Study of thermal stresses on a joint for aerospace applications

B.D. Simões (INEGI,Porto), R.J.C. Carbas, P.D.P. Nunes, F. Razemani, E.A.S. Marques (UPorto, Portugal), L.F.M. da Silva

ADVANCED JOINING PROCESSES UNIT

Abstract

The use of composites have become progressively more popular in aerospace applications due to their unique characteristics, allowing the development of lightweight and high performance structures [1]. Fibre metal laminates (FMLs) are hybrid composites, used to reduce delamination in adhesive joints, and which possess the advantages of metallic materials, like damage resistance, as well the good strength to weight conferred by the composite part [2].

The presence of residual stresses in fibre metal laminates (FML) materials can significantly affect material performance, especially when integrated in bonded joints. These stresses, often generated during the cure process, can cause cracking and distortion of the material, and are caused by differences in the coefficients of thermal expansion or cure shrinkage. The present work investigates the influence of these stresses in the performance of single-lap joints with CFRP/Aluminium adherends.

Experimental details

Adhesive

The adhesive used in the study was the Scotch Weld AF 163-2k supplied by 3M Company. This material is a modified epoxy in a film form with high fracture toughness and peel strength [1].

Adherend

For all the configurations used in the tests the unidirectional prepreg CFRP, commercially named Texipreg HS 160 T700, was used. For the FML an aluminium alloy of the series 2024-T3 Alclad was used, supplied by AMI Metals.

Joint geometry

The specimens' geometry, as well as the material distribution in the adherends, that were used to perform the tests can be observed in Figure 1.

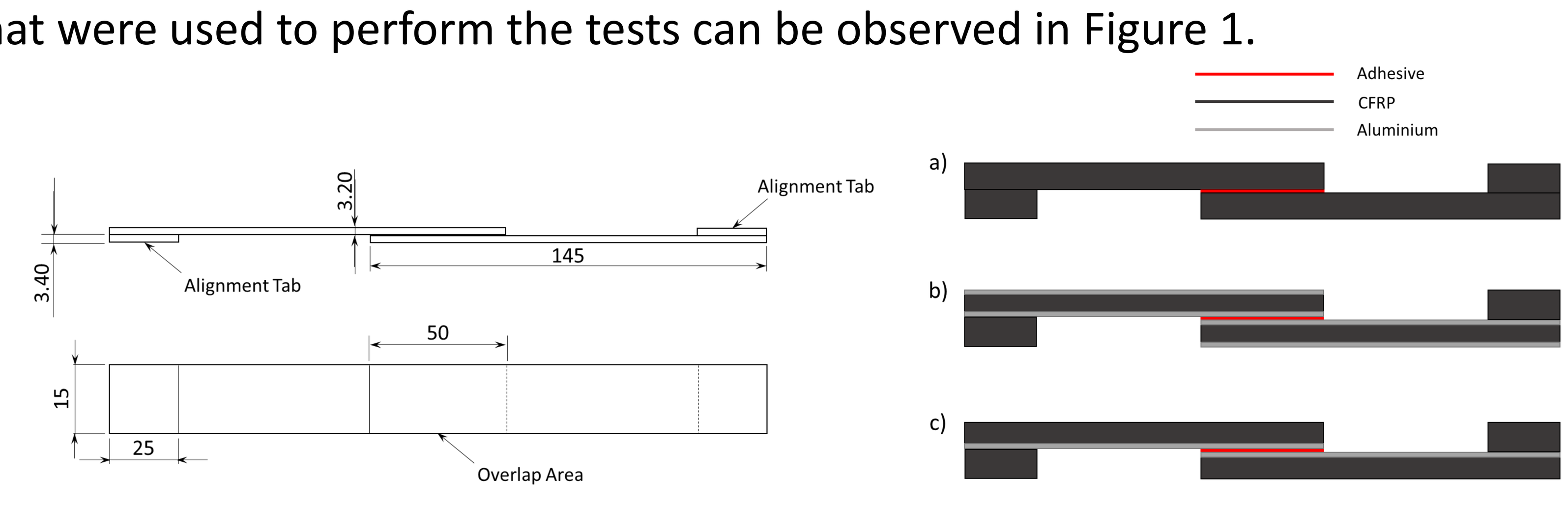

Figure 1 – Specimens' geometry, in mm (left) and SLJ different configurations (right).

