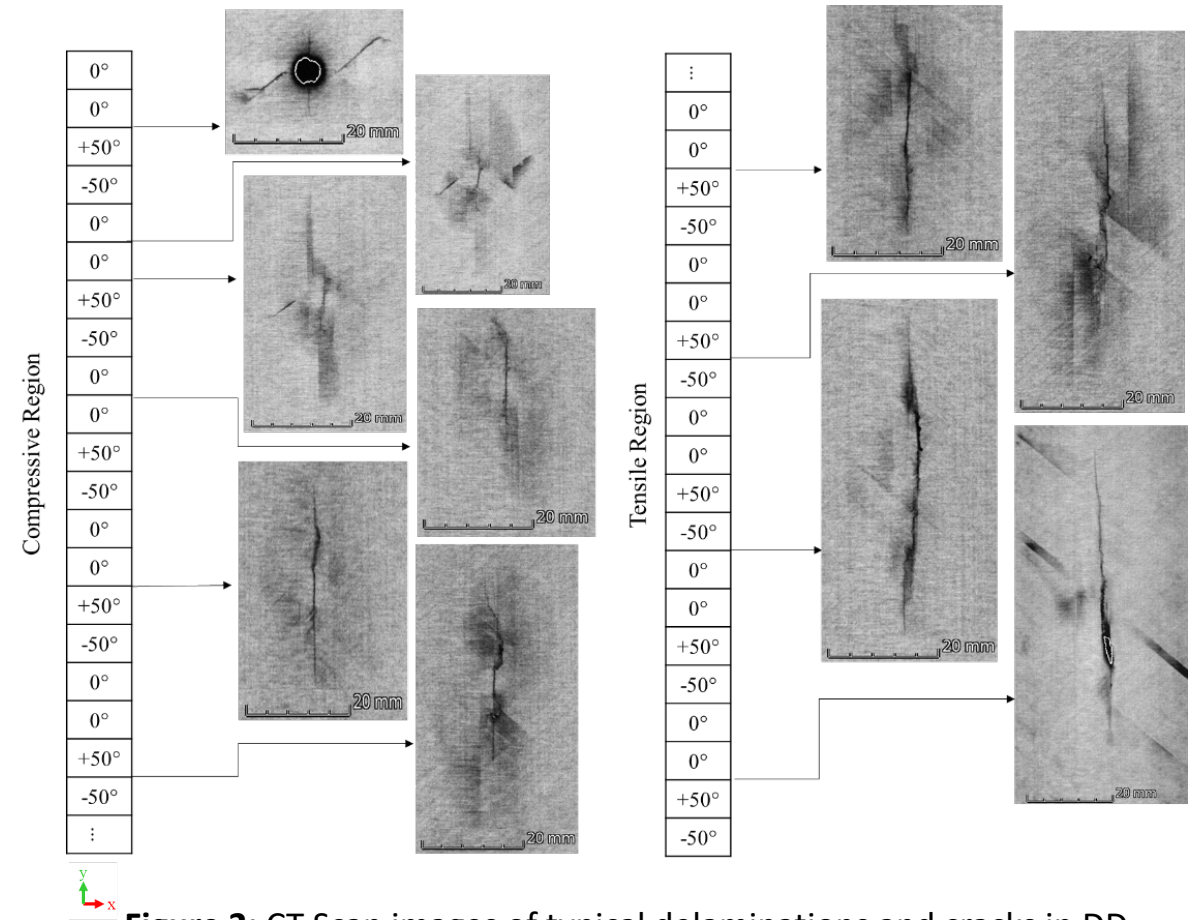


Figure 2: CT Scan images of typical delaminations and cracks in DD laminates after impact.

