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FRACTOGRAPHY OF THE FRACTURE MODE ON THE HYBRID POLYMERIC COMPOSITES GLASS / CARBON

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Abstract. *The investigation of this work has the objective of studying the failure modes of hybrid laminates composites reinforced by bidirectional E-glass fiber and AS4 carbon impregnated with polymer resin (NOVAPOL L120). The test specimens were initially subjected to mechanical tests of uniaxial traction, three-point bending and interlaminar shear ILSS (Short beam). The fractographic analysis of the final fracture of the laminates was performed by scanning electron microscopy (SEM). The fracture aspects in the fiber / matrix interface region were detailed, so it was possible to determine the direction of crack propagation and to characterize the fractures caused by the loading action.*

Keywords: *fractography, analysis, composites, interlaminar shear.*

1. INTRODUCTION

Polymeric composites reinforced by fibers are increasingly used in structural components. However, concentrated studies have been performed due to the occurrence of failures involving parts manufactured with these materials to prevent accidents and incidents.

The polymer composites reinforced with continuous fibers exhibit anisotropic behavior, meaning that their mechanical properties show variations in their planes of symmetry. In this way, when subjected to tensile, bending, compression and / or shear stresses, the composites can fail in several ways, these types of faults are directly related to the orientation of the fibers and the direction of application of the load. Damage to the laminate structure can occur in several ways, such as: interlaminar, intralaminar and translaminar, as shown in Figure 1. In the interlaminar fracture the failure occurs between the laminates that make up the laminate; In the intralaminar the fracture is located internally in the matrix, while in the translaminar the fracture is oriented in the transverse direction to the plane of the composite (Franco, 2003).

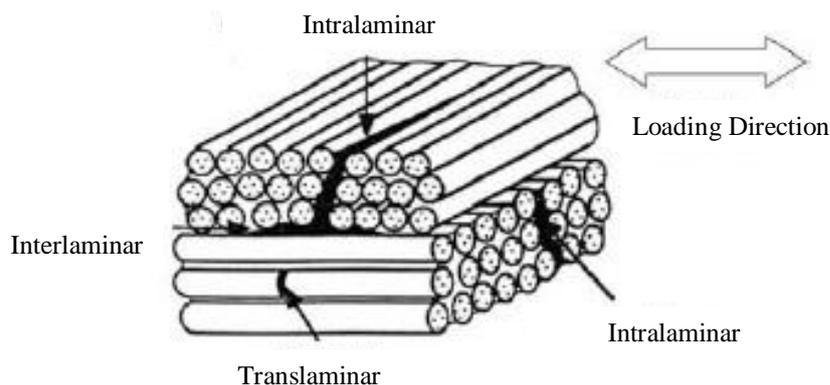


Figure 1. Failure modes of composite materials: intralaminar, interlaminar and translaminar. Adapted Franco (2003)

Fractography is one of the main tools used in the post-damage or failure analysis process. It consists in identifying the fractures and establishing the relationships between the presence or absence of these aspects, evidencing the sequence of events, which can lead to determination of loading and stress conditions at the time of failure. The fractography confirms or removes suspicions that may fall on the failure modes that occurred. (Franco, 2003).

According to Franco (2003) composite defects can be described by the mechanisms of damages that occur in the fracture. These can be identified by breaking the fibers, cracking in the matrix or interlaminar delamination, among others. Fracture and cracking are dependent on the strength properties of the constituent materials, while delamination may be caused due to fabrication, stacking of the layers of the laminate, curing process or impacts occurring over the life of the material. As loading progresses, accumulation of local damage or failure in the laminate causes the composite to fail. The catastrophic fault occasionally occurs in the load corresponding to the initial failure or the failure of the first layer. The prediction of subsequent failure requires an understanding of the initial failure modes and propagation modes of failure in the laminate.

Microstructural analysis of the composite provides information on fiber morphology, orientation and number of layers, fiber distribution, size and distribution of failures that may occur at the manufacturing stage, such as voids, porosities, fiber misalignment, layers, resin bags, and structural damage caused by delaminations and microcracks. In view of the above, the objective of this study is to investigate the damage mechanism of polymeric two-way laminate reinforced by hybrid fabric E-glass fiber and AS4 carbon. In this study the bidirectional hybrid tissue was employed by the ortho-terephthalic unsaturated polyester resin (NOVAPOL L120). The manual lamination process is used (hand lay-up) with four layers of reinforcement. The specimens were submitted to mechanical tests (uniaxial traction, three-point flexion and interlaminar shear ILSS). The fractographic analysis of the failure mode of the laminates was performed by scanning electron microscopy (SEM).