Results

Deflection after curing

The deflection after curing exhibited by the CFRP-Al specimens can be depicted in Figure 2. The DIC results measured in the experimental joints and the numerical values presented a good agreement, showing a considerable deformation of the joint.

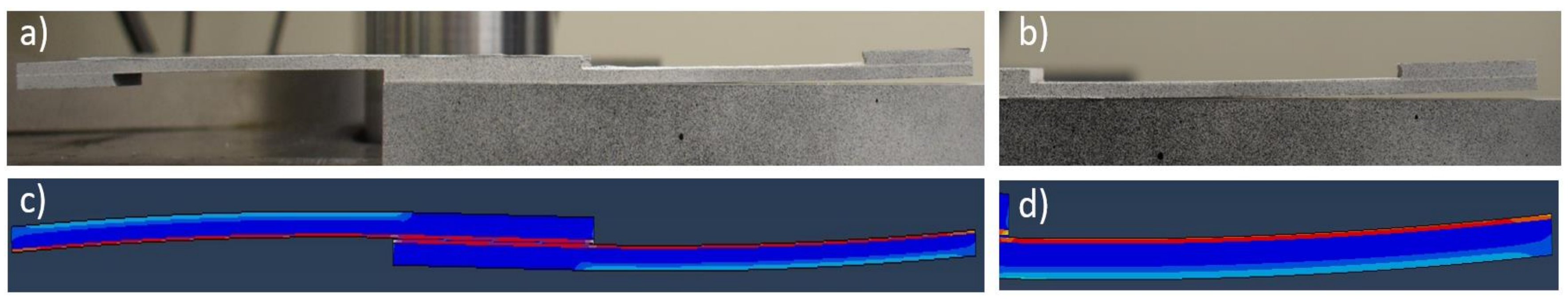

Figure 2 – CFRP-Al deflection after curing: experimental (top) versus numerical (bottom).

Elastic modelling

The stresses that the joints experienced during the experimental tests were simulated, resorting to an elastic model. Therefore, it was possible to compare the stress states at various joints and monitor the evolution of peel and shear stresses along the adhesive layer. The maximum peel and shear stresses reached in the edge of the overlap in the adhesive layer can be observed in Figure 3. For the displacement predicted for the CFRP failure, where failure occurs via delamination, this CFRP-Al joint presents the same value for peel stress, although it does not present joint failure. Since the edges of the overlap are under a compressive state after curing, loading this joint up to this displacement develops less peel stress in this zone, which increases the load-bearing capability of the joint.

