The joint strength of SLJs reinforced with hybrid composite adherends

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Introduction

The use of Carbon Fibre Reinforced Polymers (CFRP) in industry has increased in the last years, with relevant interest for industries that operate in technological cutting-edge sectors such as the aeronautical industry. CFRP allows to develop more efficient structures in terms of energy consumption and emissions. However, the main problem associated with the composite use is the onset of delamination, which conducts to a reduction of joint strength. In order to avoid or retard this problem the use of hybrid laminates is the key [1]. Hybrid laminates consist of CFRP reinforced with other type of laminates (such as metal or polymers). This approach combines the best properties of CFRP and the material used as reinforcement, increasing the joint strength in the through thickness direction, minimise peel stresses and limiting delamination [2]. The objective of this work was to evaluate the performance of hybrid joints, bonded with different laminate reinforcements (metal and polymers) by comparing them against a reference joint using a conventional CFRP adherend. The joints were experimentally tested at different strain rate (quasi-static and intermediate rate). Numerical models were developed, using the ABAQUS software to study the behaviour of all joints studied. The numerical predictions of failure loads and modes were compared to the experimentally obtained results.

Experimental details

Materials:

• Adhesive: AF 163-2.K (3M), modified epoxy structural adhesive, knit supported;

• CFRP: unidirectional 0º carbon-epoxy composite, HS 160 T700. Manufactured using manual lay-up method;

• Aluminium : 2024-T3 Alclad, with copper being the main alloying metal.

Cure process:

• 130 °C during 60 minutes.

FML configuration:

• Thickness of the adherends: 3.2 mm;

• Ratio in volume: 25% of Aluminium/Adhesive and 75% of CFRP.

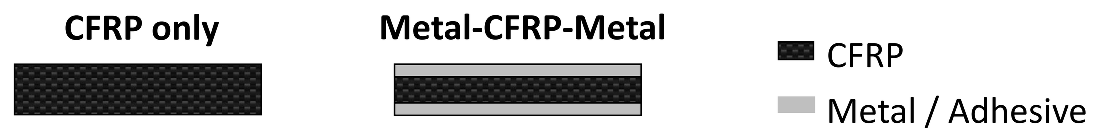

Figure 1 – Lay-up configurations

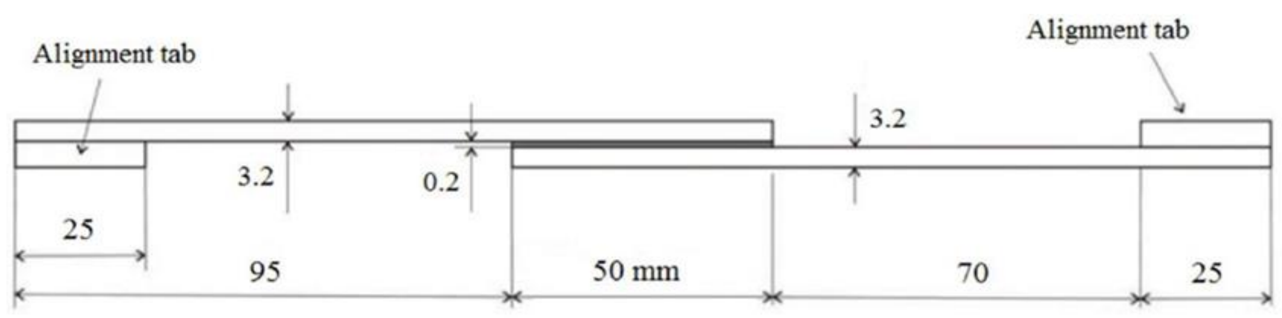

Figure 2 – SLJs geometry

Numerical details

- 2D analysis in ABAQUS® software;
- Solid elements were used for elastic sections (CPE4R);
- Cohesive elements with traction separation laws (COH2D4) [3].

Figure 3 – Numerical model – boundary conditions

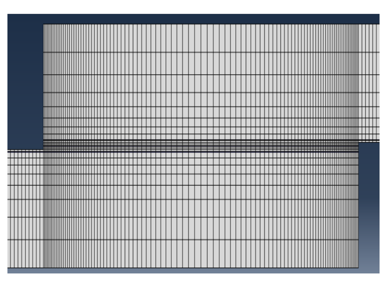

Figure 4 – SLJ mesh refinement

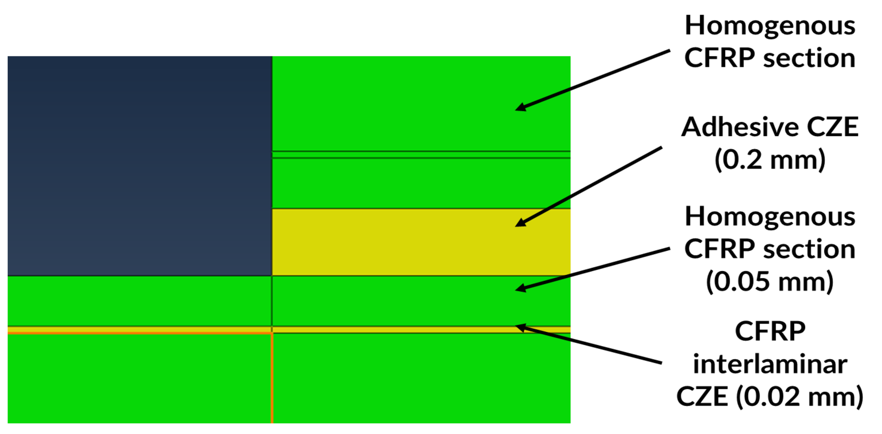

Figure 5 – The peel stress vs density as a function of Young's modulus.

