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STUDY OF INFLUENCE OF INTERLAMINAR SHEAR STRENGTH IN POLYMERIC COMPOSITES HYBRID GLASS / CARBON IN STRUCTURAL APPLICATION

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Abstract. *The objective of the present work is the mechanical characterization of polymeric composites reinforced by hybrid fabric of fiber glass-E and AS4 (carbon) for structural applications. The hybrid glass / carbon fabric was impregnated by the unsaturated polyester resin (NOVAPOL L120) consisting of four layers. The mechanical characterization of the test specimens was performed by uniaxial tensile tests, three-point bending and ILSS shear (Short beam). The results presented in the mechanical tests obtained good performances, including a high flexural strength, being attributed to such characteristic the hybrid glass / carbon fabric configuration and the fiber / matrix interface quality compared to the literature.*

Keywords: *composites, shear, reinforcement, resistance.*

1. INTRODUCTION

Currently, polymer composites reinforced by fiber have been used in large scale in structural elements, due to the gain in mechanical properties and the low density. The use of polymeric composites reinforced by hybrid fabrics can improve the structural applicability of these composites by joining in a single element high mechanical strength in projects where they require loading and service conditions (Felipe et al., 2017).

The joint use of glass fiber reinforcements and carbon fibers in a polymer matrix, for example, instead of only carbon fibers reduces costs, since carbon fibers are more expensive. Carbon fibers are rigid and lightweight, but are relatively expensive, while glass fibers have low stiffness and are more dense. Thus, by combining the two fibers in the same polymer matrix it is possible to obtain a balance between the properties of the composites. Therefore, the hybrid glass / carbon composite will be a low cost, catastrophic failure resistant material with sufficiently high rigidity when compared to glass fiber reinforced composite or carbon fiber only composite (Oliveira, 2013).

According to Pandya et al. (2011) hybrid composites are classified, depending on the geometric fiber / wire / layer, in: interply and intraply. In interply hybridization, the hybrid composites are composed of different layers of fibers bonded together in a matrix; and intraply-type hybrid composites, each fabric is composed of two or more types of fibers. The resulting material is anisotropic and its mechanical properties depend on the constituent materials and the structure of the components due to the rolling sequence.

Felipe et al. (2017) studied composite laminates reinforced by hybrid fabric of Kevlar-49 and E-glass fibers and matrix of polyester resin. Bidirectional tissues were developed, one of them being made with hybrid yarn and the other with hybrid fabric by hand-lay-up process. The percentages by weight of glass fiber and Kevlar were 50%. They concluded that after the mechanical tests performed on composite laminates of hybrid fabric the mechanical behavior was about 41.7% higher due to the use of the interply hybridization.

Batista et al. (2016) studied the mechanical properties (uniaxial tensile tests and three-point bending), after accelerated aging, composites of polymer reinforced by hybrid fabrics of Kevlar-49, E-glass fiber and reinforced laminate with E-glass and AS4 carbon fiber. Both tissues were impregnated with epoxy resin (Derakane 470-300) and had four reinforcing layers. They concluded that the composites obtained good mechanical performance and small

losses in the mechanical properties even after the effects of accelerated aging. The authors attribute the low structural deterioration of the laminates to the characteristics of the hybrid tissue.

Therefore, the present work aims at the mechanical characterization of a hybrid polymer-reinforced two-way composite laminate reinforced by E-glass fibers and AS-4 carbon, as well as the influence of the hybridization process on these properties, in particular in the interlaminar shear test ILSS, for structural applications.

In this study the ortho-terephthalic unsaturated polyester resin, commercially known as NOVAPOL L120, was used as the matrix. This resin has high mechanical performance and is recommended for use in adverse environmental conditions such as corrosion and oxidation. The manual lay-up process was used with four (4) reinforcement layers. The specimens were submitted under uniaxial tensile loading, three - point flexion and ILSS (Short beam) interlaminar shear.