Ref. Cunha et al. Low velocity impact response of non-traditional double-double laminates. Journal of Composite Materials 2023, Vol. 57(10) 1807–1817.⁵

DAMAGE AFTER CAI

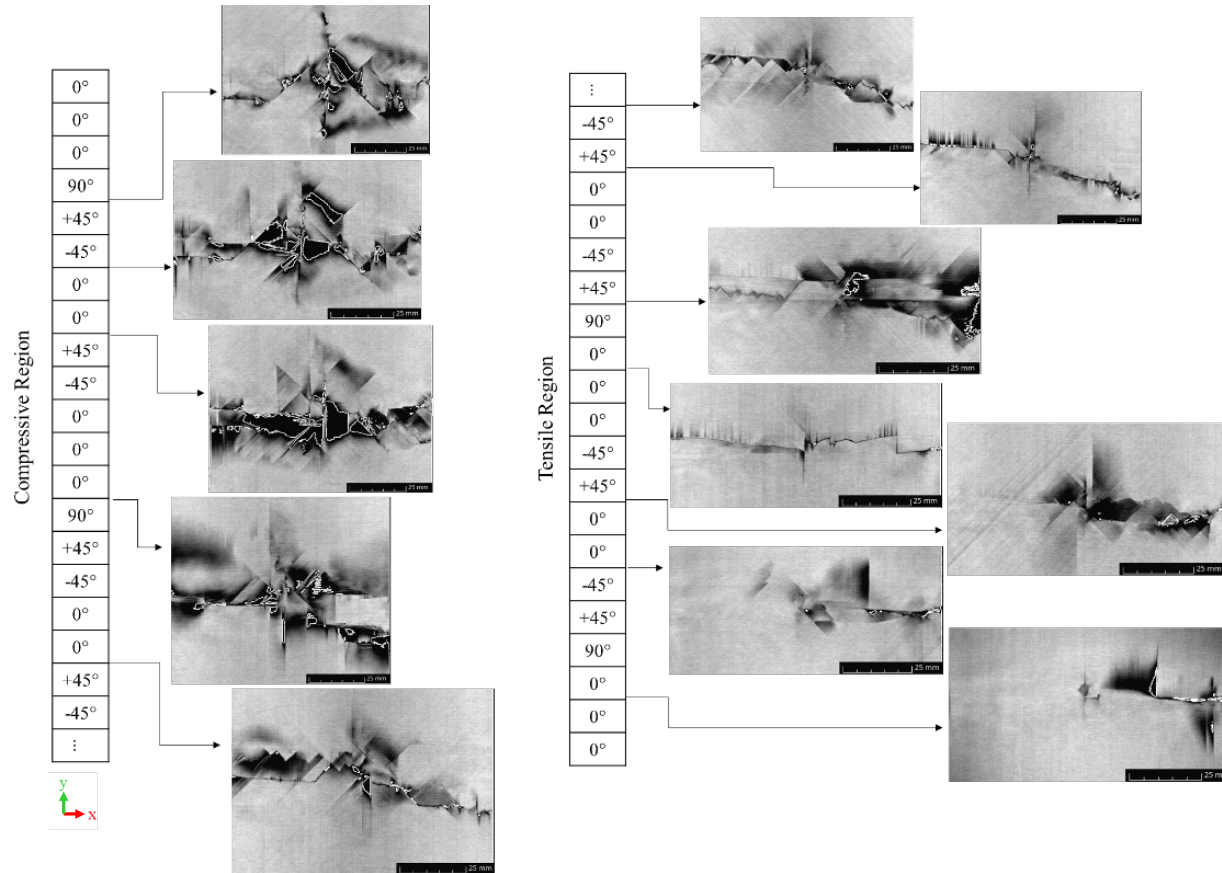


Figure 3: CT Scan images of typical damage of quad laminates after CAI testing.