Results

The SLJs were tested in a servo-hydraulic MTS model 8810 test machine with a capacity of 100 kN, at room temperature and constant displacement rate of 1 mm/min for quasi-static and 0.1 m/s for intermediate rate.

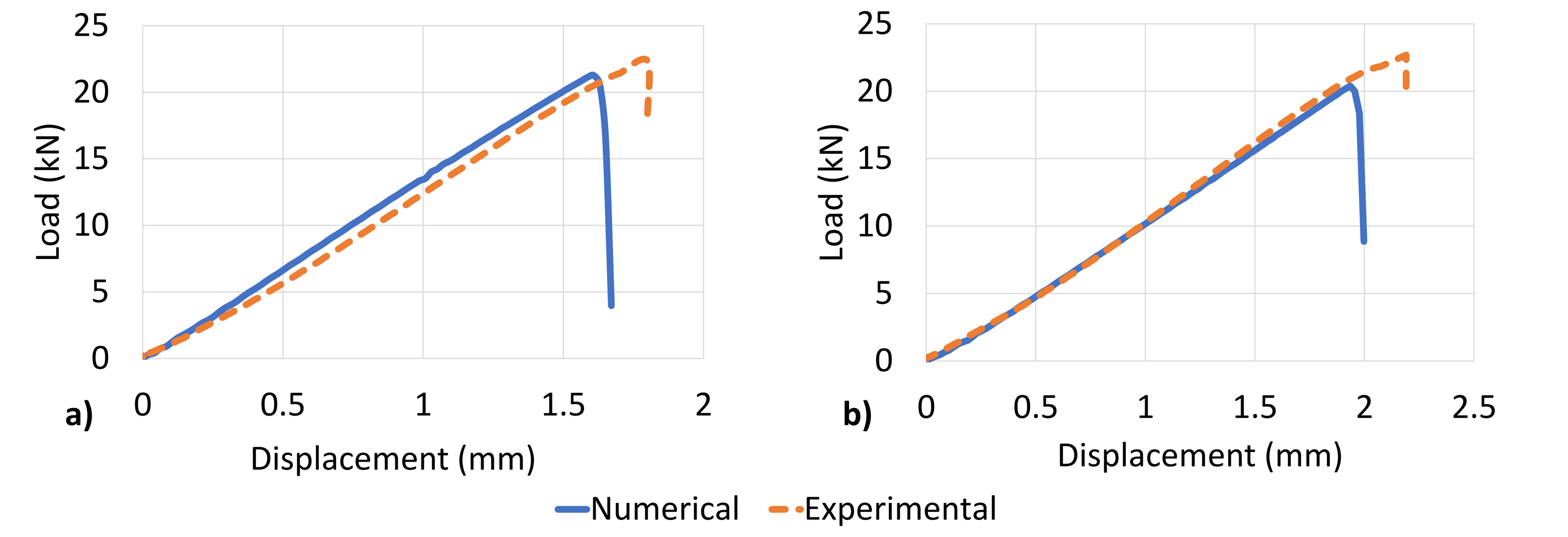

Figure 6 – Numerical and experimental load displacement curves
a) CFRP+25%Al and b) CFRP+25%af under intermediate rate loading

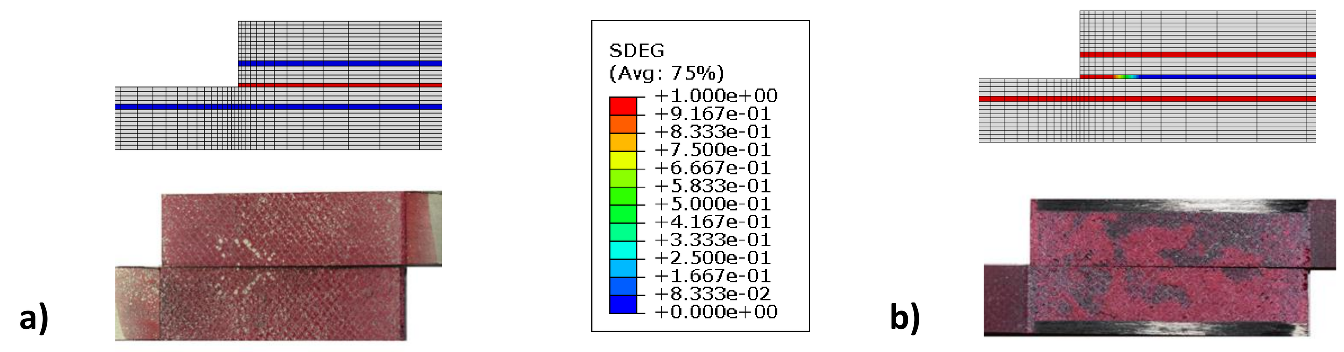

Figure 7 – Failure mechanism obtained numerically and experimentally
a) CFRP+25%Al and b) CFRP+25%af under intermediate loading

