Influence of bent adherends in single-lap joint performance

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Introduction

Adhesive bonding has emerged as a promising technique in the transportation industry due to its design versatility, vibration damping capabilities, and capacity to join dissimilar materials. Composite materials, such as carbon-fibre-reinforced polymers (CFRPs), are commonly employed for their high strength and stiffness-to-density ratios; however, delamination remains a prevalent failure mode in CFRP single lap joints (SLJ), caused by high peel stresses [1].

The objective of this study is to address delamination issues in CFRP SLJs by introducing curved substrates and non-uniform adhesive layer thicknesses, as illustrated in Figure 1. The desired curvature is achieved through variations in composite layer orientation. By using asymmetric stacking sequences, warpage of the composite is induced by thermal expansion mismatch between the longitudinal and transverse directions during curing. This curvature results in non-uniform adhesive layers with thicker edges, leading to higher compressive thermal stresses, which are intended to mitigate delamination. By combining these geometric and thermal stress factors, the aim is to reduce peel stresses, enhance joint ductility, and ultimately improve the overall performance of the joint.
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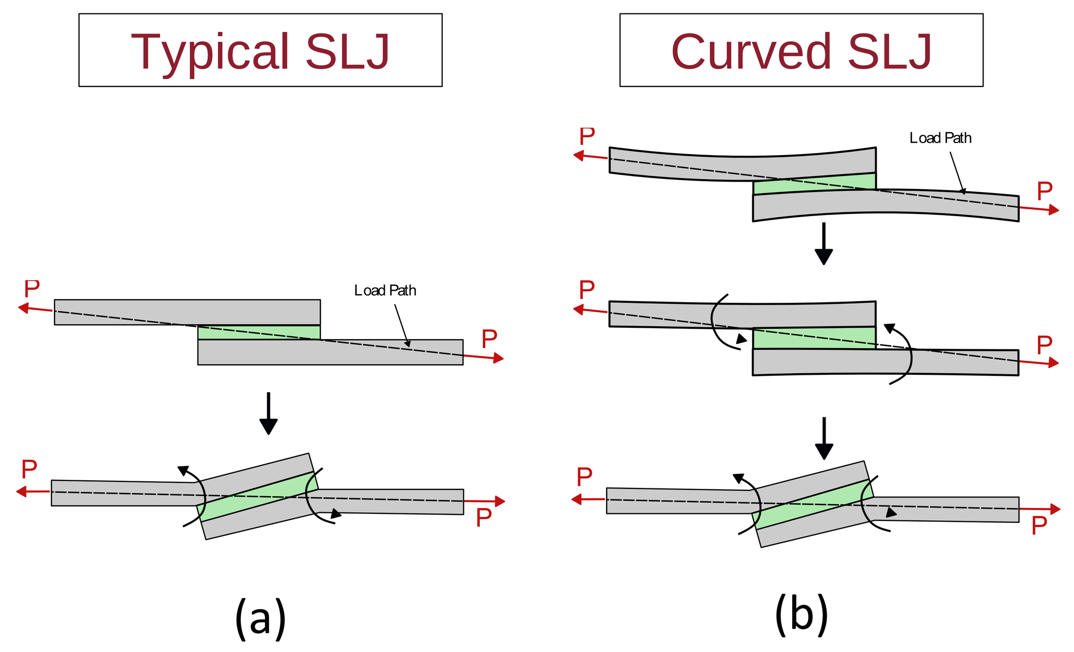

Figure 1 – Behaviour of SLJ under traction, (a) planar SLJ and (b) curved SLJ.

Experimental details

Adhesive
The adhesive utilized in this study was the Scotch Weld AF 163-2k, provided by 3M Company. This material is a film-form modified epoxy known for its high fracture toughness and peel strength [2].

Adherend
In all of the tested configurations, the unidirectional prepreg CFRP material used was Texipreg HS 160 T700, a commercially available product.

Joint Geometry
Figure 2 illustrates the geometry of the specimens and the material distribution in the adherends that were utilized for the tests. The geometry parameters adopted were : L_T = 215 mm, L_0 = 25 mm, t_s = 3.20 mm, $t_{a,min}$ = 0.2 mm, $t_{a,max}$ = 1.0 mm and h = 1.4 mm.

