# The effect of thermal residual stress on the strength of joints with multi-material laminate composite adherends

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## Introduction

The study examines the impact of residual stresses resulting from coefficients of thermal expansion mismatch during curing on bonded joints, particularly when multi-material adherends are used. The use of a multi-material concept, specifically comprising CFRP and aluminum, is anticipated to give rise to significant improvements in joint strength and failure mode. A finite element software (ABAQUS) was used to conduct the numerical analysis, with the resultant models being validated with experimentally obtained data [1].

## Experimental details

**Adhesive**
Scotch Weld AF 163-2k – film-form modified epoxy adhesive.

**CFRP**
Texipreg HS 160 T700 – unidirectional prepreg carbon-epoxy.

**Aluminium**
Al2024 T3 Alclad aluminium alloy

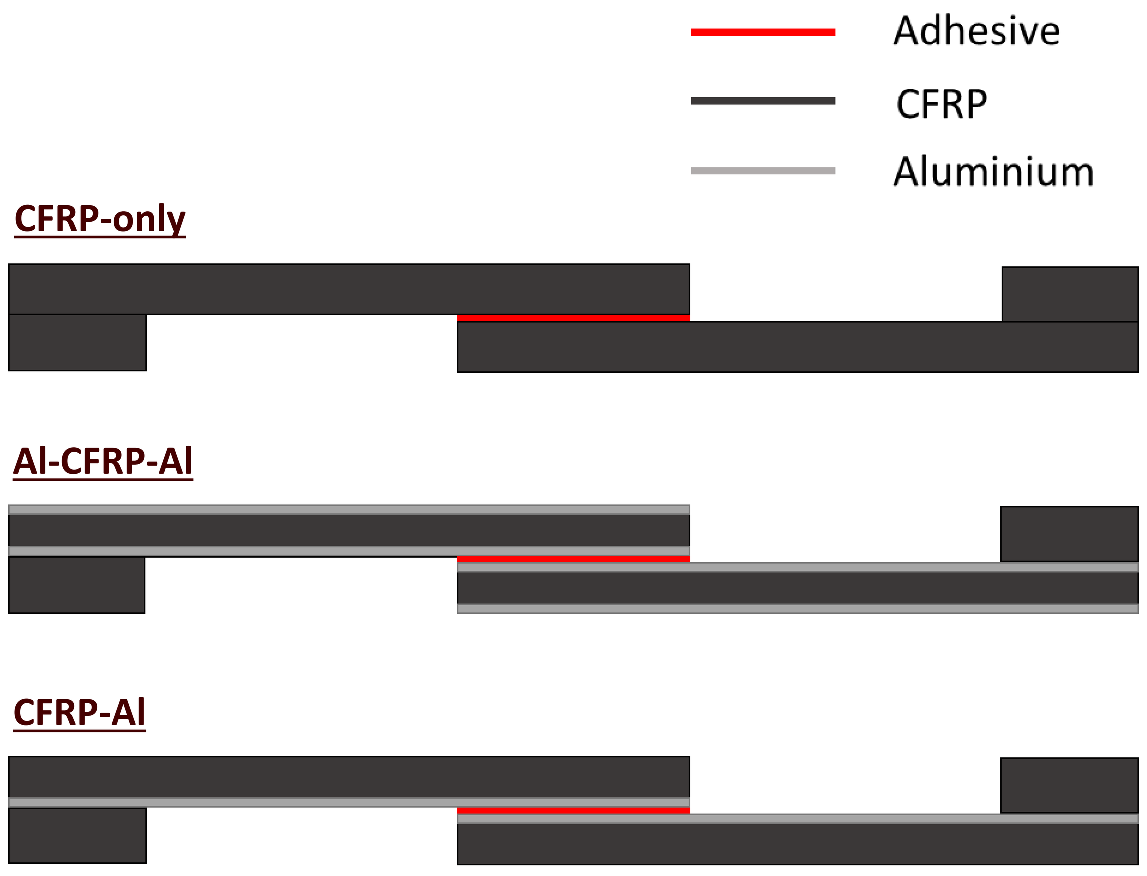


Figure 1 – Schematic representation of the configurations used.

