SALT-WATER AND UV RADIATION CONDITIONING EFFECTS ON SHEAR MECHANICAL PROPERTIES OF CARBON FIBER/PPS COMPOSITES

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Abstract Carbon fiber reinforced composites with thermoplastic matrices have been more and more used in structural components for aerospace, automotive and marine applications. The composites with polyphenylene sulfide matrix (PPS) and carbon fiber reinforcement are known by their attractive properties such as: good mechanical properties (flexural, tensile and shear properties); elevate temperature resistance; excellent chemical attach resistance; low humidity absorption and dimensional stability. In service, failures of continuous fiber-reinforced thermoplastic composites are commonly attributed to ageing of the material in a particular environment, brought about by a combination of the effects of heat, light, water and mechanical stresses on the material. Several studies have addressed the important effects of absorbed water and ageing temperature on the physical and mechanical properties of composite materials. It has been observed that, above a threshold related to a given temperature and a given ageing time, mechanisms other than simple diffusion can take place within the material. Both UV radiation and moisture have adverse effects on the mechanical properties of polymeric matrix. The polymer matrix in a fiber-reinforced composite helps to transfer applied loads to the reinforcing fibers and provide interlaminar shear strength, whereas the fiber-matrix interface governs the load transfer characteristics and damage tolerance. The purpose of this work is to evaluate the influence of salt-water conditioning and UV radiation on shear properties of PPS/Carbon Fiber composite. For this work, the laminates have been supplied by Ten Cate Dutch Company. The specimens were divided into two sets: first set: PPS/carbon fiber specimens have been immersed in artificial sea water, prepared according to ASTM D 1141-98; second set: PPS/Carbon fiber specimens have been submitted to UV conditioning chamber for time periods of 300, 600 and 900h. Both conditioned specimens sets have been tested by ILSS and Iosipescu shear tests, according to ASTM D-2344 and ASTM D-5379 normatives, respectively, and compared with the obtained values of non-conditioned specimens. According to this work, for all specimens studied the ILSS values decrease significantly when exposed to hydrothermal conditioning. Wet conditioning induces strong matrix plasticization but the moisture adsorption is not uniform thoughtout the material.

Keywords: *thermoplastic composite, environmental effects, ILSS shear test and Iosipescu shear test*

1 INTRODUCTION

Continuous fiber reinforced thermoplastic composites have been developed as an alternative to thermoset fiber composites (Botelho, et al., 2005). In general, they have high specific stiffness and specific strength, better mechanical resistance, and their process do not require complex chemical reaction and can be formed without curing processes (Kishi, et al., 2004).

The PPS (polyphenylene sulfide) have been studied as a matrix in thermoplastic composite materials due to present a high performance polymer with processing temperature associated with good mechanical properties principally when reinforced with continuous fibers. Polyphenylene Sulfide is a highly crystalline polymer (range of 50-60%) with appreciate combination of properties, like chemical and fire resistances and thermal stability. It’s also an excellent corrosion resistance, to its inertness to organic solvents, inorganic salts, and bases (Arici, et al., 2005)(Jang, et al., 1996)(Perng, 2000).

Polymeric composite materials may be subjected to mechanical stresses and environmental attacks when in practical use. The environmental attacks are more usually related to temperature, moisture, salinity environment and ultra-violet light exposition (Botelho, et al., 2007). They have adverse effects on the mechanical properties of polymeric matrix, while the ceramic continuous fibers are not significantly affected by either environment.

Literature studies propose different devices to comprehend the shearing properties of composites. One of the most used shear test, which allows a nearly pure-shear stress state at the shear plane, is the v-notch shear test (Liu, 2005)(Wang, et al., 2007)(Baker, et al., 2004).

This work reports the influence of seawater and UV effects on the shear strength properties of carbon fiber/PPS laminates. In order to achieve this objective, carbon fiber/PPS specimens were evaluated by Iosipescu and short beam shear tests before and after to be submitted to seawater and UV conditionings.

2 EXPERIMENTAL PROCEDURE

2.1 Material

The carbon fiber/PPS composite was supplied by TenCate Company (from Netherlands). The laminate, with 2.3mm of thickness was made with Poly(phenylene sulfide) and 64% volume content of carbon fiber in 5HS fabrics layers with [0/90] orientation.

