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EXPERIMENTAL CHARACTERIZATION OF THE MODE I TRANSLAMINAR FRACTURE TOUGHNESS OF CFRP USING INFRARED AND DIC MEASUREMENTS: COMPACT TENSION AND COMPACT COMPRESSION TESTS

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ABSTRACT

The extensive use of carbon fibers reinforced polymers (CFRP) in the aeronautics field has created a need for a deeper understanding of their failure mechanics, one of them being cracks propagation. The failure of CFRP occurs according to 3 primary damages: interlaminar, intralaminar, translaminar [1]. Translaminar failure occurs at the mesoscopic scale (at the scale of multiple plies), and cracks propagate through the thickness of the laminate.

The goal of this study is to analyze the translaminar fracture toughness of a carbon fiber reinforced thermoset material (UD carbon/epoxy). The stacking sequence is $[-45/45/(90/0)_4]_s$. CT (Compact Tension) and CC (Compact Compression) specimens are used to study respectively tensile and compressive damage. The critical strain energy release rate in mode I, G_{IC} , (opening mode) is calculated with 3 methods. A particular attention is paid to detecting secondary damage, i.e. damage not directly linked to the crack growth [2].

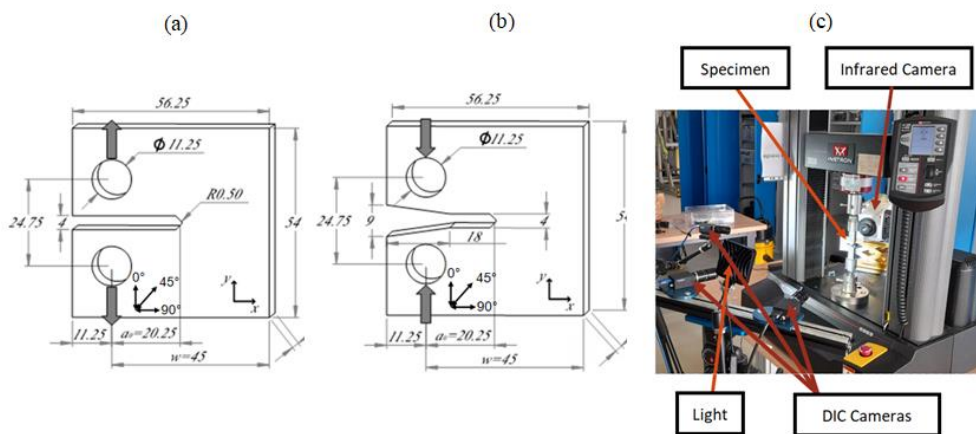


Figure 1: (a) CT geometry – (b) CC geometry – (c) Experimental setup

Geometries and experimental setup can be seen on Figure 1. Two cameras film the face of the specimen to calculate displacement and strain fields using digital image Correlation (Figure 2b).

Another camera films the opposite side of the specimen to detect respectively compressive or tensile secondary damage. An infrared camera is placed behind the specimen to follow the crack during its propagation (Figure 2a - b).

G_{IC} is calculated using three different methods: the ASTM-e399 method [3], the area method [4], and the compliance method using the Irwin-Kies formula. Three laws are compared to approximate the compliance of the specimen as a function of the crack length ([1], [3], [4]).

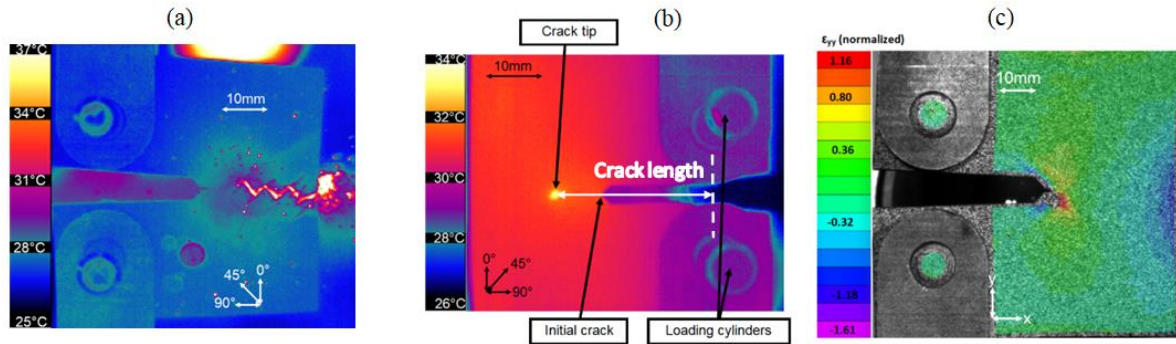


Figure 2: (a) IR image showing compressive failure at the end of the test on a CT specimen - (b) IR image showing local heating after a crack propagation on a CC specimen – (c) Strain fields in the y direction on a CC specimen, showing compression exceeding the fibers maximum allowable

G_{IC} computing resulted in the plotting of R curves, i.e. G_{IC} as a function of the crack length. These showed an initiation value around 100 kJ/m^2 for CT tests and around 15 kJ/m^2 for CC tests. A large increase of G_{IC} with the crack length was observed on both tests, which for the CT tests can be linked to the damage zone size increase, and for the CC tests crushing phenomena largely contribute to this increase. Finally, the fiber fracture toughness of the ply in mode I G_{IC}^{ply} was calculated using the rule of mixtures [1].

Particular attention was paid to secondary damage. None was observed on CC specimens. However, CT with 11.25 mm wide loading holes suffered from failure around loading axis; although this is the value recommended by the ASTM test standard E399-12. This resulted in a geometry modification to 8 mm holes. CT specimens also suffered from compressive damage on the side opposite to the loading axis [2]. Although, this damage occurred for a measured compressive strain 40% higher than the value given by the manufacturer and observed on CC specimens.

Contrary to other studies, $\pm 45^\circ$ plies are placed in surface. Their primary role is to hold shear force and avoid plasticity of the resin [3]. These plies seem to be beneficial to CC specimens, as the damage zone and thus the heated dots indicating the tip of the crack remain small compared to other studies [3]. However, this architecture resulted in large delamination of the surface plies and an increasing size of damage zone on CT tests, making the identification of the crack tip more difficult (figure 2a).

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