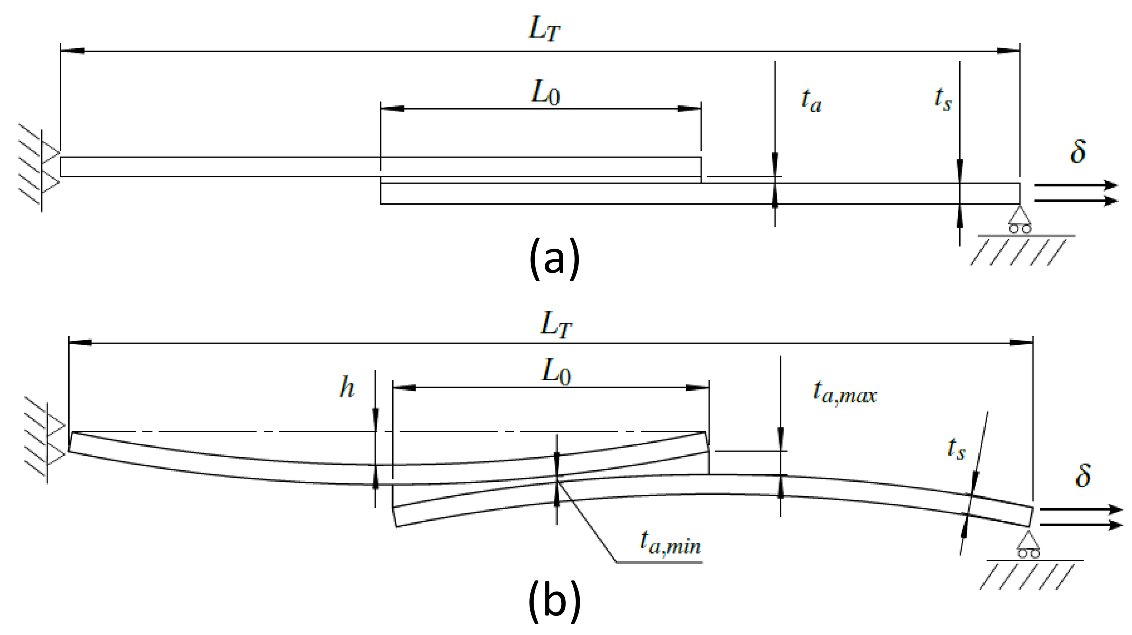

Figure 2 – SLJ specimen geometry, (a) planar SLJ and (b) curved SLJ.

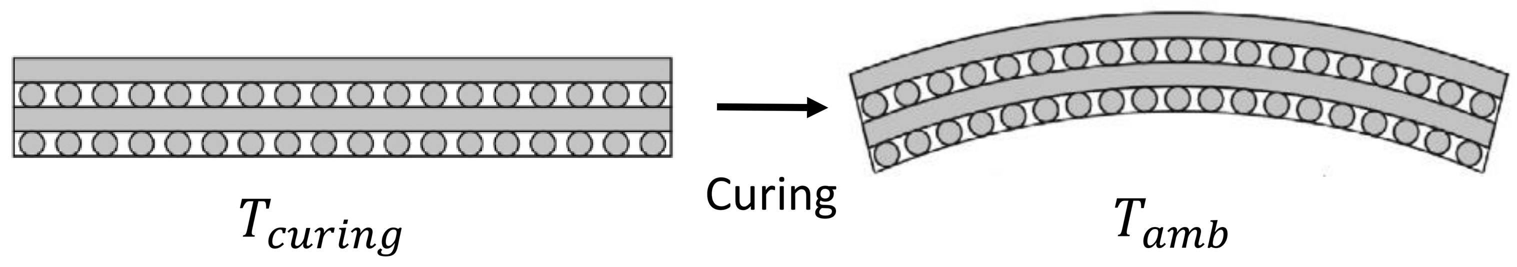

Figure 3 – Warpage deformation caused by orthotropic coefficient of thermal expansion of a composite plate [0º/90º/0º/90º], adapted from [3].

Experimental results

The joints were tested under quasi static conditions, to analyse their failure load and failure mode. The results of the failure modes can be seen in Figure 3, where delamination was obtained for the conventional CFRP SLJ, while cohesive failure was obtained for the other two configurations.

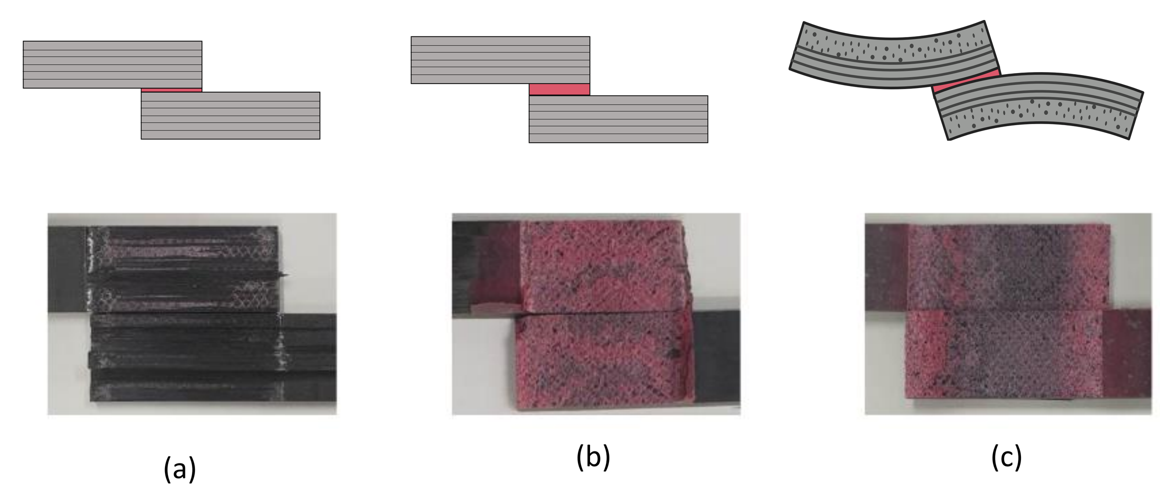

Figure 4 – Failure modes obtained for all configurations, a) planar SLJ with t_a=0.2mm, b) planar SLJ with t_a= 1 mm and c) curved SLJ.