2.2 Environmental Conditioning

The specimens designated to seawater environmental were firstly dried in a vacuum chamber and heated at 60°C for 24 hours. Then, these specimens were weighed and immersed in salt water bath prepared according to ASTM D 1144- 98 standard, that covers the preparation of solutions containing inorganic salts in proportions and concentrations representative of ocean water.

The specimens were immersed for a period of approximately one month in a recipient with this solution until the saturation point of the material, verified by weighting every three days.

The degradation mechanisms caused by UV radiation were determined according to ASTM G154 standard to test methodology for QUV/Se weathering chamber (Q-Panel Lab Products, Cleveland, Ohio). According to this standard, damages caused by sunlight and rain was reproduced by cycles of period of eight hours under UV-B light and eight hours under water condensation provided by the generation of vapor from a water bath. In this test, the specimens were submitted until 300, 600 and 900h.

2.3 Mechanical tests

All mechanical tests were done with 5 specimens to get the average and standard deviation values. The geometries required for the specimens were manufactured according to the specific standards to each shear test method.

The conditioned specimens were evaluated by Iospescu shear and ILSS shear tests according to ASTM D 5379 and ASTM D 2344 standards, respectively and both tests were done in an universal Shimatzu mechanical tests machine. In this case, the ILSS shear tests were done using speed test of 1.0 mm/min and a load cell of 10KN and the o Iosipescu shear tests were done using speed test of 2 mm/min and a load cell of 50KN.

The ILSS test is known by its simplicity of specimens confection and low cost to use. Its method test determines the interlaminar shear strength of composite laminates by the load applied and the dimension of the specimens. However, spite of the specimens dimensions are normalized by the standard, the material properties have influence above the failure modes. Thermoplastic polymer materials could not failure by interlaminar shear and can failure by flexure mode because of their viscoelastic nature, how it is illustrated by the Fig. 1 (ASTM-D2344).

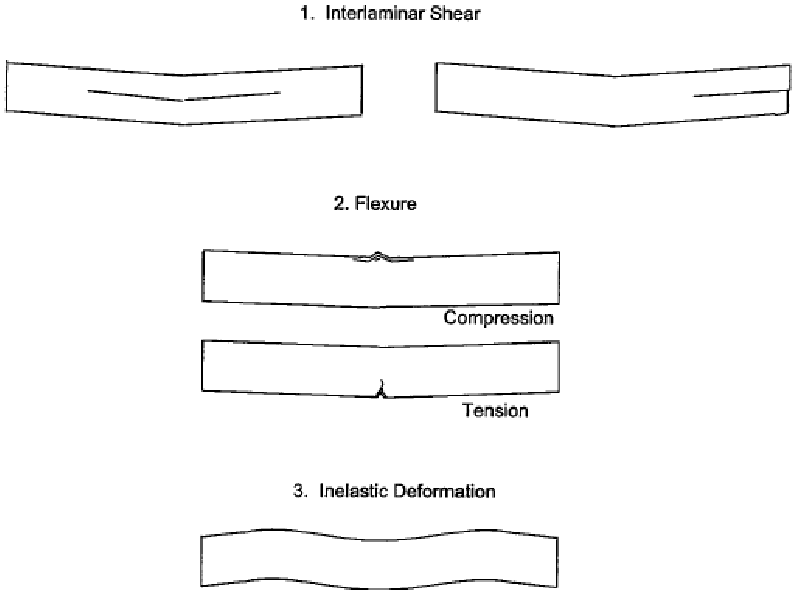


Figure 1 Failure modes in an ILSS test (ASTM-D2344).

The maximum interlaminar shear strength obtained from the ILSS test was determined using Eq.1. (ASTM-D2344).

$F\text{sbs} = 0.75 * Pm/b * h$ (1)

Fsbs = short-beam strength, MPa (psi);
Pm = maximum load observed during the test, N (lbf);
b = measured specimen width, mm (in.), and
h = measured specimen thickness, mm (in.).

The Iosipescu shear test is better to characterize the shear properties of composite laminates, especially when the matrix material is a thermoplastic polymer. It is because the test induce a pure shear stress on material due to the specimens confection and the load applied, how shown in Fig 2 (a).

