EXPERIMENTAL CHARACTERIZATION OF TRIAXIALLY BRAIDED COMPOSITES

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Abstract

Manufacturing and testing textile composite materials is a time consuming and expensive procedure. Therefore numerical methods can be used to simulate the material behavior under certain loading conditions. In this research, mechanical properties of two-dimensional triaxially braided composites were determined by means of experimental testing to get insight in the material behavior as well as for providing data to support the development of analytical and numerical methods. In-plane properties were obtained using tensile and shear tests. Post-mortem specimens were used to indentifying damage mechanisms, which were visualized using metallographic samples. Interlaminar as well as translaminar fracture toughness were determined in Mode-I and Compact Tension tests respectively. Unstable crack growth propagation was found in the specimens from both test due to fiber bridging and fiber branching.

1. Introduction

Textiles composites are nowadays being used in a large range of applications in the aeronautical and automotive industry because of their high strength-to weight ratio and lower manufacturing costs against unidirectional composite laminates. Among them, triaxially braided composites offer improved in-plane shear mechanical properties due to the additional inlay yarns that follow the longitudinal direction into the off-axis bias yarns and drapability in compared to other composite materials [1]. However, they are not in the same state of development as unidirectional composites because of their complex architecture [2]. This necessitates development of analytical and numerical models to predict the mechanical properties of the braided composites.

While in the literature there are finite element models related with the meso-structure of the textile reinforcement [3-6] that offer a representation of the bundle waviness inside the repetitive unit cell (RUC) geometry, the design parameters are mostly empirical. Limitations are the tow interpenetrations and the maximum fiber volume fraction that can be archived with this methodologies, typically 40%. An adequate experimental characterization of the in-plane behavior is needed to validate the existent finite element models. These experimental results will be used to validate a quasi-physical thermo-mechanical finite element modeling approach [7], [8] used to remove the tow interpenetrations and to archive a realistic fiber volume fraction (50%) In addition to the in-plane mechanical tests, double cantilever beam (DCB) and compact tension (CT) are also performed to quantify/determine the behavior of the textile composite laminate in the damage regimen.

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The damage phenomena in textile composites is closely related with the macro, meso and micro-structure of the textile reinforcement: strength and strain to failure prediction of the sample (macro), damage initiation and evolution within the architecture of the preform (meso) and local damage inside the fiber tows (micro). A proper study is needed to determine its localization and development. The process can be monitored using metallographic samples coupled with X-ray computer Tomography (XCT).

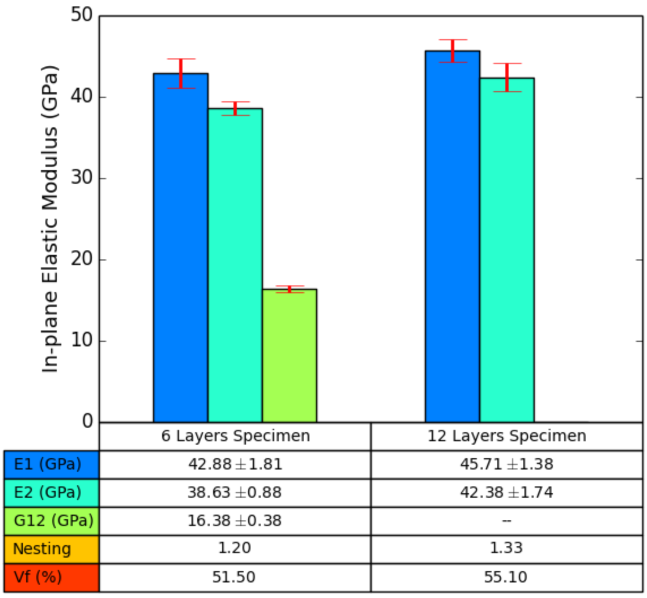
2. Experimental testing

Braided specimens were manufactured infusing Hexcel RTM-6 epoxy resin on A&P Tech. QISO L-52 triaxial braided preform using resin transfer molding (RTM). Since variation in the manufacturing process can alter the resin content and therefore its fiber volume fraction, they should be accounted while measuring their mechanical response. After manufacturing, Non Destructive Tests (NDT) were performed in order to determine the quality of the specimens and to localize potentially damage initiation zones such as defects. The evaluation revealed no significant defects in the specimens.

Tensile and shear tests were conducted on the triaxially braided composite to evaluate its mechanical performance. Additionally Mode I and CT tests were performed to compute the interlaminar and translaminar fracture behavior of the material.