2. EXPERIMENTAL

The bi-directional hybrid fabric used in this work was manufactured by TEXIGLASS Indústria e Comércio Têxtil, which is commercially identified as Hybrid Fabric CVQ-339 containing 23.35% of AS-4 (PAN) carbon fiber, 76.65 % E-glass fiber and weight 340 g / m². The fabric used is shown in fig.1.

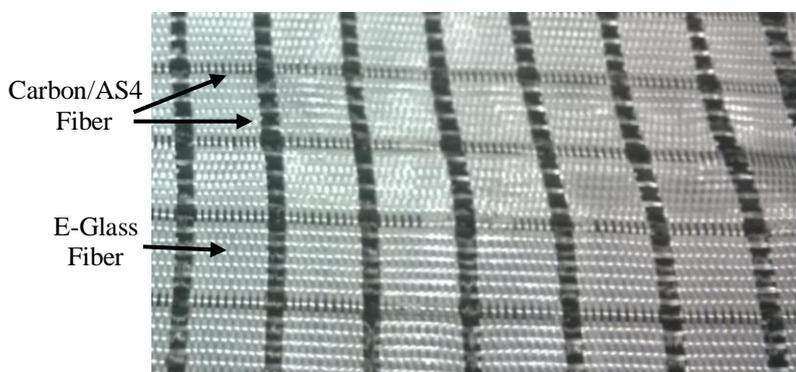


Figura 1. Hybrid fabric CVQ-339 used in the manufacture of laminate.

The composite laminate was made using the manual lamination process (hand lay-up). Four (4) hybrid E-glass / AS4 carbon reinforcing fabric layers impregnated with NOVAPOL L120 ortho-terephthalic polyester resin were used without the additional use of styrene. A proportion of 1% methyl ethyl ketone (MEKP) of the resin volume was used as the catalyst and curing was done at room temperature. The resin has the following characteristics: Viscosity brook (SPD 2/60 rpm) 250-350 cP; Density 1.23 g/cm³ at 25 °C; gel time (MEKP) 9-13 min at 25 °C; Exothermic peak of 150-190 °C; and acid value: maximum 30 mg KOH/g.

The laminate in its final design had the following dimensions; 400 mm wide, 500 mm long by 2.30 mm thick. In this study intraply-type lamination was performed in a way that did not combine the carbon fiber strands of the E-glass hybrid fabric / AS4 carbon in each layer. In order to perform the mechanical tests, the specimens were cut using a disc with diamond cut wire and their sides sanded and polished according to metallographic techniques.

2.1 The uniaxial tensile test

The uniaxial tensile test was performed according to ASTM D3039-08, with eight fractured test specimens and five values recorded according to standard. The uniaxial tensile test was performed on a universal test machine (DL 300 KN EMIC) with a loading speed of 1.0 mm/min. The mean ambient temperature during the test was 25 ± 2 °C. Figure 2 shows the specimen for the uniaxial tensile test.

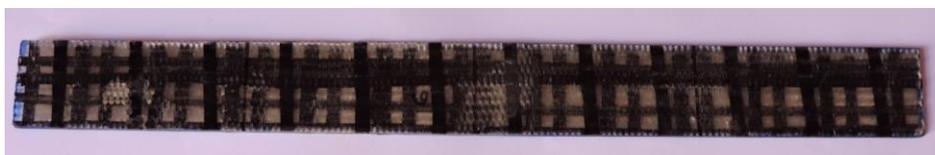


Figure 2. Specimen LCV uniaxial tensile.

Due to the reduced thickness of the specimens, special care was taken during the tensile test, such as adjustments of the specimens in the machine claws and precise dimensions of the useful length of the specimens. With this, it was possible to determine the ultimate stress, the longitudinal modulus of elasticity (in the direction of load application) and the maximum deformation of the specimens of the LCV hybrid laminates.

