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# Experimental study using interfacial inserts to create bridging to improve delamination response in composites

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## Abstract

Composite materials have grown rapidly due to their ability to provide high stiffness at low weight, resulting in increased use in aerospace and automotive applications, among others. However, interlaminar adhesion is a problem with these materials, as cracks can form between the laminae, leading to delamination and subsequent structural collapse. This work analyzes different strategies to improve the delamination response of carbon fiber-reinforced composites, focusing on delaying and stabilizing crack propagation, a critical challenge for performance and reliability in advanced industrial applications. The main proposal in this work is to modify the interface by adding heterogeneities with two different materials to create bridging. This will reduce crack propagation and help maintain stability in the load-displacement curve.

The material studied was unidirectional carbon fiber (HexPly M79), fabricating specimens by prepreg at 120 °C for 1 hour and at a pressure of 5 bar, with a stacking. To create the bridging ligaments, two types of materials were incorporated as interlaminar inserts: mat-type fiberglass (E-glass) and TPU 92-A patterns 3D printed on a Stratasys 270 printer. Two different patterns were designed, consisting of squares with equal dimension, having different orientations with respect to the crack propagation direction. They are defined as "diamond" and "square" patterns in the following.

Two types of experimental tests were performed to study crack propagation: the Double Cantilever Beam (DCB) test in mode I, according to ASTM-D5528, and the Climbing Drum Peel (CDP) test in mixed mode, according to ASTM-D1781, which is usually used to evaluate adhesion in sandwich panels. The aim was to investigate the robustness of the improved performance depending on the mode mixity and type of test. For the DCB test, the inserted materials (mat and TPU) were placed in the midplane, while for the CDP, they were inserted between plies 2 and 3. Both tests were performed at a 1 mm/min test speed on a Zwick-Roell Z100 electromechanical machine with a maximum capacity of 100 kN.

DCB experimental results showed that the inserts generated fiber bridges, creating long process zones that slow down crack propagation compared to the baseline case. The mat and the

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TPU diamond inserts displayed similar behaviors, while the TPU square introduced some instability in the crack propagation. In the case of the CDP test, the inserts did not have the same behavior. Few or no bridging ligaments were observed in all cases, as the crack tended to deviate towards the peel arm side of the insert. Due to its brittleness, no effective bridges were formed for the mat material, and its behavior was like that of the baseline case. In contrast, the two types of TPU did increase the delamination energy, although they also caused instabilities in crack advancement.