2.1. Tensile and shear tests

Tensile tests were performed following ASTM D3039 while shear V notch tests were done using ASTM D7078. All tests were conducted through displacement control with a constant speed of 1 mm/min using a servo-mechanical test machine. In both tests elastic modulus, strength and strain to failure were obtained for the longitudinal and transverse direction. Longitudinal direction is defined as the direction in which the loading direction is parallel to the axial yarn direction. Digital image correlation was used to measure the full field strain of the specimens painted with a speckle pattern [9]. A quasi-isotropic response was found in the tests, typically of these materials. Results from the tests are illustrated in the following fig (Figure 1):



	6 Layers Specimen	12 Layers Specimen
E1 (GPa)	42.88 ±1.81	45.71 ±1.38
E2 (GPa)	38.63 ±0.88	42.38 ±1.74
G12 (GPa)	16.38 ±0.38	--
Nesting	1.20	1.33
Vf (%)	51.50	55.10

Figure 1 Tensile and Shear properties.

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It can be seen from Figure 1 that due to the nesting effect within the laminate, the fiber volume fraction is increased in the 12 layers specimens and therefore a stiffer response was found in both longitudinal and transverse direction in compariso with the 6 layers specimens.

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2.1. Mode 1 and CT tests

Due to the architecture of the textile composite, three damage zones can be identified: i) the matrix to filament within a tow (intralamina), the matrix to tow interface (interlaminar) and breakage perpendicular through the tow (translaminar). To study the damage behavior in these zones of interest, Mode-I (interlaminar) and compact tension (translaminar) tests have been performed.

Interlaminar fracture toughness for composites materials was reported by *Mouritz et al*.[10] and it was noted that the fracture toughness for a two-dimensional glass fiber triaxial braided preform was more than double of the fracture toughness for the unidirectional composites. In this research, Mode-I tests were performed based on ASTM Standard D5528-13. Several reduction methods described in the standard were used to obtain the fracture toughness of the material. Results are illustrated in the following figure (Figure 2):

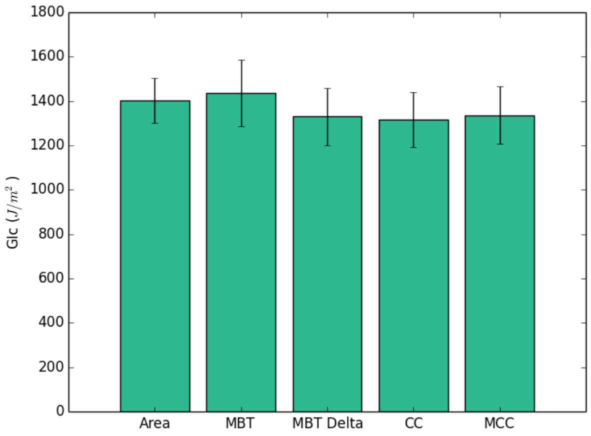

Figure 2 Mode-I **c**ritical strain energy release rates obtained with different methods.

Pinho et al. [11] described a way to obtain the translaminar fracture toughness of laminated composites by using compact tension (CT) specimens. Due to the lack of specific standard to calculate the translaminar fracture toughness in textile composite materials, this paper was used as basis for the research performed. Compact tensions specimens were manufactured according the description provided by *Pinho et al*. [11], in both longitudinal and transverse to the loading direction. An unstable crack growth propagation was found as shown in Figure 3 a) and b), typically of these complex architectures, in which fiber bridging and fiber branching occur.

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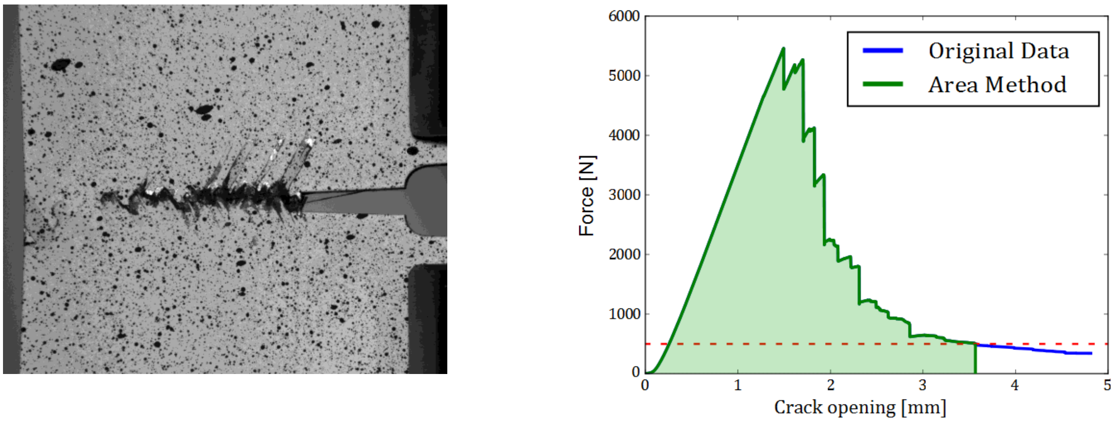