2. EXPERIMENTAL

2.1 Preparation of the Composites

The hybrid composite laminate was made using the manual lay-up process. Using four layers of hybrid fabric glass-E / AS4 carbon commercially identified CVQ-339, manufactured by TEXIGLASS Industria e Comércio Têxtil. Bi-directional hybrid fabric contains 23.35% AS-4 (PAN) carbon fiber, 76.65% E-glass fiber and 340 g / m² fabric weight, see Fig.2.

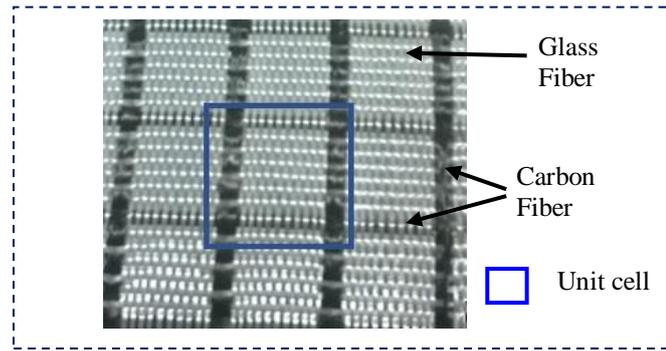


Figure 2. Configuration of hybrid fabric glass-E / AS4 (CVQ-339)

Hybrid fabric CVQ-339, Figure 2, was impregnated with ortho-terephthalic polyester resin (NOVAPOL L120), without the additional use of styrene. As the catalyst agent, methyl ethyl ketone resin (MEKP) was used.

For the accomplishment of the mechanical tests, the specimens were cut using a disc with diamond cut wire and its sides sanded and polished according to the metallographic techniques.

The dimensions of the test specimens and the performance specifications of the tests followed the standards ASTM D3039 M-08, ASTM D790 and ASTM D2344 for the tests of uniaxial traction, three-point bending and interlaminar shear ILSS (short beam), respectively. The assays were performed at room temperature (25 ± 2 ° C).

Table 1 shows the dimensions adopted for the specimens according to each test. Figure 3 shows the hybrid laminates glass-E / carbon AS4, HVC laminate prior to mechanical testing.

Table 1. Dimensions of specimens HVC.

Mechanical Tests	Length (mm)	Width (mm)	Thickness (mm)	Span (mm)
Uniaxial Tensile	250	25	2,30	127
Three-Point Bending	58	25	2,30	37
Shear Interlaminar (ILSS)	25	6,4	2,30	10

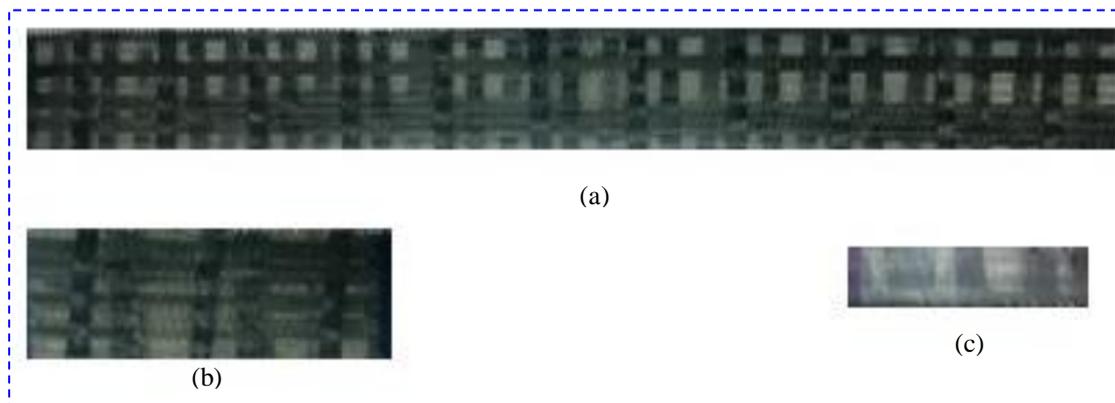


Figure 3. Images of HVC laminates before mechanical tests: a) uniaxial traction; b) three-point bending and c) shear ILSS (short beam) .

