11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

MECHANICAL JOINING TECHNOLOGY BETWEEN METAL AND CARBON FIBER REINFORCED POLYMERS THROUGH PUNCHING

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Keywords: Mechanical joint, Punching, Metal, CFRP, Automotive.

ABSTRACT

The joint between different lightweight materials plays a significant role in multi-material design of structural components for automotive industry, aiming to reduce the vehicle's weight without compromising performance or safety. Yet, conventional mechanical joining technologies between metals and Carbon Fibre Reinforced Polymers (CFRP) either create the need of drilling a hole in the composite material, leading to damages which reduce the load bearing capacity, or increase the weight of the part due the incorporation of fasteners [1]. At the same time, alternative mechanical joining methodologies involve complex and costly processing [2], compromising their industrial application.

To overcome the previous drawbacks, a new mechanical joining strategy between aluminum and CFRP was developed and characterized in this work. Such joining technology consists of a single step punching process performed on metal sheets where layers of uncured CFRP prepreg have been laid up. The CFRP is placed on the punch side of the set-up, while the metal sheet is placed on the die side. By adjusting the cutting clearance and the punch stroke, the aluminum sheet is completely punched while the carbon fibres are not (Figure 1a). Instead, the carbon fibres are pushed inside the hole in the metal sheet, generating a mechanical interlock between both materials (Figure 1d). The specimens are then co-cured by thermoforming (Figure 1b), thus adhesive bonding between both substrates also occurs.

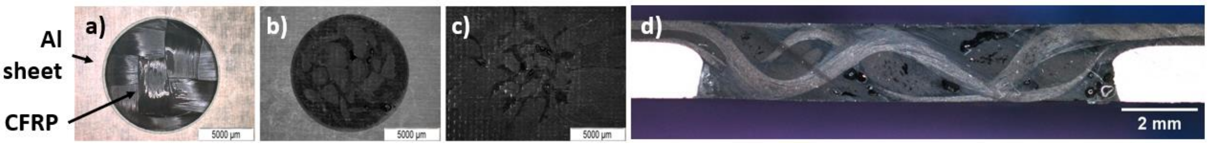

Figure 1: a) Mechanical interlocking joint after punching, prior to curing., b) cured joint (aluminum side side), c) cured joint (CFRP side) and d) Cross-section of the developed mechanical joint.

Non-destructive testing was conducted via ultrasonic C-scan to detect metal-composite debonding prior to mechanical testing and no debonding was observed in any of the analysed specimens. The shear strength and absorbed energy of the joint were evaluated by Single Lap Shear test (SLS) at constant crosshead speed of 1mm/min. Three different types of specimens with 5 repetitions each were evaluated: reference specimens (RS) with no mechanical interlock to evaluate the adhesive bonding between both substrates; mechanically interlocked specimens (MI) prepared with the described joining methodology; and manually places specimens (MP), were only the aluminum had been punched and the CFRP prepreg was placed afterwards. Both the shear strength and the absorbed energy were increased with the incorporation of the mechanical interlock (Figure 2). Such improvement was higher in the MI specimens than in the MP specimens, especially in the absorbed energy, where the improvement was almost double (Table 1). This was attributed to the fact that in MI specimens the carbon fibres were being pushed through the aluminum hole by the punch, while in MP specimens they were not. This resulted in a different failure mode: MI specimens failed by unbuttoning of the CFRP bulge (Figure 3a and b), while MP specimens failed by adhesive failure between the carbon fibres and the epoxy resin within the CFRP bulge (Figure 4c and d).

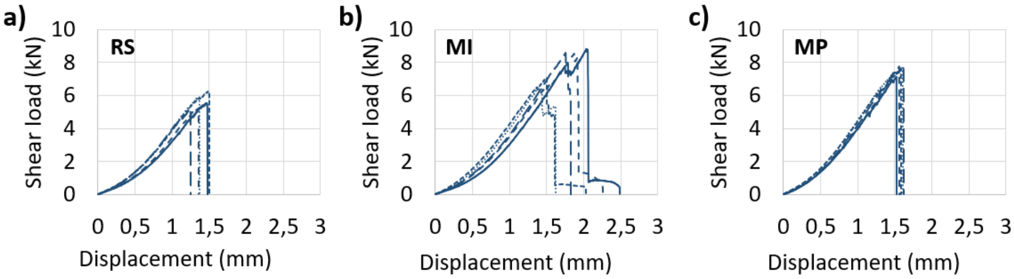

Figure 2: Single Lap Shear load-displacement curves for a) reference specimens (RS), b) mechanically interlocked specimens (MS) and c) manually placed specimens (MP).

Table 1: SLS results regarding shear load and absorbed energy.

Specimen type		Max. shear load (kN)	Absorbed energy (J)
RS	Mean	5.6 + 0.5	3.3 + 0.6
MI	Mean	7,9 + 1.1	6.4 + 1.3
	%improv.	40	94
MP	Mean	7.6 + 0.3	5.2 + 0.5
	%improv.	36	57

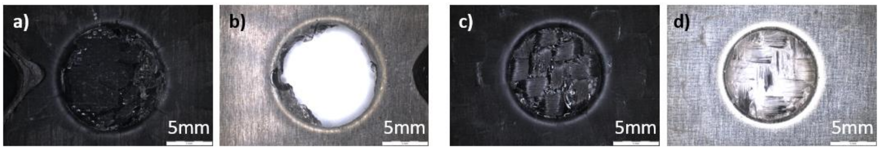

Figure 3: Joint failure for MI specimens (a and b) and MP specimens (b and c).

In order to further understand the failure mechanism of the joint under shear loads, the SLS test of identic specimens was stopped at different stages of the load-displacement curve (Figure 4).

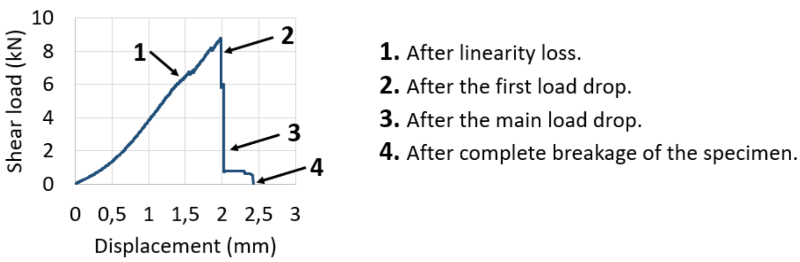

Figure 4: Stages at which the SLS test was stopped.

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