When comparing the $P-\delta$ curves, it is evident that the curved SLJ exhibits a failure load that is comparable to the reference 0.2 mm configuration, while significantly surpassing the 1.0 mm configuration in terms of failure load.

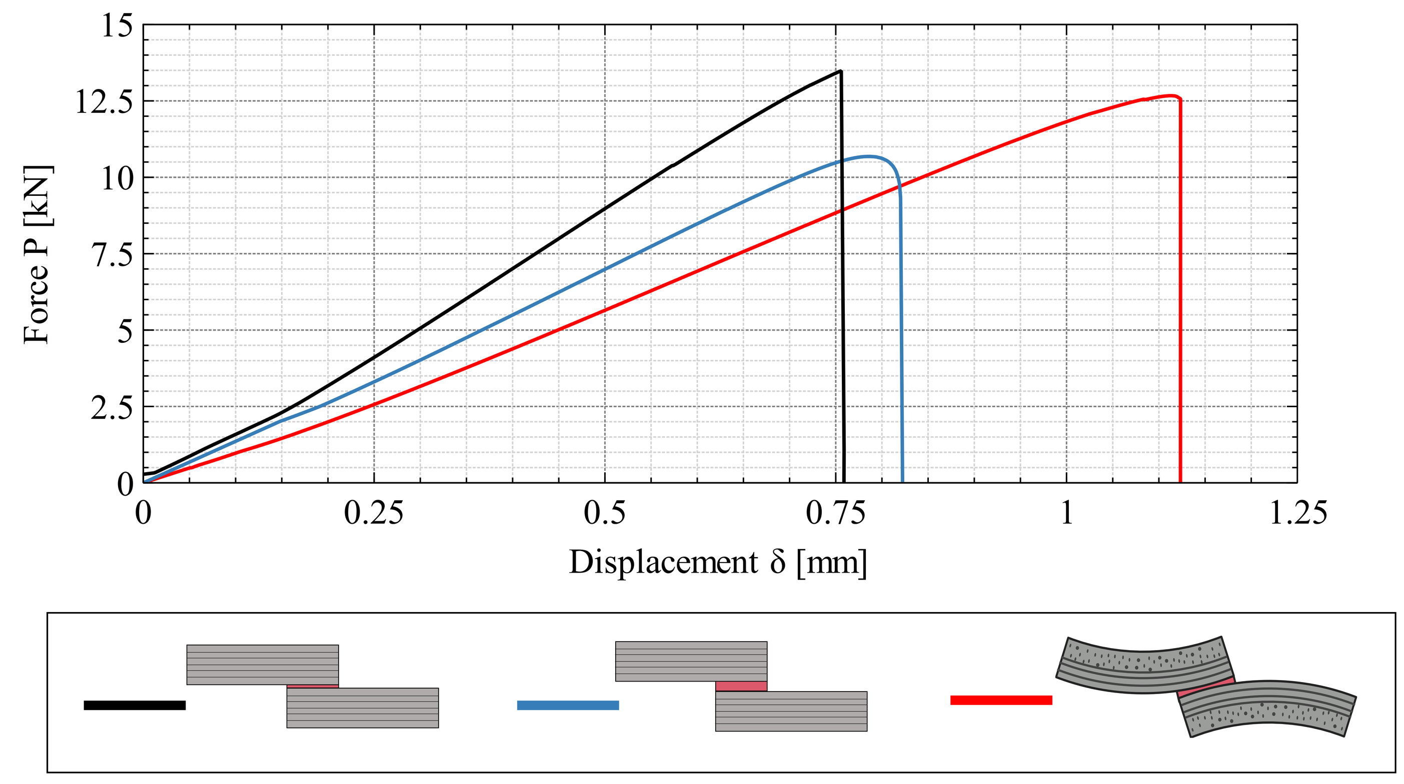

Figure 5 – $P-\delta$ curves obtained experimentally for the three configurations.

Conclusions

- The cohesive failure mode observed in the curved joint can be attributed to the combined effect of compressive residual thermal stresses generated during the curing process and the curved geometry of the joint.
- This configuration effectively reduced the tensile peel stresses that typically lead to delamination, resulting in a prevention of delamination and an improved failure mode. Additionally, it is noteworthy that the failure load of the curved joint remained comparable to that of the conventional CFRP SLJ, indicating an overall improvement in performance.
- Another important finding is that increasing the adhesive thickness in planar SLJs led to a transition from delamination to a cohesive failure mode. However, this transition came at the cost of a significant decrease in the failure load. On average, a reduction of 22.1% in the failure load was observed for these thicker adhesive configurations.

References

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