2.2 Morphological Surface Analysis

The fracture characteristics of the specimens were performed in two stages. The first step consisted of a macroscopic analysis of the mechanical failure with the objective of knowing the formation and distribution of the same along the entire length of the test body. The second step consisted of the microscopic analysis of the damages, in order to detect fracture of the types: adhesive (fiber / matrix interface), cohesive (in fiber or matrix), and microcracking of the matrix and delamination along the cross section) of the specimen.

Scanning electron microscopy (SEM) images were performed for further detailing of the cross-section of the HVC laminate. The scanning electron microscope, brand TECSAN model Vega 3 LMU, operated with acceleration voltage from 10 kV to 20 kV and varied magnifications for the study configurations. HVC laminates were placed in an oven for 4 hours at a temperature of 80 ° C to remove moisture, and then covered with a layer of gold. This procedure aims to

provide information about the interactions between the phases and disruptions, in addition to visualizing the damages in the specimens.

3. RESULTS

The microstructural analysis of the HVC laminate was performed using the optical microscopy technique prior to the mechanical tests. As can be seen, in Fig. 4, the layers of the composite laminate have a good compaction of the matrix in the reinforcement of the hybrid laminate. These conditions are adequate and expected with good adhesion at the interface between the matrix and reinforcement, a condition necessary to obtain good mechanical and viscoelastic properties in the composite laminate.

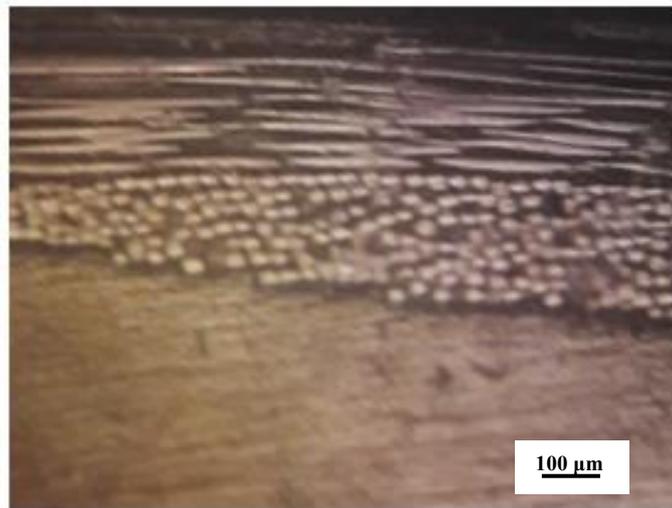


Figure 4. Optical photomicrography of composite HVC laminate.

3.1 Uniaxial Tensile Test

The characteristic of the macroscopic fracture observed in the HVC test specimens is shown in Fig. 3, where it is observed that the fracture was not catastrophic. The rupture mode can be classified according to ASTM D 3039, as type LGM (Lateral-Gage-Middle). It should be noted here that this standard does not address composites using hybrid fabrics.

Figure 5 shows the tearing of glass fiber / carbon in the traction direction and the whitening of the region near the rupture site, which may be characterized by the displacement of the glass fibers of the composite interface and resin at the interface. These types of damages are characteristic of composite materials reinforced by synthetic fiber fabrics (Serafim, 2015).

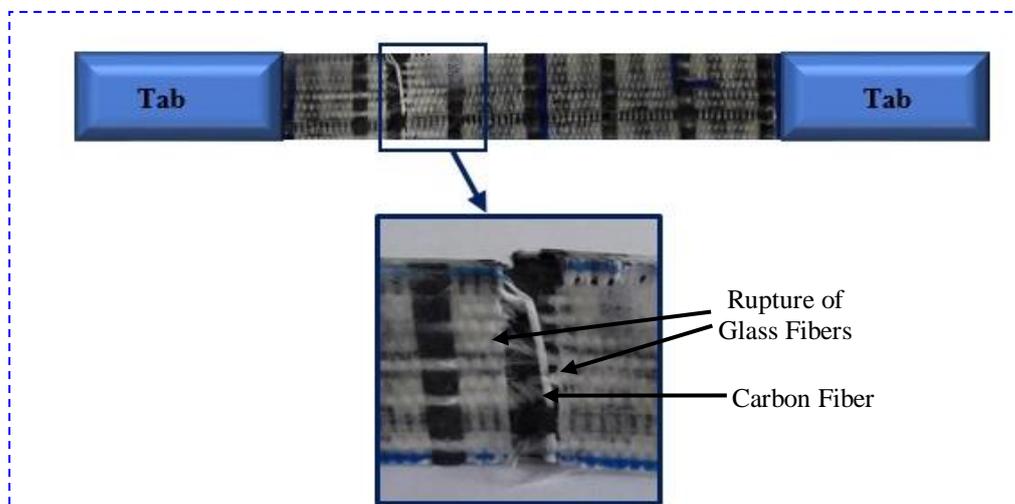


Figure 5. Fracture characteristic - HVC laminate - uniaxial tensile.