2.2 The three-point flexural test

The three-point flexural test was performed according to ASTM D790-15. The three-point bending test was performed in a universal machine (DL 300 KN EMIC) with load cell 20 KN and loading speed of 2.0 mm/min. The temperature during the test was ambient (25 ± 2 °C). Figure 3 shows the test body for the three-point bending test.



Figure 3. Specimen LCV flexure three- point bending.

The flexural strength was defined as the tensile strength responsible for the fracture of the specimen on the drawn face. The values of flexural strength, stiffness and maximum deflection were determined by normalized equations.

2.3 The interlaminar ILSS shear test (*short beam*)

For the interlaminar ILSS shear test, the test body consisted of a beam with very small dimensions, so that the shear force generated in the median plane was maximized with respect to tensile and compression tensions. This method provides the apparent interlaminar resistance of the bond strength between the various layers in the composite.

Due to the anisotropic characteristics of the polymer composites, the study of the interlaminar fracture has become indispensable due to failure that would limit the life of the component. The ILSS test is used as a tool for evaluating the composites because it has fastness, economy of raw material, ease of obtaining a test specimen, providing an evaluation of fiber / matrix adhesion occurred during processing. For the result to be significant, the failure mode must be shear, resulting in failure by delamination (Botelho et al., 2002).

The interlaminar ILSS shear test device, Fig. 4, uses a fastening system similar to the three-point bending test, the load being applied to the specimen by an upper cylinder, with a length / thickness ratio (l / e) of 6 and span / thickness (v / e) recommended of 4: 1 for fiber reinforced composites. The load is applied at the midpoint of the test body by a 6 mm diameter roller until the laminate fails.

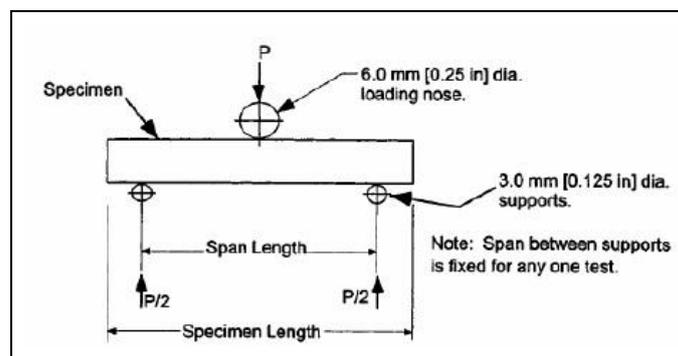


Figura 4. Short beam shear test loading configuration (ASTM D2344/D2344M-00).

The interlaminar shear test ILSS (Short beam) was performed according to ASTM D2344 in a universal machine of mechanical tests (DL 300 KN EMIC), with load cell of 20 KN and the loading speed of 1.3 mm/min as shown in Fig. 5.

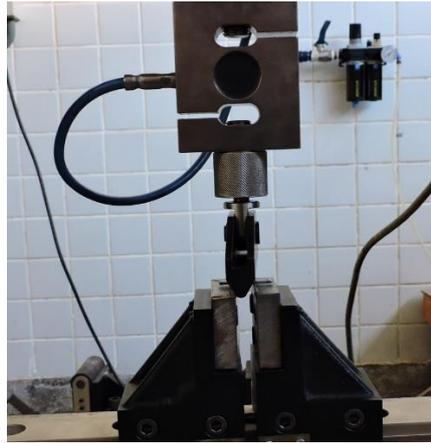


Figure 5. The interlaminar ILSS shear test.

A The temperature during the test was ambient ($25 \pm 2 \text{ }^\circ \text{C}$). Figure 6 shows the test body of the ILSS assay. Ten (10) test bodies were used to obtain a reliable data set, and for each sample the interlaminar shear stress was calculated using equation (1)

$$ILSS = \tau = \frac{3P_B}{4bd} \quad (1)$$

Where: τ = Interlaminar shear strength (MPa);
PB = Load used in the test (N);
b = width of the test piece (mm);
d = thickness of the specimen (mm);



Figure 6. Specimen LCV shear interlaminar ILSS – short beam.