a) b)

Figure 3 Crack propagation a) and force-crack opening curve of one of the longitudinal specimens tested

Due the unstable crack growth propagation not all the methods listed by *Pinho et al.* were suitable. Therefore among them, the area method was chosen to obtain an average value as shown in Figure 3 b). Results of the tested specimens are listed in Table 1 for both longitudinal and transverse direction:

Table 1 Translaminar strain energy release of the CT specimens tested.

Specimen Type	G_{Ic} (KJ/m^2)
Longitudinal	86.04±2.87
Transverse	169.86±16.12

From Table 1 it can be seen that the fracture toughness in the transverse specimen is approximate two times higher than the in the longitudinal specimen. The orientation of the axial yarns according to the crack propagation plays a major role, being in tension when the crack propagation is transverse to the axial direction producing a growth in the translaminar fracture toughness. In the other hand, in the longitudinal coupons the crack propagates parallel to the axial yarns decreasing the value of the translaminar fracture toughness.

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3. Damage intiation and evolution

Metallographic samples were produced from the tested specimens to observe the damage mechanisms using an optical microscope equipped with a camera. Figure 4 shows a cross-section perpendicular to the loading direction

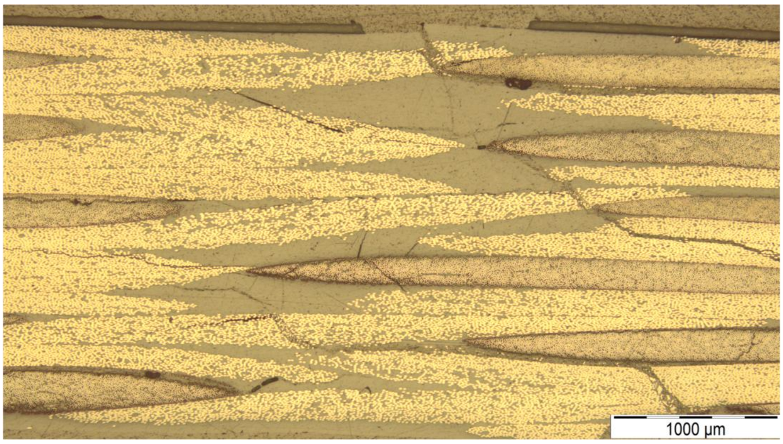

Figure 4 Transverse cross-section of a 6 layers tensile specimen.

Preliminary results can be obtained from Figure 4. Damage phenomena can be summarized in 3 steps; i) initiation by a transverse crack of the fiber bundles or cracking along their boundaries, ii) propagation and multiplication of cracks up to the debonding of the yarn/matrix interface, and iii) fiber breakage and total failure of the sample.

4. Conclusions

In this research an in-plane mechanical characterization was carried out, in which properties such as elastic modulus, Poisson´s ratios, and ultimate stresses and strains were determined by means of tensile and shear tests. These tests provided sufficient results to serve as validation for future analytical and numerical models [6], [7].

In addition a fracture toughness characterization was performed. Two types of tests were carried out: Mode-I tests to determine the interlaminar fracture toughness and Compact Tension tests to evaluate the contribution of this tailored-up fiber architecture to enhance the translaminar fracture toughness. Unstable crack growth was observed in both tests, and therefore damage mechanisms occurring during this tests were investigated with experimental techniques. It can be concluded that the fracture toughness of this material is higher than for traditionally composite laminates (500 J/m^2 [12] and 133 KJ/m^2 [11] for interlaminar and translaminar fracture toughness respectively), which makes it potentially useable in applications in which the ability to dissipate energy in the damage regimen is a must. To conclude, this work can serve as a base for future research in this field.

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