In figure 5, it can be seen that no total damage of the carbon wires occurred in the direction of the fabric web. This phenomenon can be justified because the tensile strength of the AS4 carbon fibers is much larger than the E-glass fiber.

Figure 6, by means of SEM analysis, it is possible to observe in detail, fig.6 (a), the transverse region of the specimen, the presence of microcracks and cracks. Figure 6 (b) shows the presence of adhesive fracture in glass and carbon fibers, cohesive fracture in the matrix (both in the form of microcracks and cracks) and rupture of glass and carbon fibers.

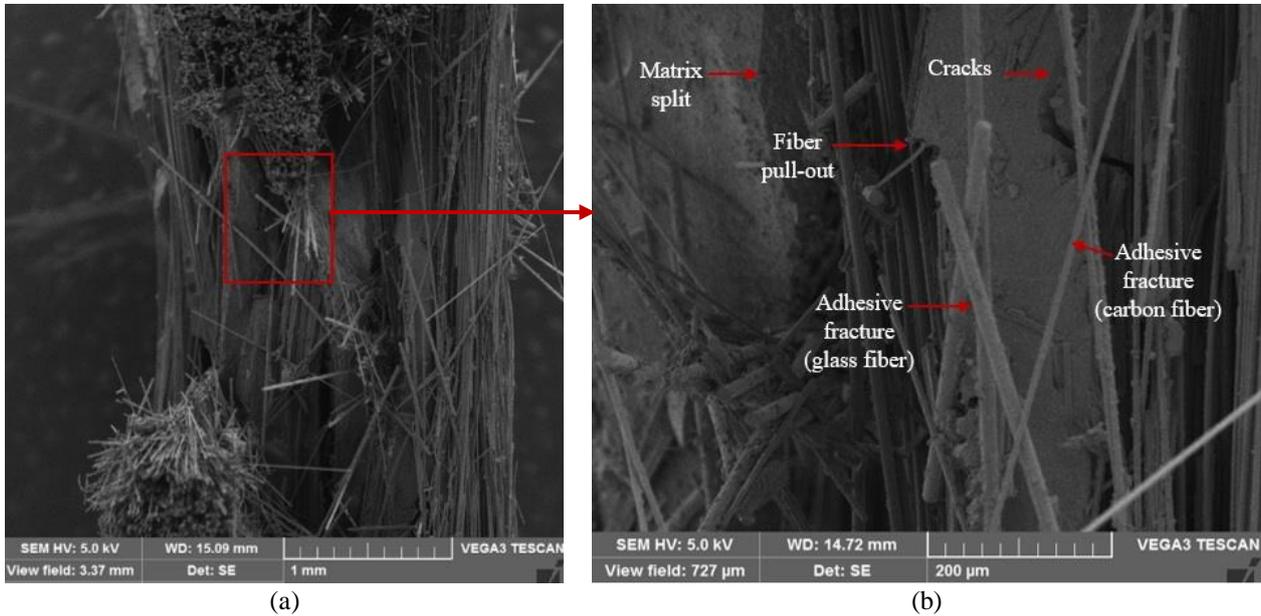


Figure 6. (a) Uniaxial tension – Fracture characteristics – HVC laminate; (b) highlight of the characteristic damage.

Figure 7 (a) and (b) shows some of the damage characteristics of the HVC laminate. It can be highlighted, Figure 7 (a), the presence of cracks present in the matrix propagate towards the interior of the hybrid reinforcement leading to the fiber-matrix interface, and this type of fracture is called an adhesive fracture. Looking at fig. 7 (b), we can observe the microcracks and cracks in the matrix (cohesive fracture). This type of damage tends to break the fiber, this characteristic was detected in the fiberglass, fig. 7 (b).