3. RESULTS

In this item the mechanical characterization of the LCV composite laminate in relation to the manufacturing process in terms of quality due to the uniaxial tensile loads, three-point bending and ILSS - short beam interlaminar shear is presented.

3.1 Uniaxial tensile test

The characteristic of the fracture region occurring in the LCV laminate specimens, Fig. 7, can be classified as LGM fracture (Lateral Gage Middle), according to ASTM 3039. We can observe the non-occurrence of total rupture of the specimen.

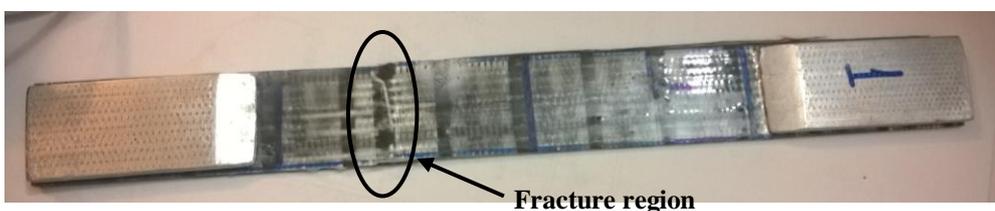


Figure 7. Region of fracture of the uniaxial traction test body.

The behavior of the stress-strain curve, Fig. 8, shows a linear elastic profile up to the final fracture, characteristic profile of the E-glass and AS4 carbon fibers and strongly influencing the final response of the composite laminate. The fact that the geometry of the test specimens involving by random carbon fiber strands directly influences the results, emphasizing that among the advantages of using carbon fiber is its high tensile strength. Thus, it is possible to state that the geometry of the specimens by virtue of the hybridization form of the fabric had an influence on the mechanical response in the glass-E / AS4 composite laminate. The variations occurring in the curve are characterized by decreases in the load bearing capacity and refers to the fracture of the different types of fibers, before the final fracture.

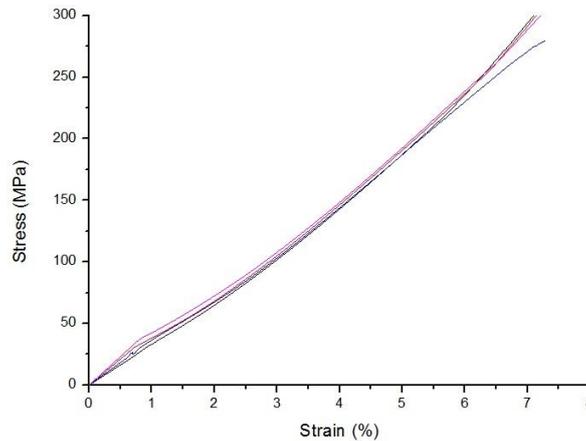


Figure 8. Diagram of stress versus strain.

Table 1 shows the results of the mean values and the respective standard deviations obtained in the uniaxial tensile test of the LCV laminate. With respect to the values of the modulus of elasticity, it was calculated before loading on the initial damage, to avoid the same influence on the rigidity of the material.

Table 1. Experimental results for uniaxial tensile properties of LCV composite. Average results of 5 specimens.

Mechanical properties	LCV	
	Average	Standard deviation
Tensile Strength (MPa) ⁽¹⁾	297,25	18,12
Elastic Modulus (GPa) ⁽¹⁾	10,98	4,36
Elongation (%)	7,34	1,4

(1) measured at 25°C

Batista et al. (2016) studied the mechanical properties of hybrid composites with bidirectional fabric composed of E-glass fiber and AS 4 carbon strands as reinforcement and epoxy resin (Derakane 470-300). It was observed that the tensile strength of the obtained laminate was 172.5 ± 5.7 MPa and the modulus of elasticity was 8.5 ± 1.0 GPa.