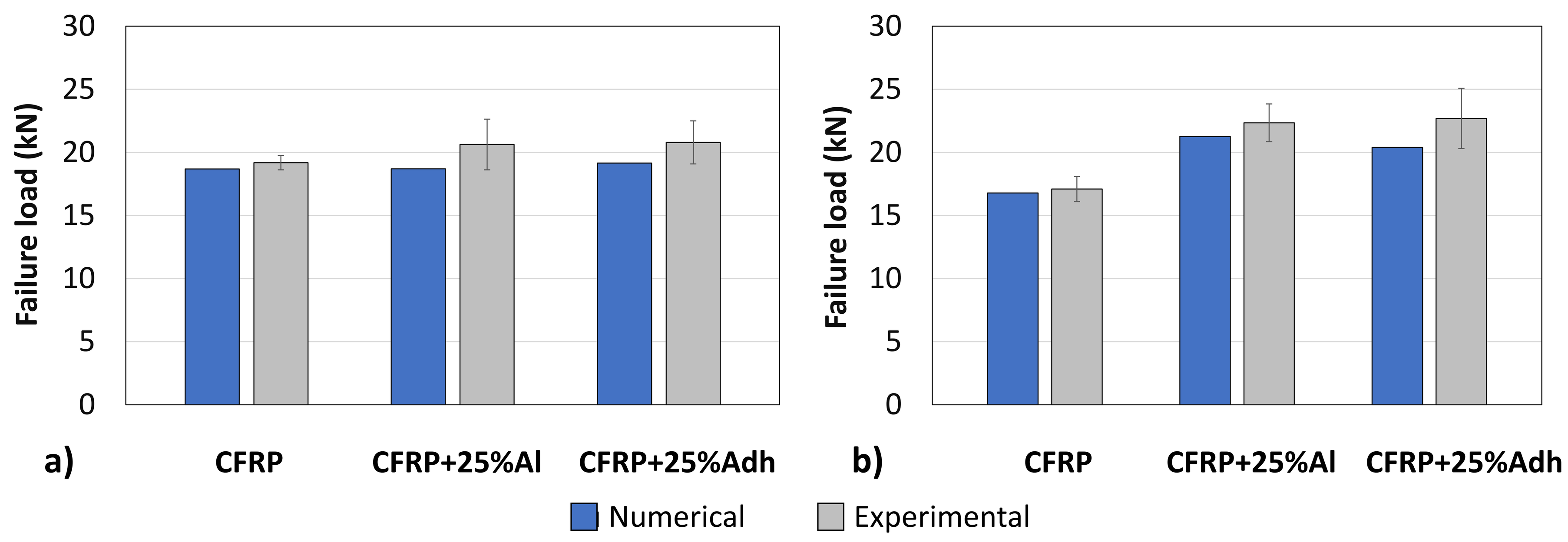

Figure 8 – Experimental and numerical failure lode under
a) quasi-static (1 mm/min) and b) intermediate rate loading (0.1 m/s)

Conclusions

- The first method used aluminium metal laminates in the outer surfaces of the adherend as a reinforcement. This configuration successfully eliminated delamination and increased the failure load, especially under intermediate loading rates;
- The second technique used layers of adhesive on the outer surfaces of the adherends, did not fully avoid delamination but still exhibited greatly improved performance when compared to the reference CFRP SLJs, for both intermediate rate and static loading rates;
- In terms of the simulation of the tensile testing of the joints, the numerical results were acceptably coherent with the experimental results. Regarding the failure mode obtained numerically for the configurations under study, the results were, in every case, coherent with the experimental results.

References

[1] L.F.M. da Silva, A. Öchsner, and R.D. Adams. Handbook of Adhesion Technology, (Springer-Verlag, Berlin, 2011)

[2] M.A. Morgado, R.J.C. Carbas, E.A.S. Marques, L.F.M. da Silva, (2019) Reinforcement of CFRP single lap joints using metal laminates, Composite Structures, 230, 111492,

[3] L.F.M. da Silva, and R.D.S.G. Campilho, Advances in Numerical Modelling of Adhesive Joints, (Springer-Verlag, Berlin, 2012)

Acknowledgements

The authors gratefully acknowledge the Portuguese Foundation for Science and Technology (FCT) for supporting the work presented here, through the individual grant's CEECIND/02752/2018 and CEECIND/03276/2018.