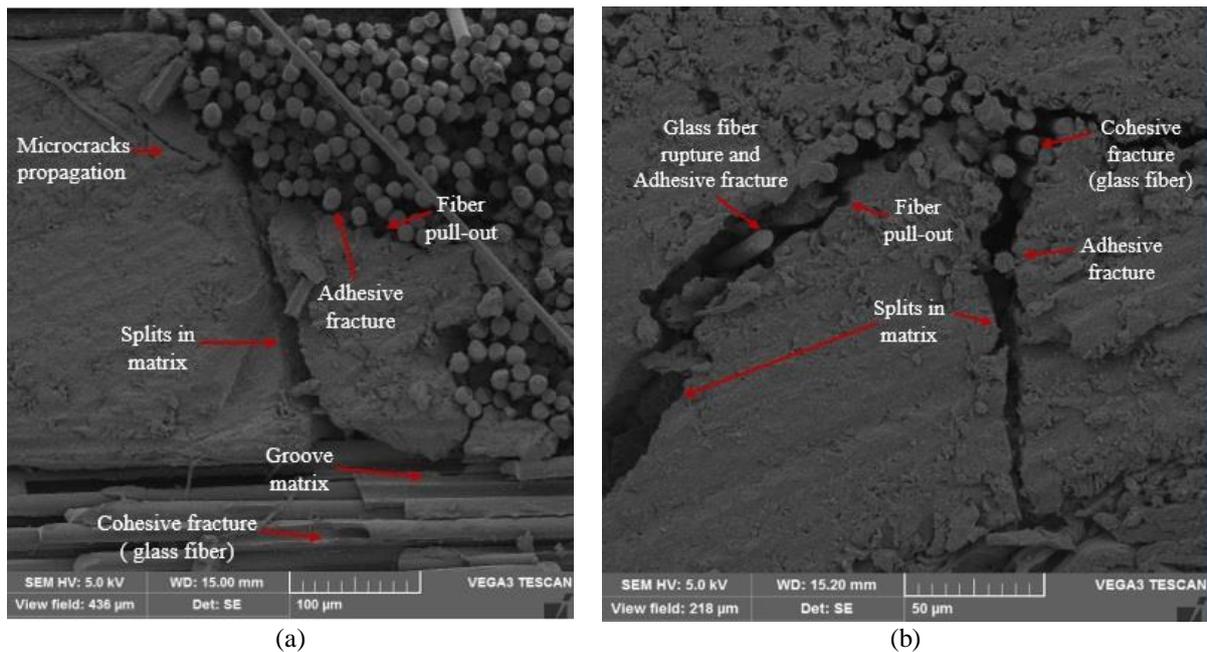


Figure 7. (a), (b) Uniaxial tension – Fracture characteristics – HVC laminate.

3.2 Three-point Bending Test

The characterization of the final fracture of the specimen of the three-point flexural test, Fig. 6, is located on the traced surfaces of the specimen. There was no complete fracture of the specimen resulting in bleaching of the final fracture region, fig.8, located in the cross section of the specimen.

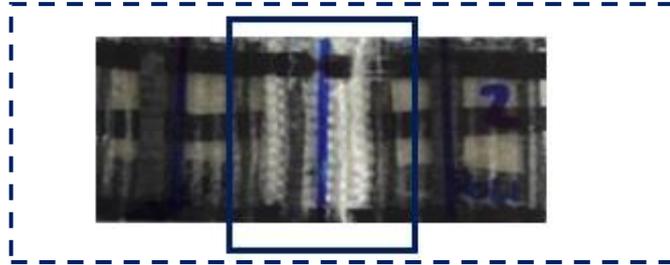


Figure 8. Fracture characteristics – HVC laminate – three-point bending.

Continuing the analysis of the fracture, but more detailed through the use of SEM, figure 9 shows the fracture of the specimen, linking HVC.