Oliveira (2013), studied the normative geometry in hybrid composites reinforced by fabric E-glass, wicks of AS4 carbon and epoxy resin (Derakane 470-300). The intraply laminates were made with wicks of carbon superimposed one on top of the other. In response to the mechanical tests of uniaxial traction and flexion at three points the specimens with 2 carbon fiber strands obtained a higher percentage, presenting a 33.15% increase in resistance and 9.91% in rigidity, in relation to the bodies with 1 wick of carbon fiber.

In this study the process of elaboration of the intraply laminate, arranging the carbon wicks in a random way improved the average value of the tensile strength, as well as the modulus of elasticity.

3.2 Three-point bending test

In Figure 9 the final failure region of the LCV test body obtained from the three-point bending test can be observed. Reported that there was no total rupture in the LCV test specimen.

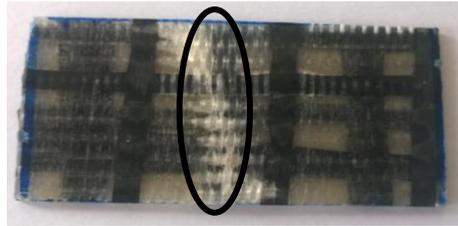


Figure 9. Failure region of the test body of the three-point bending test.

Figure 10 shows the mechanical properties obtained in the three-point bending test for the LCV laminate from the strain-strain diagram. The LCV test body has a linearly elastic behavior up to the final fracture of the material.

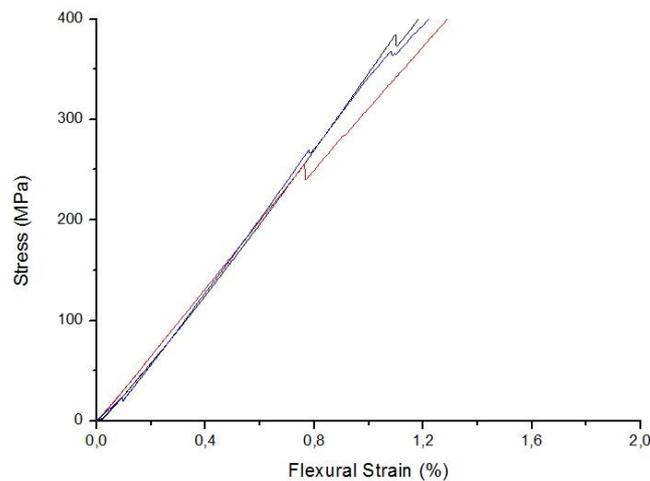


Figure 10. Diagram of Stress versus Flexural strain.

The elastic linear behavior of the tension-deflection diagram obtained in the three-point flexural test until the final fracture has the presence of small falls (and later gains in the load support) characterized by the different stress intensities corresponding to the fractures and of the different types of fibers used.

In Table 2, it is possible to observe the synthesis of the results of the mechanical properties (mean values) determined in the three point bending test, as well as the values of the respective standard deviations. The modulus of elasticity was measured before the beginning of the damage in about 30% of the last tension in order to avoid possible influence of the same in the calculation.

Table 2. Experimental results for flexural properties of LCV composites. Average results of 5 specimens.

Mechanical properties	LCV	
	Average	Standard deviation
Flexural Strength (MPa) ⁽¹⁾	343,08	28,6
Flexural Modulus (GPa) ⁽¹⁾	23,61	3,85
Flexural strain (%)	1,85	0,43

⁽¹⁾measured at 25°C

The standard deviations presented by the results are considered high, characterizing the behavior due to the hybridization process, manufacturing process, among others.

Batista et al. (2016) obtained values for hybrid fabric with E-glass / AS4 carbon in the three-point flexural test: 251.07 ± 21.9 MPa and for flexural strength and 10.9 ± 1.1 GPa for flexion. It was observed that the flexural properties of the glass / carbon laminate are higher, with strength and modulus of elasticity being higher by 41.73% and 16.3%, respectively.