In general, the specimens have a rectangular flat strip with a symmetrical centrally located *v*-notches, as shown in Fig. 2 (b), inserted into the fixture with the notch located along the line of action of loading . Also that, the Iosipescu can determine the three failure mode to laminated composites (interlaminar, intralaminar and in plane modes), according to the orientation of the material plane. Whereas, this work used specimens with plane orientation of 1-2 and 2-1, that characterize the in-plane mode failure (ASTM-D5379).

The maximum interlaminar shear strength obtained from the Iosipescu test was determined using Eq.2. (ASTM-D5379).

$F^u = P^u/A$ **(2)**

F^u = ultimate strength, MPa (psi);
Pm = the lower of ultimate or load at 5% shear strain, N (lbf);
A = cross section area, mm^2 ($in.^2$)

(a) (b)

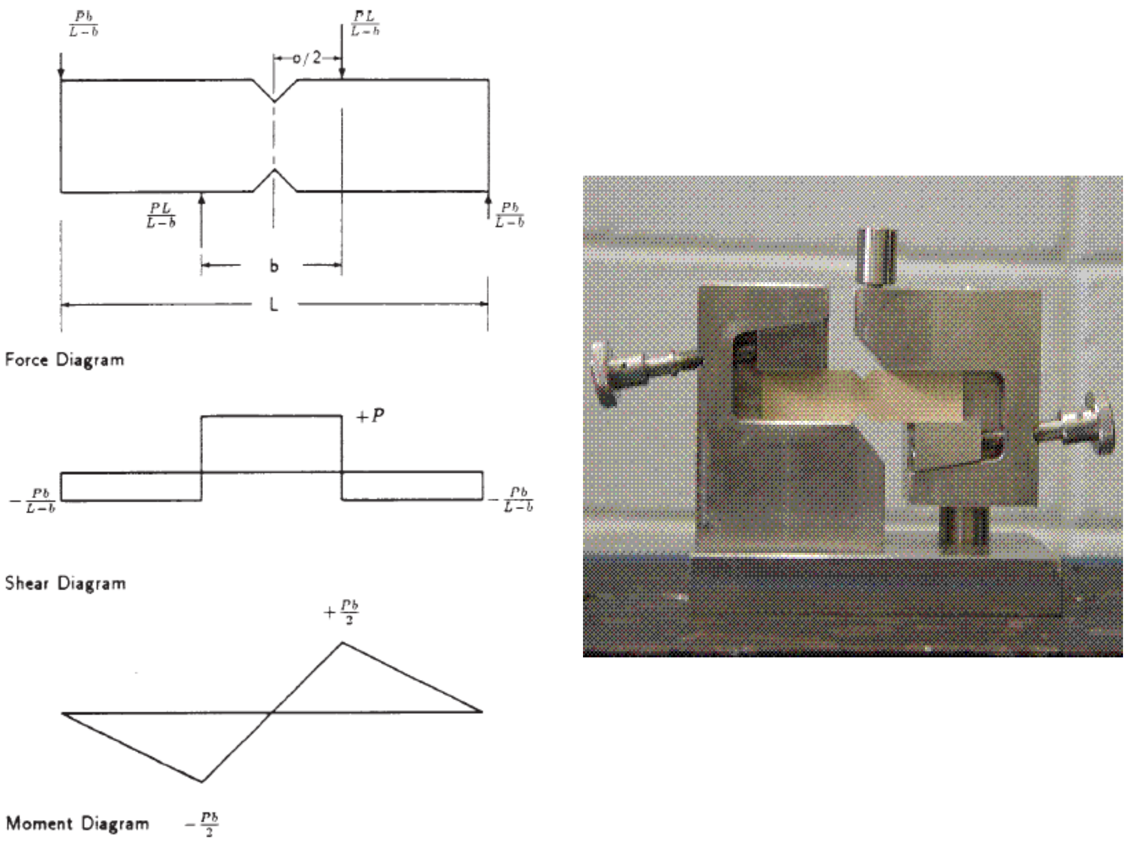


Figure 2 (a) Idealized Force, Shear, and Moment Diagrams (ASTM-D5379); (b) a representative V-Notched Beam Test Fixture Schematic (material: glass fiber/PPS).