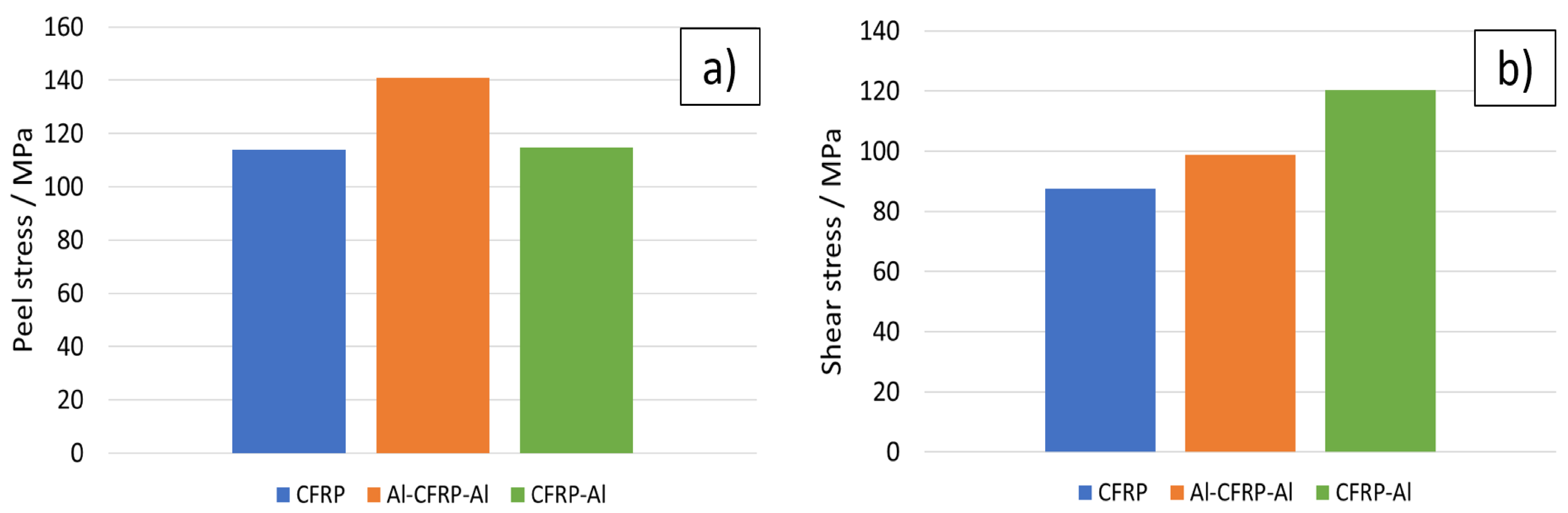

Figure 3 – Maximum stress in the edge of the overlap: peel (a) and shear (b).

SLJ performance

Load-displacement curves

The joints were tested under quasi-static conditions, to analyse their failure load and critical displacement. Additionally, a cohesive zone model (CZM) model was developed to predict the adhesive behaviour. The comparison between experimental and numerical results is presented in Figure 4, where a good correlation