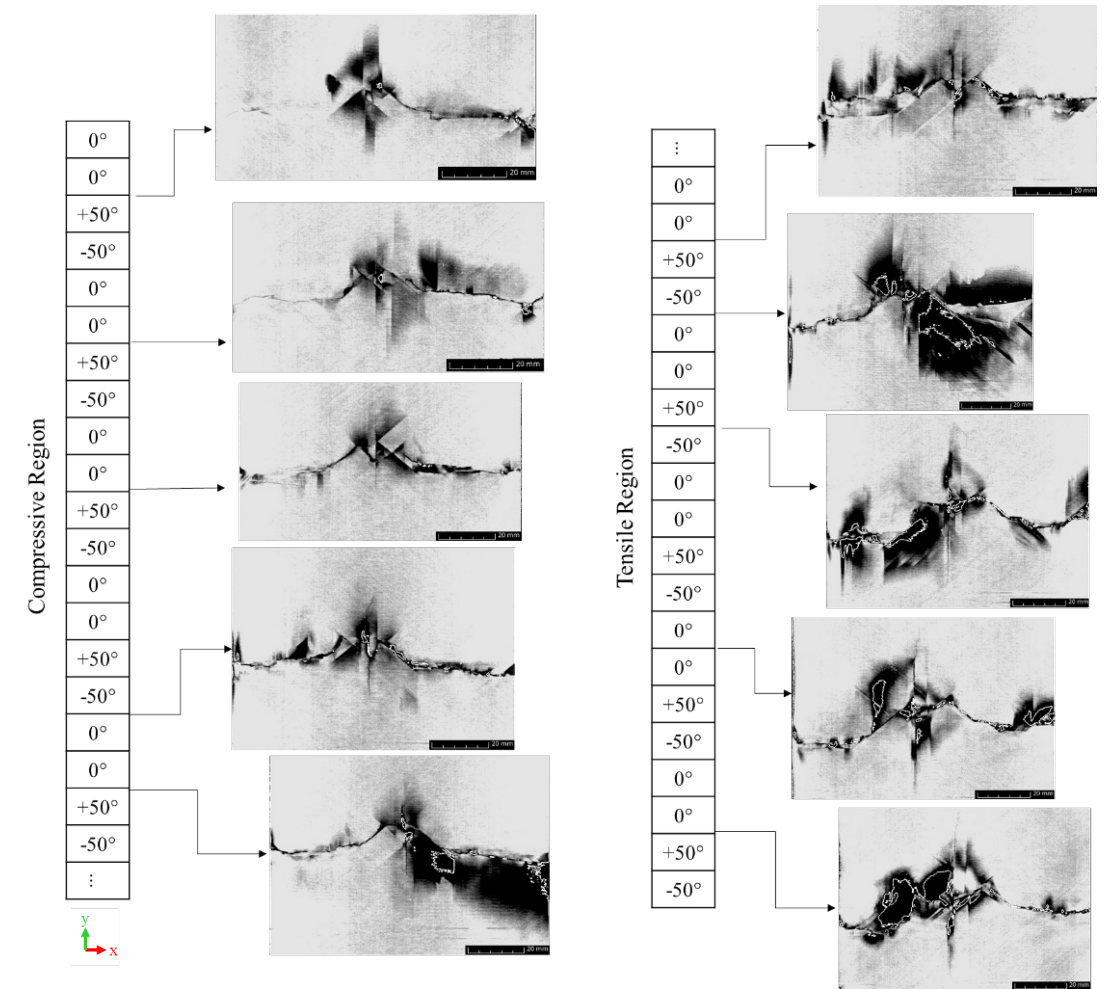


Figure 4: CT Scan images of typical damage of DD laminates after CAI testing.

