The use of tough layers in composite adherends to improve joint strength and performance

R.J.C. Carbas (INEGI, Porto, Portugal), F. Ramezani, E.A.S. Marques, L.F.M. da Silva

Advanced Joining Processes Unit

Introduction

The use of adhesive joints with composite adherends in high-performance structures has increased significantly, being now widely applied in the automotive and aerospace industry. Adhesive joining methods offer improved stress distributions and the capability of joining dissimilar materials. Composite materials show very good properties through the fibers (in-plane) but do have a significantly lower strength in the through the thickness (out-of-plane) direction [1]. Thus, the use of adhesive bonding in composite adhesive joints can lead to delamination failure, driven by this lower through the thickness strength of the composite adherends. In the literature, several techniques to improve the peel strength of composite materials can be found, such as increasing material strength and/or preventing the delamination. Z-pinning, 3D weaving, and stitching are all known to be effective methods but significantly increase the production costs [2].

In this work, composite adherends were reinforced with toughened laminates during the manufacturing process to increase the peel strength. Different toughened composite configurations were studied, searching from improvements in the strength of composite adhesive joints and preventing or reducing the delamination. The results were compared with the non-toughened composites. Numerical models were used to understand the failure mechanisms obtained experimentally.

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;

Cure process:

• 130 °C during 60 minutes.