Single lap joint (SLJ) testing were performed according to ASTM D1002-01. Constant displacement rate – 1mm/min

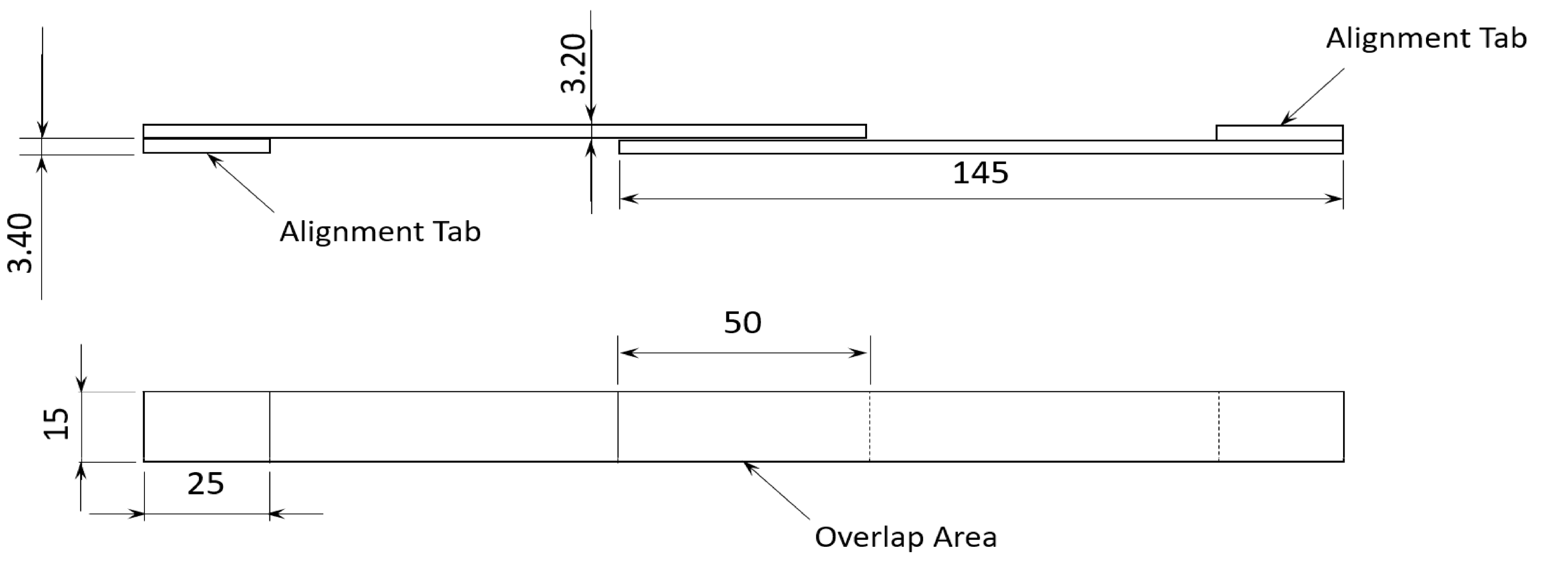


Figure 2 – SLJ specimen geometry, in mm.

## Numerical details

- 2D analysis in ABAQUS® software; Static general;
- four-node plane stress (CPS4R) elements for the aluminium;
- four-node plane strain (CPE4R) elements for the elastic CFRP);
- cohesive elements (COH2D4) for the cohesive sections