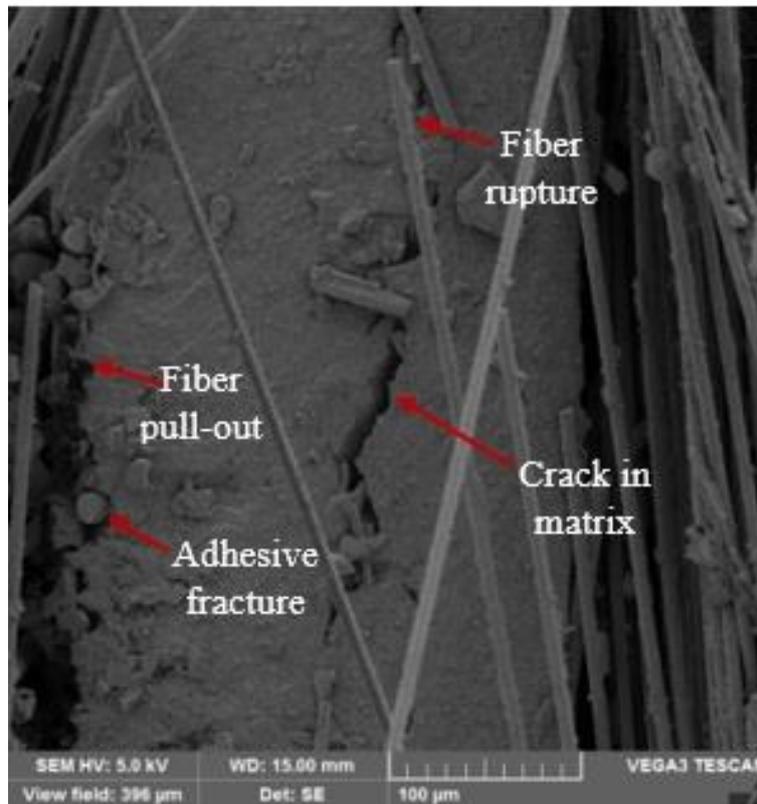


Figure 9. Fracture characteristics – HVC laminate – three-point bending.

Looking at Figure 9 one can see the crack formation in the drawn region, the location of this slit being a good characteristic of the performance of the laminate due to the loading of bending. However, there was also the formation of adhesive fracture, provoked by the adherence loss at the fiber / matrix interface, in addition to fiber bundling.

Figure 10 (a) and (b) shows the details of the slit in the cross section of the specimen, where it can be observed the formation of grooves in the matrix characterized by the transfer of tensions from the resin to the fiber, when it is requested by the loading. Figure 10 (b) shows the presence of grooves in the matrix (generation of breaking of the tensile side of the specimen) and its propagation caused adhesive fracture (Fig.10 a) and rupture of carbon and glass fibers. As might be expected due to the flexural loading in the HVC laminate.

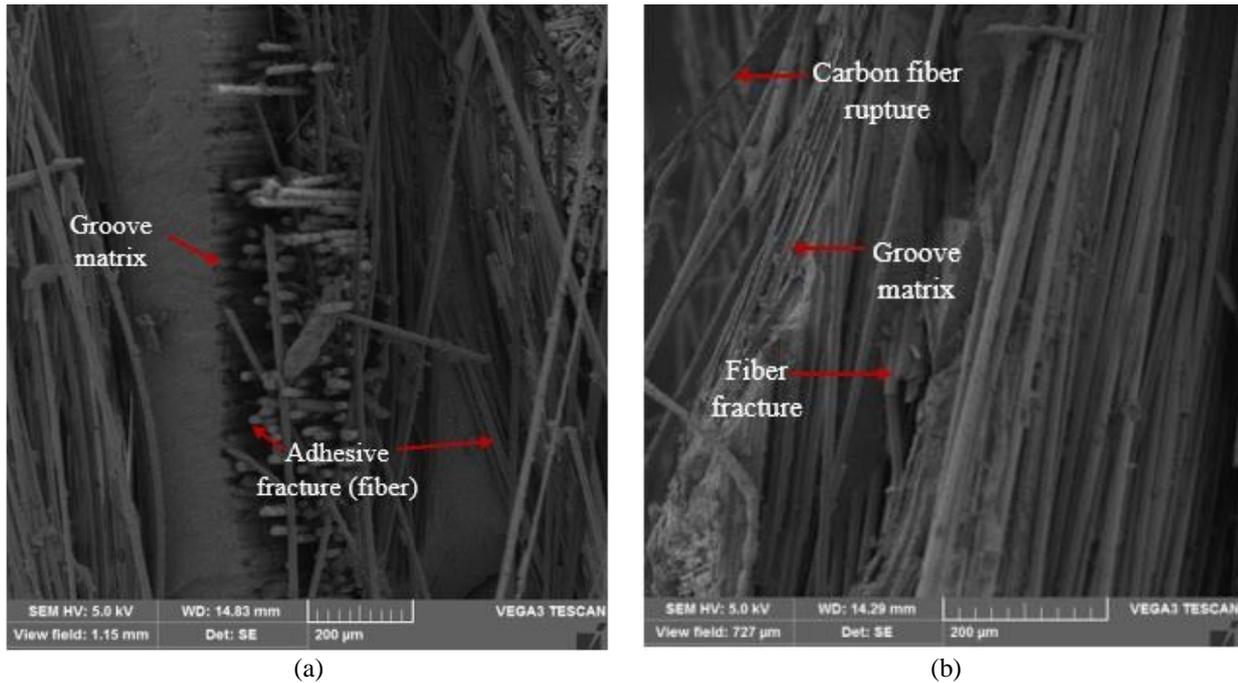


Figure 10. (a), (b) Fracture characteristics – HVC laminate – three-point bending.