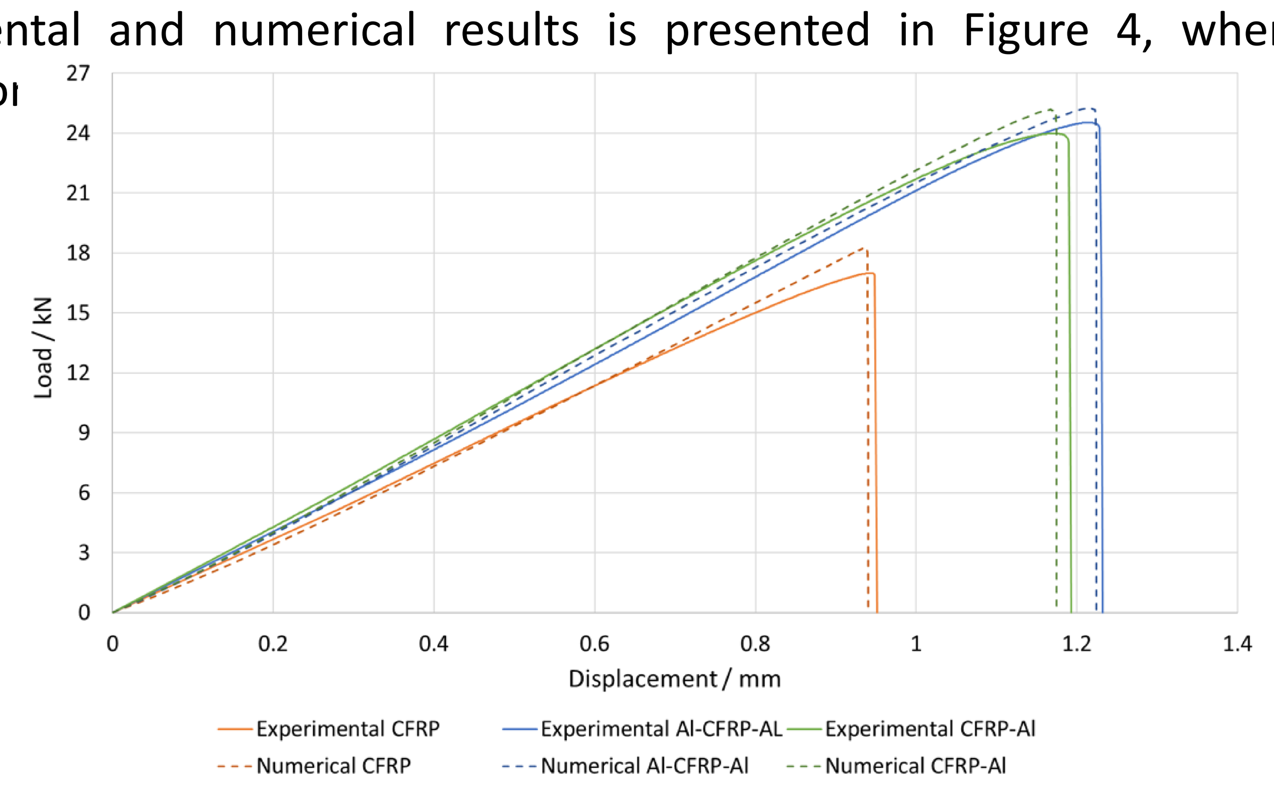

Figure 4 – Experimental versus numerical representative load-displacement curves of the different tested geometries.

Failure modes

The experimental failure modes proved that the use of FML adherends prevents delamination, which was validated by the failure modes of the simulated joints. The comparison between the them can be observed in Figure 5.

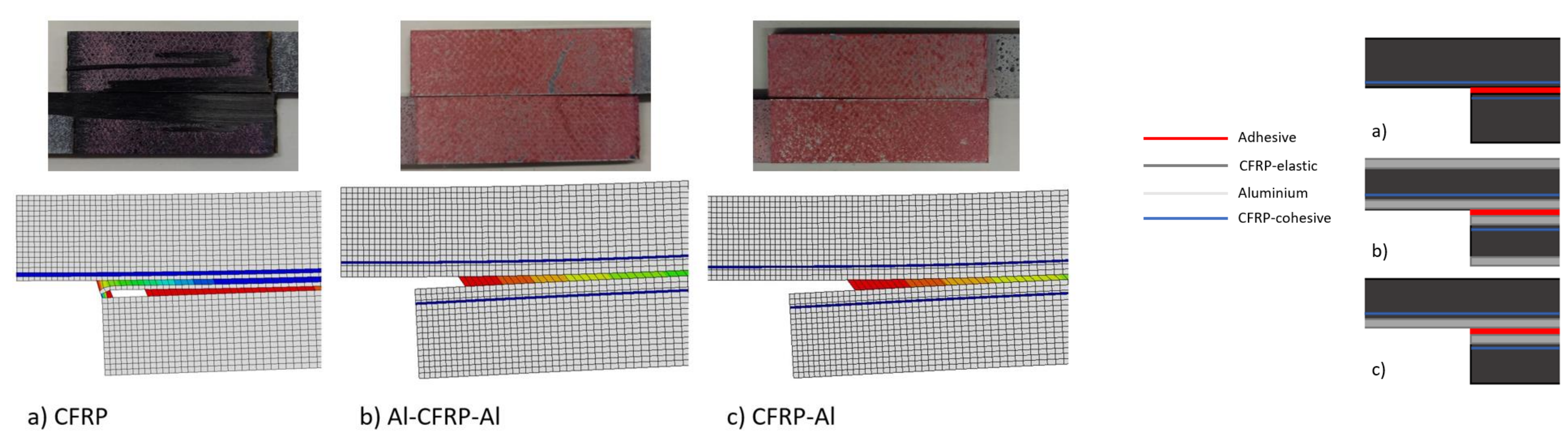

Figure 5 – Experimental and numerical failure mode of the different geometries (left) and section assignment of the CZM model (right).