DELAMINATION

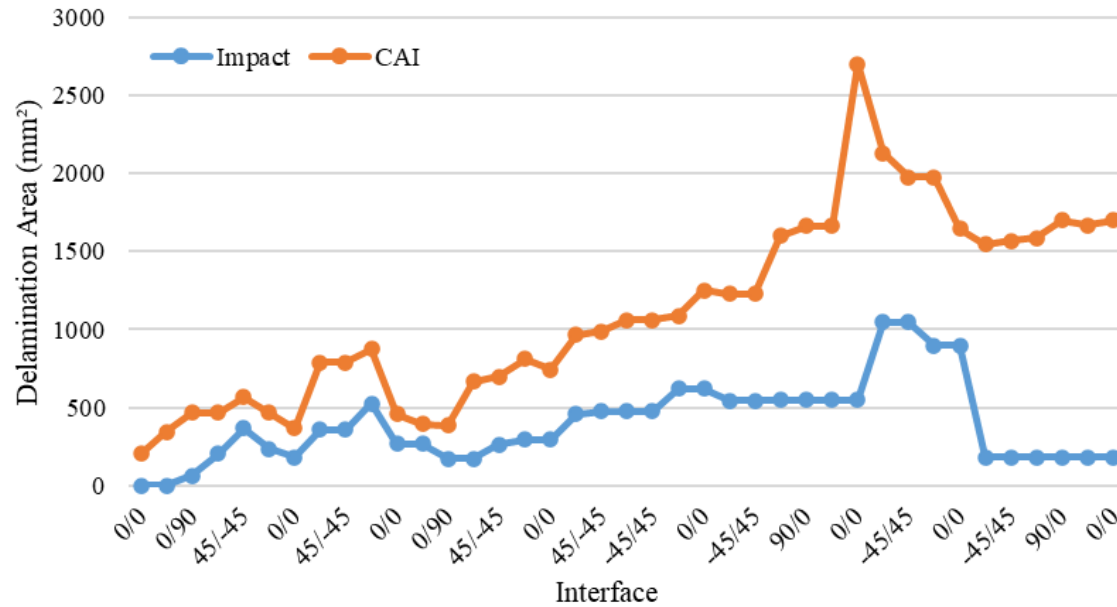


Figure 5: Typical delaminated areas of quad laminate before and after CAI test.

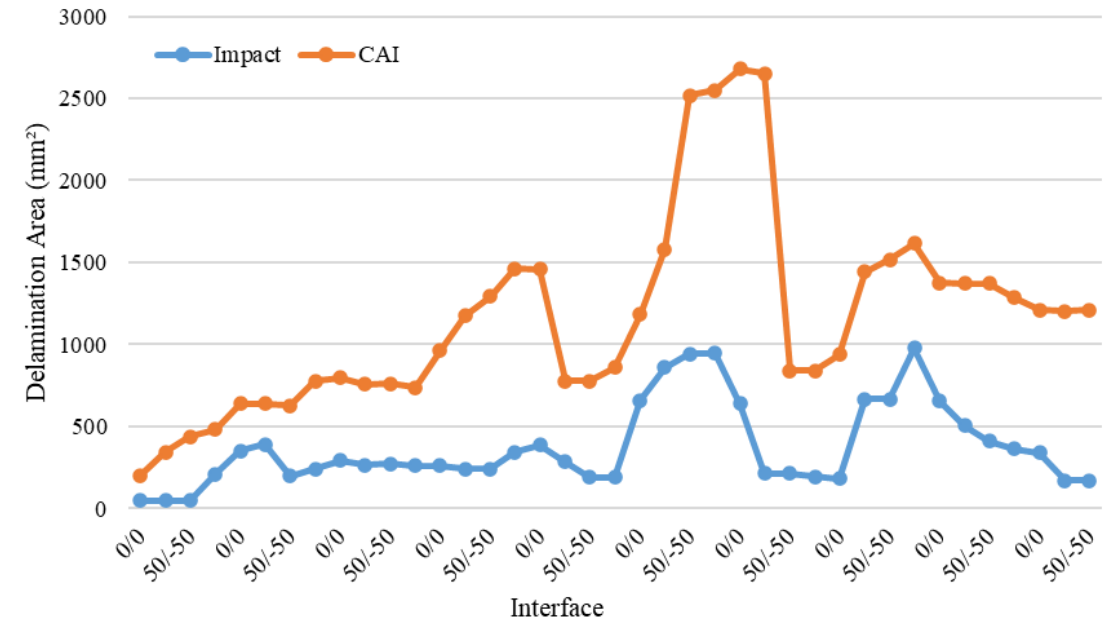


Figure 6: Typical delaminated areas of DD laminate before and after CAI test.

CONCLUSIONS

- Maximum delaminated areas were similar for the DD and the conventional quad laminates, under both conditions: after impact and after CAI tests.
- Double-double composite laminates
 - Design optimization
 - Improved manufacturability
 - Profile optimization
 - Equivalent mechanical properties
 - Great potential as a replacement of legacy laminates
 - Other studies necessary such as fatigue.

Thank you!

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