3.3 Shear Test ILSS (Short beam)

Because of the simplicity of the method and the low complexity in the preparation of specimens, this assay is often used as a material quality control tool with wide acceptance to evaluate the composite fiber / resin adhesion properties.

In Figure 11 (A and B), we can see that the fracture region caused by the ILSS test on all specimens of the LCV laminate was not catastrophic. The interlaminar fracture propagates along the lamination plane, fig.7A, the specimens were adequately delaminated with a slit along the horizontal plane.

According to Botelho (2002) the macroscopic appearance of shear failure is dull and whitish. Particularly, in the case of interlaminar failure, the fracture tends to occur in the resin-rich region between the slides, thus remaining flat.

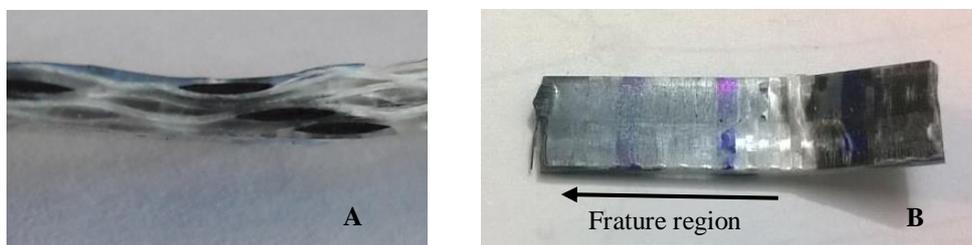


Figure 11. Laminate LCV frature region specimen. A) Vista lateral; b) Vista frontal.

Table 3 shows the average values for the ultimate stress, applied load and shear strength ILSS (Short beam) with their respective standard deviations. It is emphasized that for the shear strength ILSS the values were calculated according to the norm. It is observed that due to the characteristics of hybrid fabric, E-glass / AS4 carbon, lamination and shearing of specimens, an increase of the standard deviation occurred.

Table 3. Experimental results for Short Beam Strength properties of LCV composite.
Average results of 10 specimens.

Mechanical properties	LCV	
	Average	Standard deviation
Maximum Load (N) ⁽¹⁾	1140,57	19,85
Short Beam Strength (MPa) ⁽¹⁾	70,36	1,27

⁽¹⁾measured at 25°C

Prashanth et al. (2014) studied the interlaminar shear of hybrid composites made of glass / carbon in epoxy matrix with three-layer lamination and concluded that the ILSS value of 30.11 MPa for 5 specimens tested was justified because of the matrix material.

GuruRaja et al. (2013) studied interlaminar shear stress ILSS in glass / carbon hybrid composites in epoxy matrix, the results found that the method used was simple and effective to evaluate the structural properties of the composite laminates tested. The loading distribution due to normative geometry, 0/90 °, was best achieved due to the use of laminated composites with different materials and due to the sequence of lamination layers, resulting in a greater adhesion at the fiber / matrix interface.

4. CONCLUSION

The tests on the specimens of the LCV laminate showed a significant increase in flexural strength with respect to tensile strength being an attractive material for structural components when the tension used is essentially flexural. Shear strength showed that the use of the hybrid fabric improved the properties of the glass-E / AS4 hybrid laminate composite compared to the literature.

In the tests performed (tensile test and three-point bending) linearity is present until the final fracture.

The use of the carbon fiber glass fabric and the intraply-type hybrid lamination process overlapping the carbon fibers in random order has considerably increased the flexural strength of the hybrid laminate composite mainly due to the properties of the carbon fibers.

In this way, it can be stated that the processing conditions to obtain these composites were satisfactory in relation to the literature, even though the type of normative geometry (laminate configuration) and resin used in this study differ from those used in the literature.

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