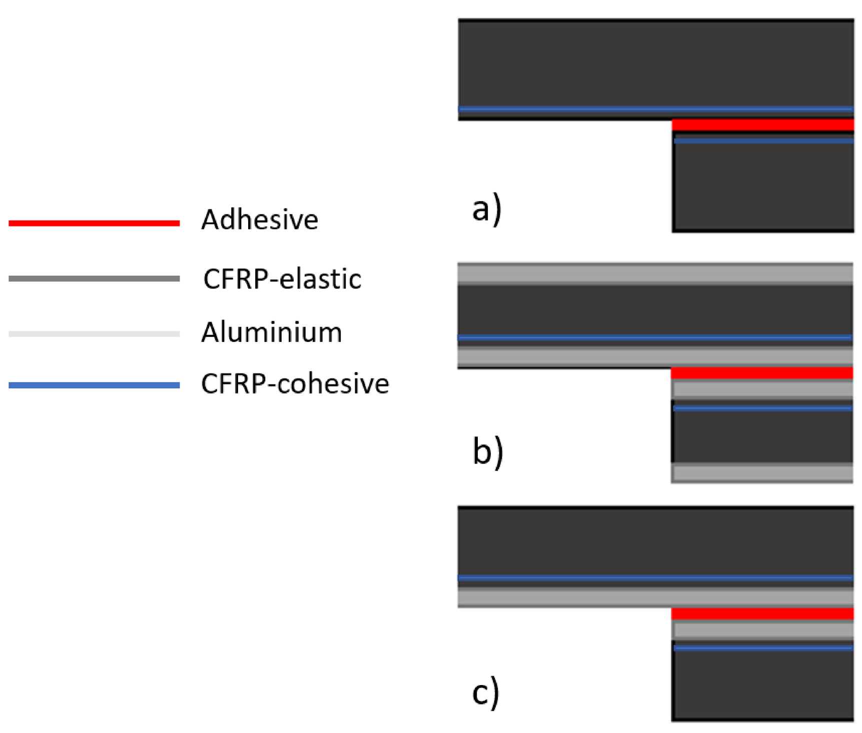


Figure 3 – Section of the numerical models used.

## Results

The digital image correlation (DIC) experimental results measured in the SLJ and the numerical values presented a good agreement, see Table 1.

Table 1 – Maximum deflection at the end of the SLJ.

| Average distance measured with DIC | Distance measured with numerical analysis |
|---|---|
| 2.05 ± 0.08 mm | 1.84 mm |

The deflection after curing exhibited by the CFRP-Al specimens can be depicted in Figure 4.

**DIC analysis to measure displacement**

**Numerical analysis to measure displacement**

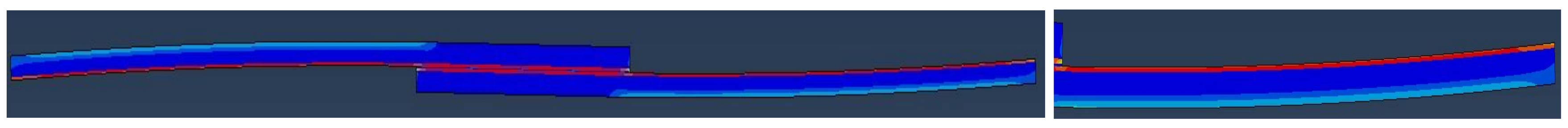

Figure 4 – CFRP-Al deflection after curing.

A good level of correlation was obtained, with the difference between experimental and numerical failure loads never exceeding 10%.