DIC strain analysis

The prediction of the strain level in the moments prior to the crack propagation were found accurate when compared with strain fields using 2D DIC analysis. This comparison proved to be very useful to understand how deformations develop in the critical zone. This comparison can be observed in Figure 6.

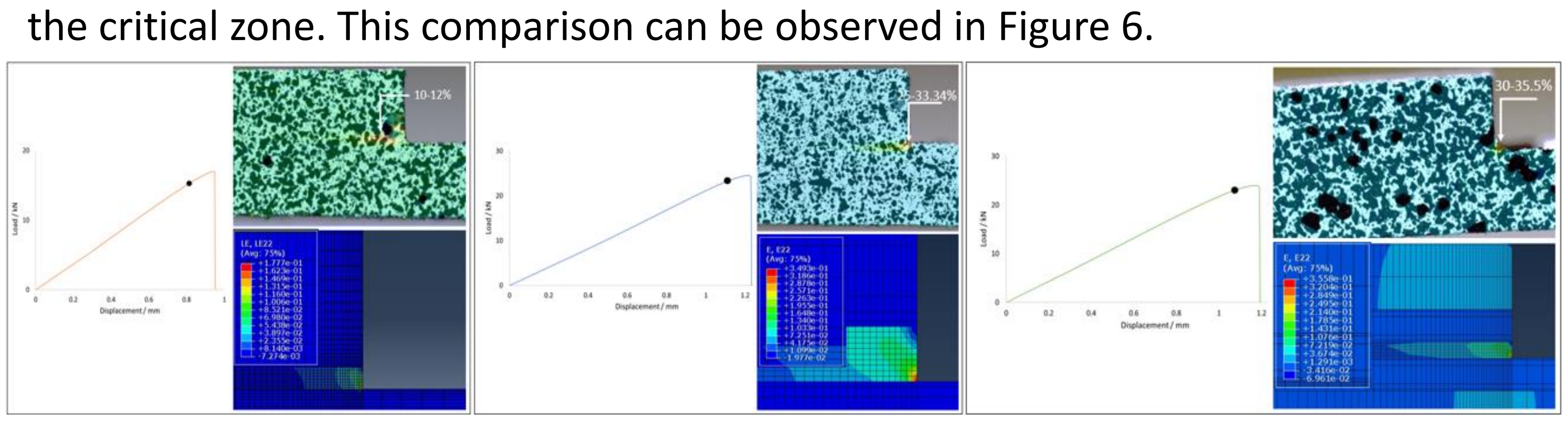

Figure 6 – Strain field in CFRP (left), Al-CFRP-Al (middle) and CFRP-Al (right) joint: DIC (top) vs numerical (bottom).

Conclusions

The results from the curing-induced deflection represent a large deviation from its initial geometry. However, the controlled use of these deformations, adapted to each application, may prove to be advantageous. The values obtained for joint strength showed smoother stress distribution in the joints with aluminium layers, where it was possible to avoid delamination, increasing the joint strength in more than 35%. The numerical models presented a good correlation with the experimental results, where, for all the simulations the failure load was close to the experimental values. Additionally, the failure modes were correctly reproduced.

Acknowledgements

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References

[1] Shang X, Marques EAS, Machado JJM, Carbas RJC, Jiang D, da Silva LFM. Review on techniques to improve the strength of adhesive joints with composite adherends. Composites, Part B. 2019;177:107363..

[2] Cai D, Wen Y, Qiu J, et al. Mechanical property and structure of polycarbonate /aluminum alloy hybrid prepared by ultrasound-assisted hot-pressing technology. J Adhes. 2022:1-24.

[3] 3M-Company. 3M Scotch-Weld™ Structural Adhesive Film AF 163-2. In. Technical Datasheet, 2009.