3 RESULTS AND DISCUSSION

3.1 Environmental conditioning

Figure 3 presents the moisture absorption rate curves for PPS/carbon fiber laminates specimens dropped to seawater solution with the average values. The profile of the curves shows an initial linear region corresponding to a steady rate of moisture absorption up to a flat plateau of maximum moisture uptake. According to Fig. 3, the composite materials reached the maximum saturation point around 30 days for specimens dropped in seawater solution. At this point, the carbon fiber reinforced material exhibits a 0.08 % increase in weight for specimens in seawater solution.

Long period of exposition to humidity or immersion bath can cause a gain of weigh and a raise of volume (Staab, 1999). This behavior happens due to water absorption by diffusion process according to Fick law, however, the presence of microcrack and voids in the material can explain the fast rate of weight gain in the first days (Huang, 2008). Other situation is that when the material is immersed in a salt solution, the salts can influence the weight gain (Cioffi, 1996).

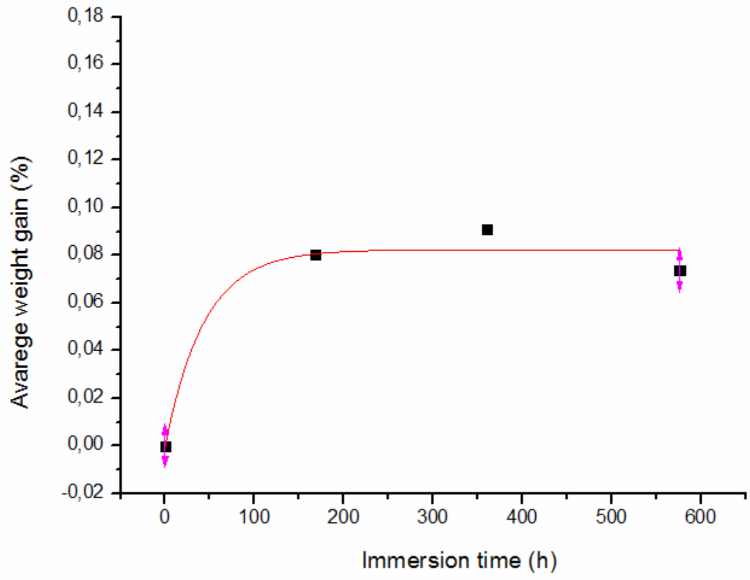


Figure 3. Average weight gain in seawater conditioning.

Figures 4 and 5 show the results obtained after the thermoplastic laminates to be submitted to UV conditioning. According to these figures, the material suffered degradation under UV-B exposition. The superficial degradation of the material was verified by the change of the surface color, as shown in Fig. 4. The structural degradation have been evaluated by the loss of weight, as a result of the increased of reticulation resulting from photo-oxidation reactions induced by UV radiation (Fig. 5).

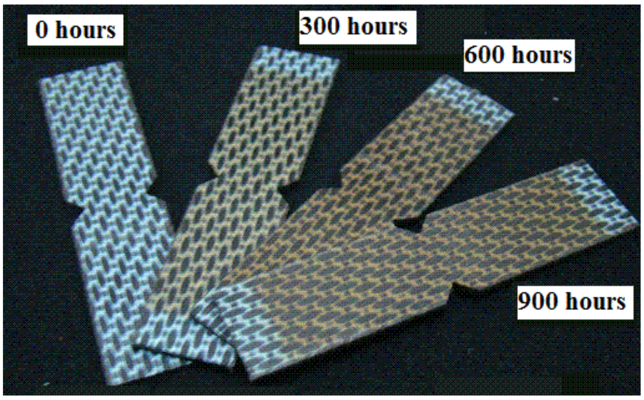


Figure 4 Carbon fiber/PPS superficial degradation.

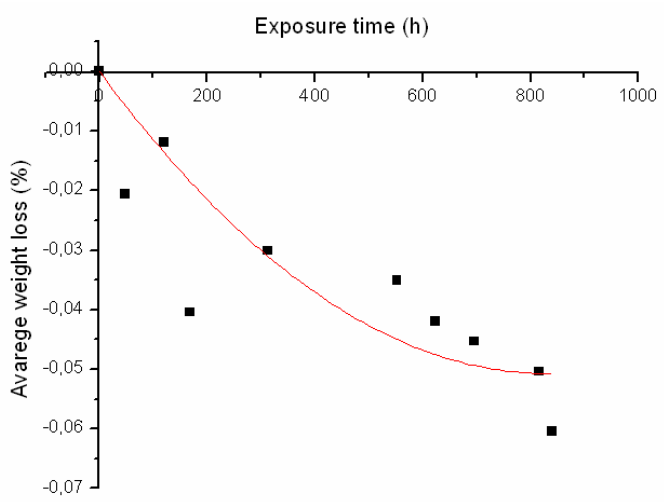


Figure 5. Average weight loss in UV radiation conditioning.