3.3 Interlaminar Shear Strength Test (ILSS)

The interlaminar shear strength test (ILSS) was used in this study to evaluate the quality control of the HVC laminate, because it was manufactured manually. This assay was used because it is easy to interpret, fast to evaluate the processing conditions and because it requires little material to perform the test (Campos, 2010).

The characteristic of the final fracture in the specimen can be classified as shear and flexion (valid) according to ASTM D2344, Fig. 11 (a) and (b) where delamination fracture is observed (Fig. cross-section along the test piece. Figure 11 (a) shows the fracture zone where the fracture occurred due to the occurrence of resin-rich regions between the composite sheets.

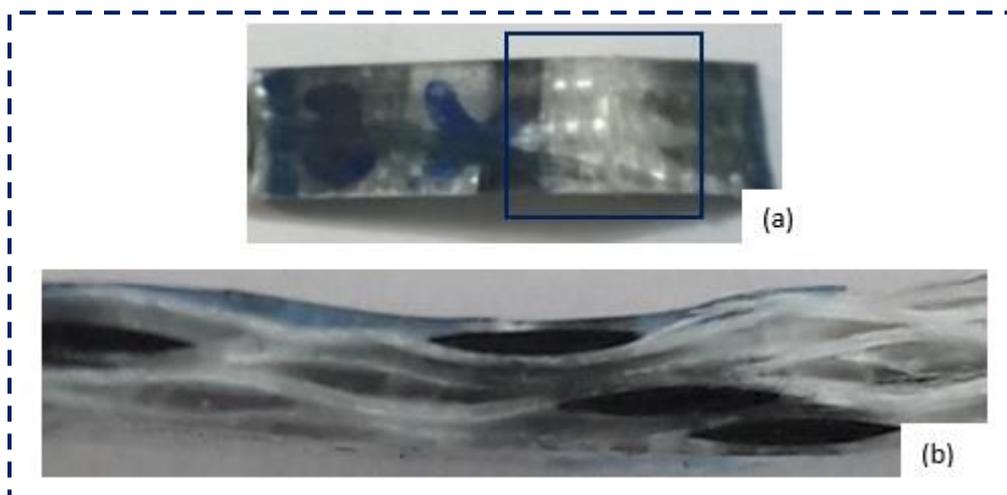


Figure 11. (a), (b) and (c) Fracture characteristics – HVC laminate – Interlaminar shear (ILSS)

Figure 12 shows the photomicrograph of the fracture characteristic of the HVC laminate. The interlaminar fracture (delamination) between the layers of the laminate, as well as the propagation of the transversal cracks along the specimen, evidences the breakage of the same by the action of the interlaminar shear loading.

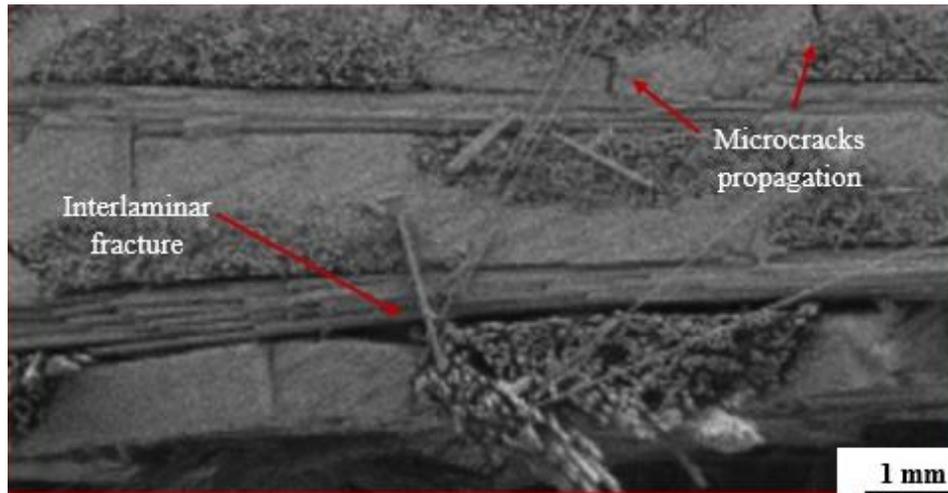


Figure 12. Fracture characteristics – HVC laminate – Interlaminar shear (ILSS).