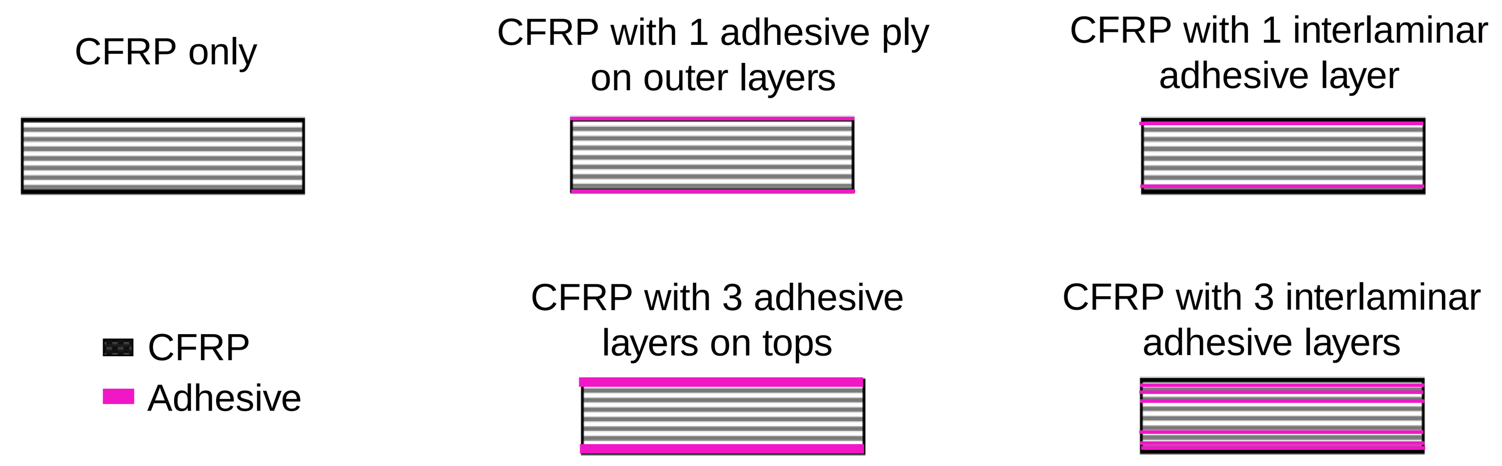

Figure 1 – Lay-up configurations

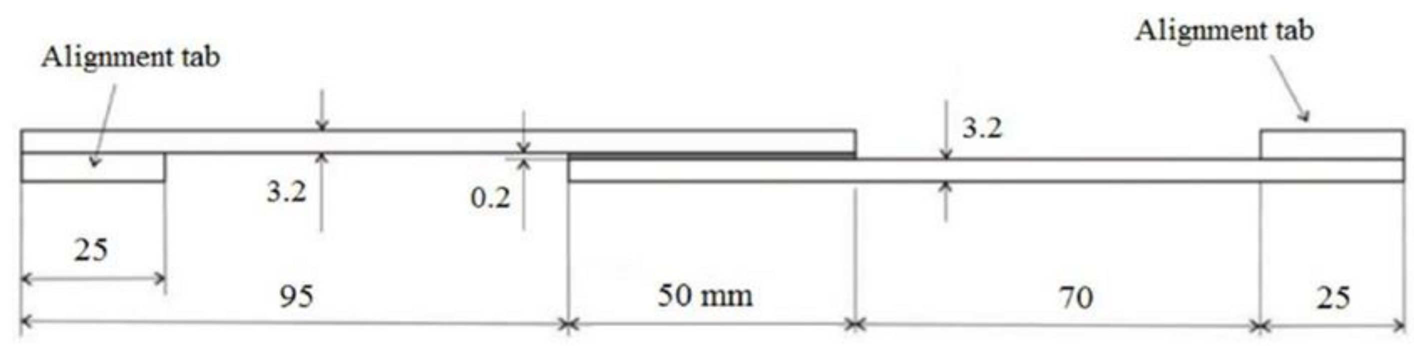

Figure 2 – SLJs geometry

Numerical details

- 2D analysis in ABAQUS® software;
- Solid elements were used for elastic sections (CPs8R);
- Cohesive elements with traction separation laws (COH2D4) [3].

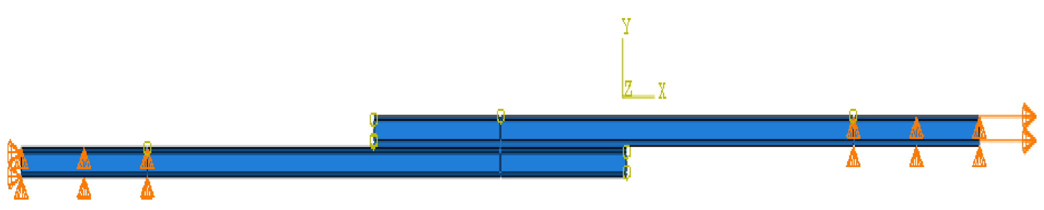

Figure 3 – Numerical model – boundary conditions

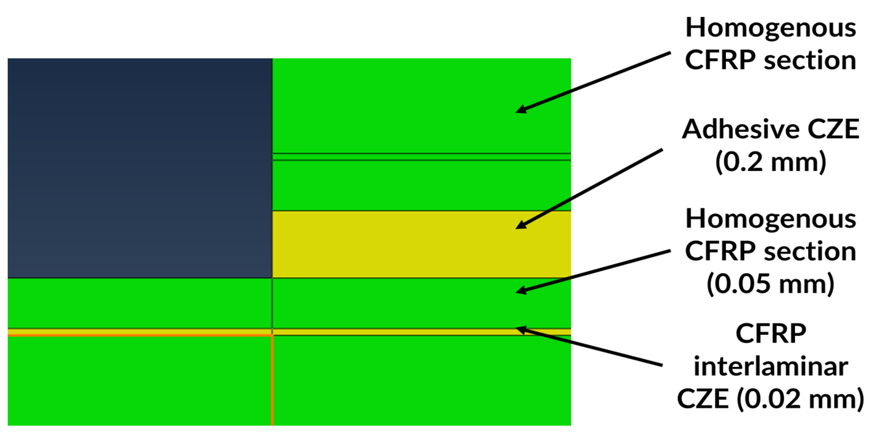

Figure 4 – Numerical model

Table 1 – AF 163-2K mechanical properties

Tensile strength [MPa]	46.93 ± 0.6
Young's Modulus [MPa]	1521.9 ± 118.3
Shear strength [MPa]	46.86 ± 0.6
G_{IC} [N/mm]	4.05 ± 0.07
G_{IIC} [N/mm]	9.77 ± 0.21

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.