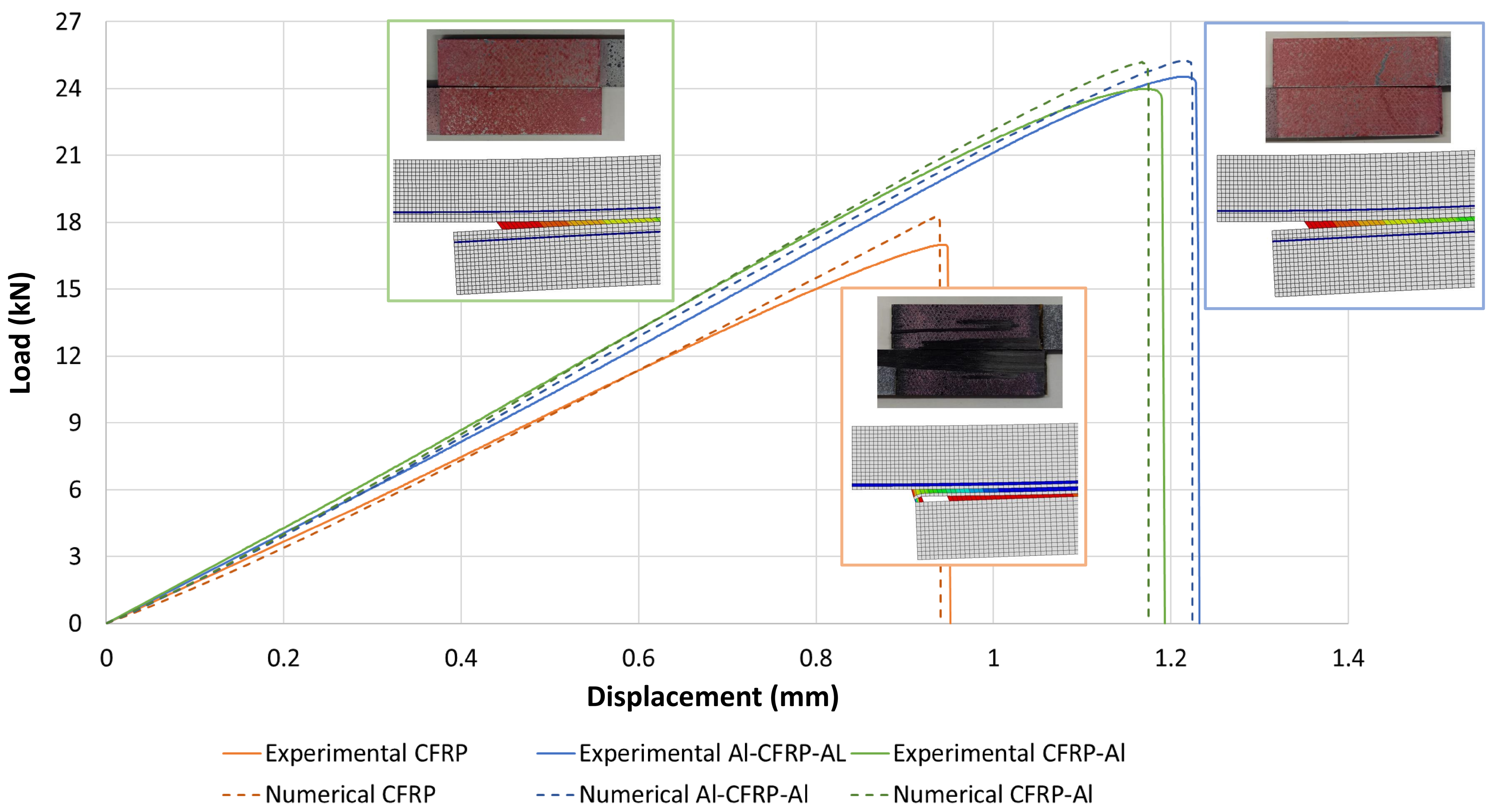


Figure 4 – Experimental versus numerical representative load-displacement curves of the different tested geometries.

## Conclusions

**SLJ performance**

- The studied SLJ geometry presented a large deviation from its initial geometry, after curing. Nonetheless, the controlled use of these deviations could be advantageous.
- Joint strength was improved in more than 35% and the delamination was avoided, for both tested FMLs.
- Although the joints with one layer of aluminium performed similar to the symmetrical one, the first has a reduced weight.

**Numerical analysis**

- The numerical models presented a good correlation with the experimental results, with a difference always lower than 10%, for the failure load.
- The failure modes were reproduced adequately.

## References

[1] Simões BD, Nunes PDP, Ramezani F, Carbas RJC, Marques EAS, da Silva LFM. Experimental and Numerical Study of Thermal Residual Stresses on Multimaterial Adherends in Single-Lap Joints. *Materials*. 2022; 15(23):8541.

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