3.2 *Mechanical testing*

The conditioning specimens were tested by the Iosipescu and ILSS method and compared with a non-conditioned material. As can be observed by using Tab. 1, the interlaminar and in plane shear strength decrease when exposed to seawater and UV conditionings.

Table 1. Carbon fiber/PPS shear properties

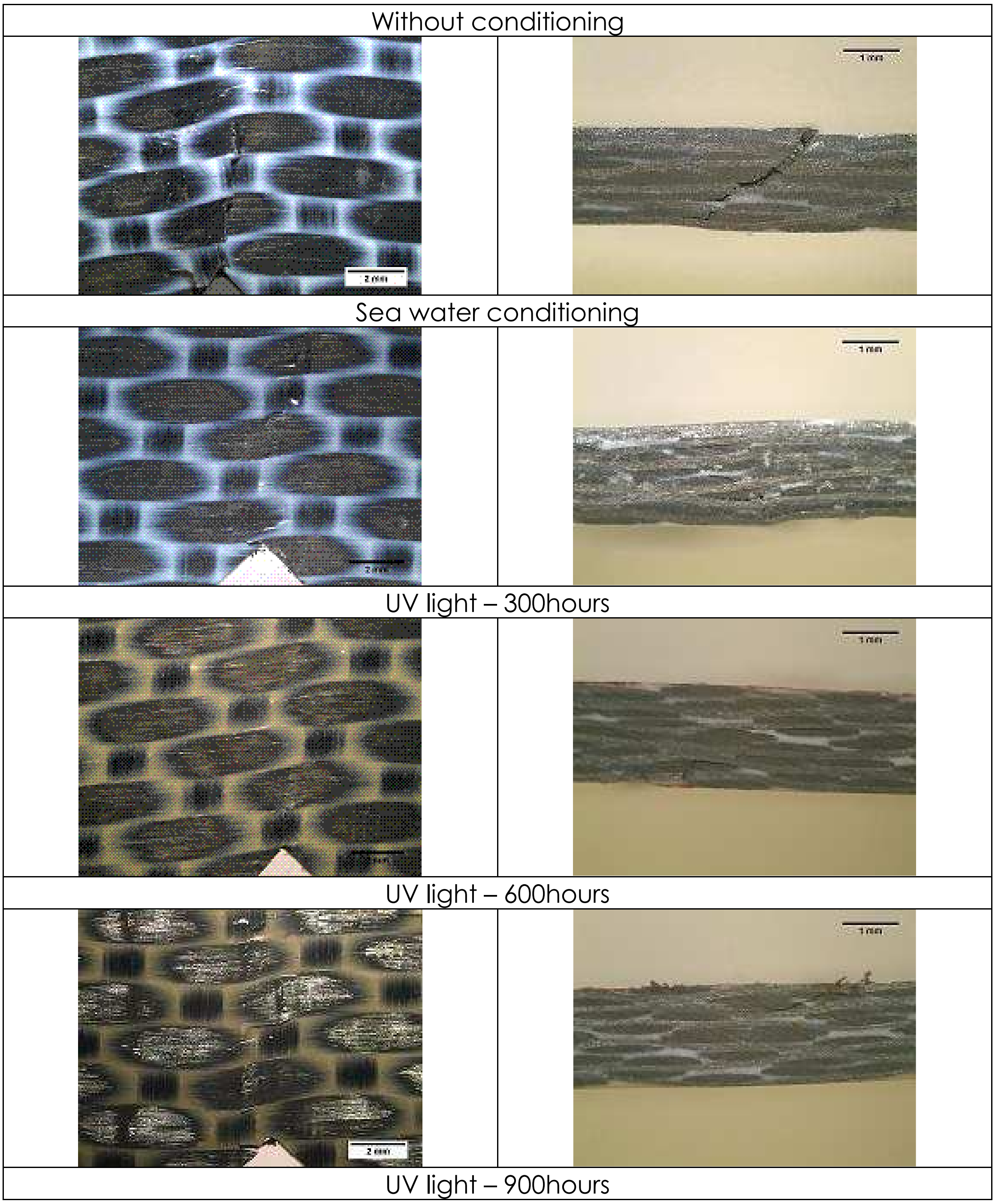
Carbon fiber/ PPS		Ultimate shear strength (MPa)	
		Iosipescu (MPa)	ILSS (MPa)
Non-conditioned		109.2 ± 0.4	58.4 ± 1.9
Sea water conditioning	exposure time: 30 days	95.56±9.06	56.4 ± 1.4
UV - light conditioning	exposure time: 300 hours	103.02±6.6	57.2 ± 2.2
	exposure time: 600 hours	98.03±10.7	52.2 ± 2.0
	exposure time: 900 hours	94.42±5.6	53.3 ± 1.3