From the photomicrograph of the HVC laminate it can be seen that there were separations (microcracks) between the layers of the laminates towards the fibers, fig.

Figure 13 (a) and (b) show photomicrographs obtained by MEV from the HVC laminate, in which it can be verified that, after the interlaminar shear test of the specimens, the fracture mode was classified as corroborating with macroscopy of the test body, as stated above.

The fracture region indicated in Figure 13 (a) indicates the crack propagation forming grooves within the matrix of the fractured laminate, i.e., the rupture occurred at the interface of the matrix (cohesive fracture). Figure 13 (b) shows the detail of shear failure between the fiber bundle of the laminated fabric causing fiber pullout as well as fiber breakage by the stresses transferred from the resin to the fiber.

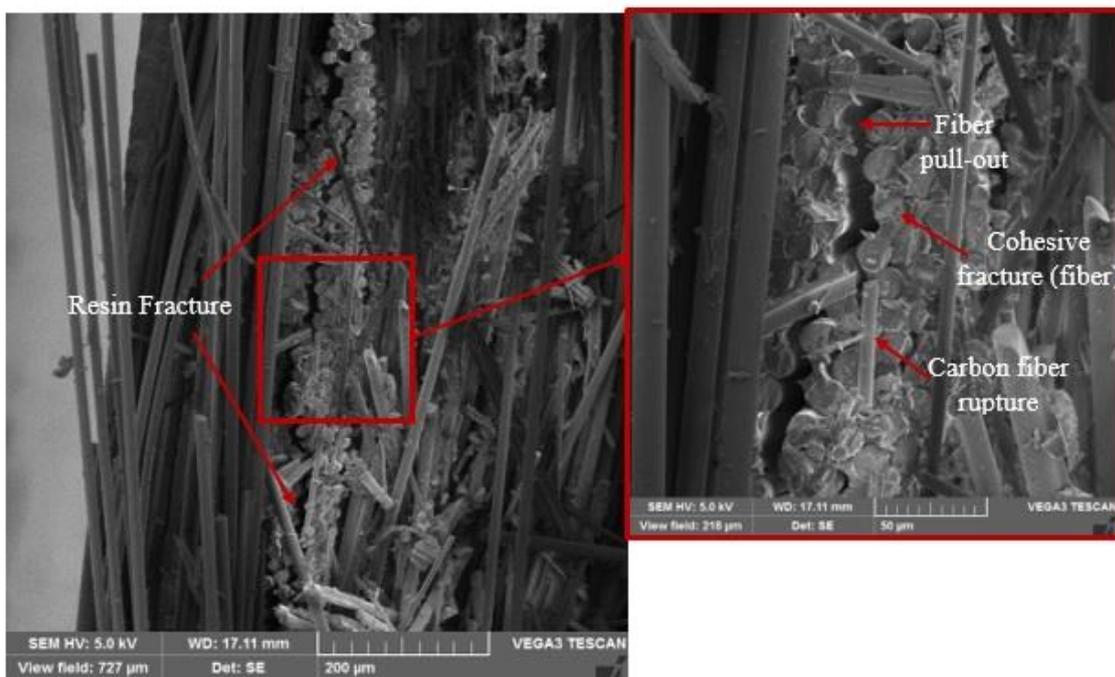


Figure 13. (a) Fracture characteristics – HVC laminate – Interlaminar shear (ILSS); (b) highlight of the characteristic damage.

4. CONCLUSION

In the analysis of the obtained results, it can be concluded that the fracture process of the HVC laminate was not catastrophic in all the specimens.

The appearance of macroscopic and microscopic fractures in the specimens established the incidence of defects (microcracks, delamination, among others). In the section of the final fracture of the specimens, it was possible to observe translaminar cracks, matrix splitting and interlaminar delamination in regions rich in resins.

Due to the anisotropic construction of the composite laminate, the fracture process has different failure mechanisms and can be influenced by the characteristics of the fibers used, the behavior of the polymer matrix, the type of hybrid fabric used as reinforcement and the properties of the fiber / matrix interface.

We can also emphasize that the HVC laminate produced good results compared to the literature.

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