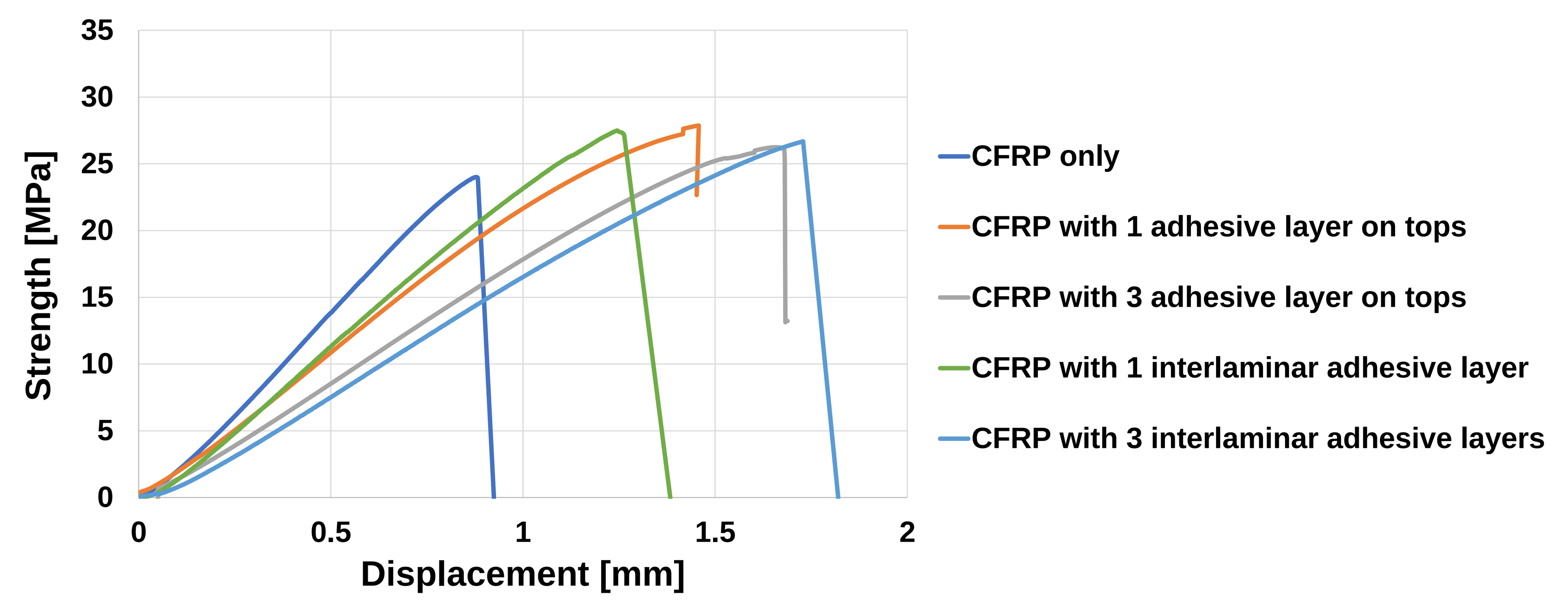

Figure 5 – Strength-displacement curves for all lay-up configurations

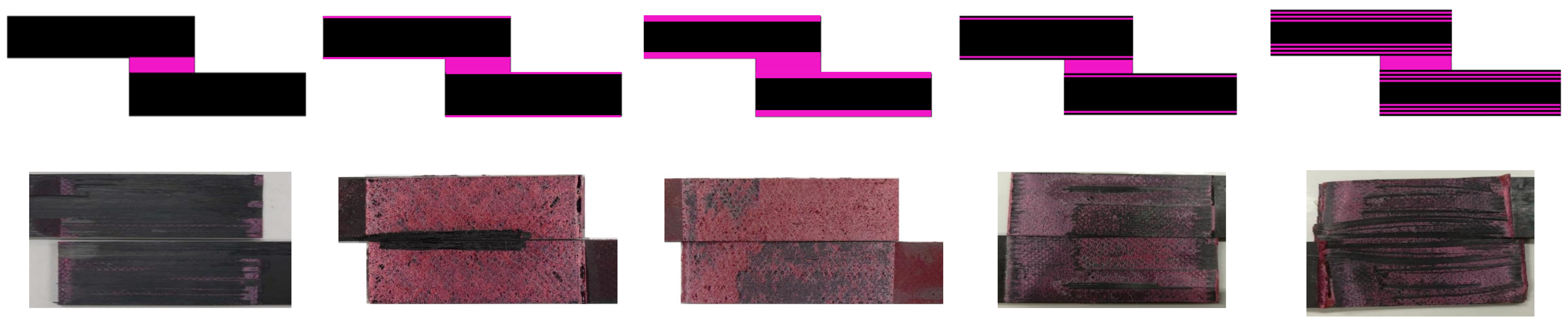

Figure 6 – Failure mechanism for all lay-up configurations

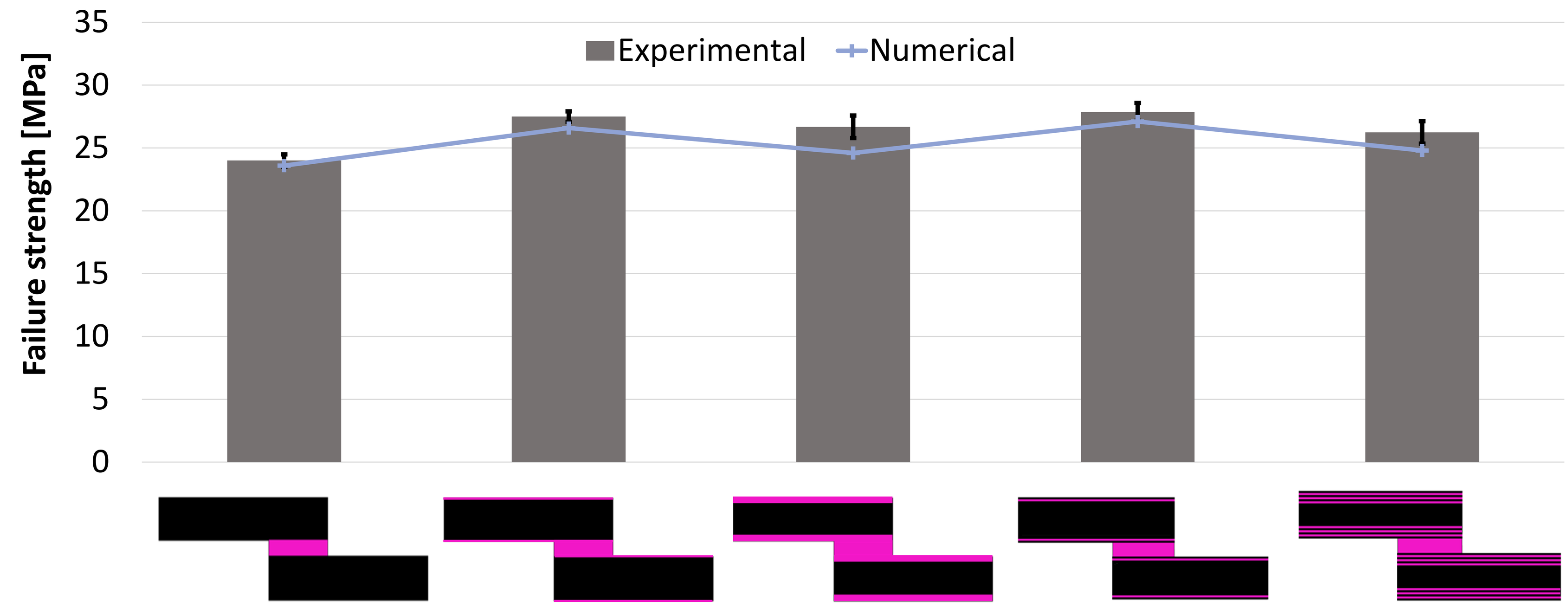

Figure 7 – Experimental and numerical joint strength

Conclusions

- The combined cure cycle for the CFRP and AF 163-2K allows to reduce production time and ensure adherends without defects;
- The average failure load of the specimens reinforced with additional adhesive layers was improved for all the specimens;
- The joints with one adhesive layer at the outer layers or in the interlaminar position allow to obtain the highest joint strength and the failure mechanism is mainly cohesive;
- The numerical results were coherent with the experimental results;
- The layout with 3 adhesive layers (interlaminar or on tops) showed the highest difference between experimental and numerical.

References

[1] L.F.M. da Silva, A. Öchsner, and R.D. Adams. Handbook of Adhesion Technology, (Springer-Verlag, Berlin, 2011)
[2] X. Shang, E.A.S. Marques, J.J.M. Machado, R.J.C. Carbas, D. Jiang, and L.F.M. da Silva. Composites Part B: Engineering, 177 (2019)
[3] L.F.M. da Silva, and R.D.S.G. Campilho, Advances in Numerical Modelling of Adhesive Joints, (Springer-Verlag, Berlin, 2012)

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