The saline conditioning causes the interface degradation due to the humidity action and a strong matrix plasticization by the water presence between the polymer amorphous places. Under UV exposure, the PPS matrix presents its principal chain scission by the photo-oxidation. This action provokes micro-cracks and voids in matrix and fiber/matrix interface and the continuous exposure to UV-light reduce the fiber/matrix interaction.

Figure 6 presents the morphology of the failure mode aspect by ILSS test in seawater and UV light conditioning carbon fiber PPS composites specimens after being submitted to these conditionings. It can be observed that the composite exhibits delamination mechanisms with interlaminar cracks, characterized for parallel failure and vertical positions created by the high out-of-plane components of stress presents in ILSS tests.

However, there are evidences of flexural fractures, with a small bended of specimens or failures in the surface that covers the material in the normal direction to the lamination.

In the Iosipescu test, the laminates before and after the conditioning exhibit the same failure modes, according to Fig. 6. In all loaded specimens, the first observable failure was in notch-root splitting which starts near the notch-roots and propagates away from the inner loading blocks along the fibers.



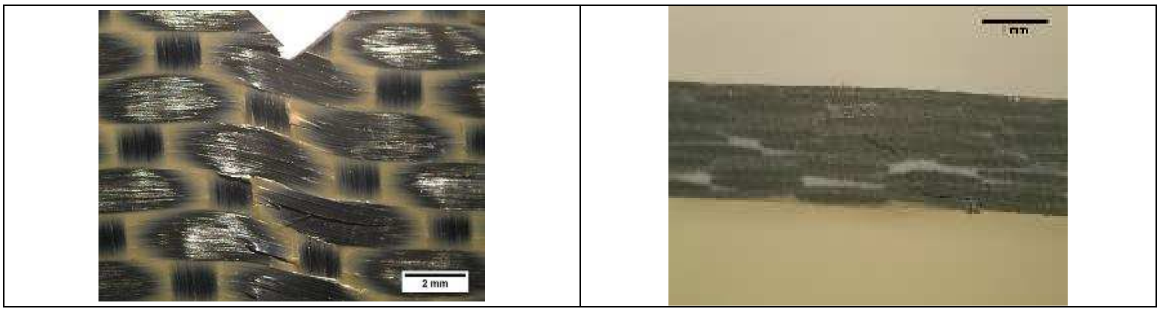


Figure 6. Representative fracture observed by Iosipescu and ILSS test respectively.

4 CONCLUSIONS

The influence of seawater conditionings and UV light in shear properties of carbon fiber/PPS composites has been investigated. It was observed that this laminate absorbed 0.08% of moisture after the saturation point, when submitted to seawater conditionings and loss 0.06% of mass on the UV light conditioning.

For all specimens studied in this work, the ILSS and Iosipescu values decrease when exposed to environmental conditioning. It is because the humidity induced matrix plasticization and, consequently, reduces the shear strength values of the laminates.

The small amount of actual decrease in the mechanical value observed in Iosipescu test is due to the fact that changes induced by UV radiation are surface phenomena. In this work it was also observed that this laminate exhibit multiple delaminations having interlaminar cracks at horizontal and vertical positions after and before to be submitted environmental conditionings. In this last conditioning, this behavior happened due probably to the higher ductility generate by the UV radiation process. Therefore, all specimens submitted to Iosipescu test exhibit the same failure modes.

5 ACKNOWLEDGEMENTS

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