EVALUATION OF THE ENVIRONMENTAL CONDITIONING ON SHEAR PROPERTIES OF GLASS FIBER/PPS THERMOPLASTIC COMPOSITES

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ABSTRACT

Composites are used in a large variety of engineering applications. Most of these applications are based on thermosets laminates that has reasonable mechanical properties, but low impact, chemical and environmental resistances. The advanced thermoplastics composites are known by their superiority properties and their easiness to be processed and stored. Among those materials, the poly (phenylene sulfide - PPS) stands out because of their structural characteristics, which provide its dimensional and thermal stability, low humidity absorption, excellent chemical resistance and good mechanical properties as flexural, tensile and shear properties. Because of these attractive characteristics, this polymer is considered as a good candidate in order to be used in the next generation of composites that could be applied in the submarine and ship building or offshore oil industries. For this reason, the focus of this work is to evaluate the seawater and the hygrothermal influences in fiber/matrix interaction associated with shear mechanical properties. In order to evaluate these properties, the fabric glass fiber/PPS laminate, provided by Ten Cate Dutch company, have been conditioned by immersion in artificial seawater for one month and by hot dipping water for two months. After these procedures the specimens were tested by the interlaminar shear (ILSS) and Iosipescu shear tests. The values obtained were compared to the dry specimens values. In this work, it was observed that both conditioning procedures results in specimens with lower mechanical values when compared with these same dried specimens.

1. INTRODUCTION

Continuous fiber reinforced thermoplastic composites have been developed as an alternative to thermoset fiber composites with a wide variety of matrix polymers, ranging from cheap commodity plastics to very expensive high performance polymers [1,2]. Recently the thermoplastic composites have increased their use in several applications. In the aeronautical area this kind of composite has found utilization in internal artifacts and wings of Boeing’s aircraft, landing gear doors, floor panels and mobile surfaces such as elevators, radomes, flaps among others [2].

Thermoplastic fiber composites were first developed with high performance polymers such as Polyphenylene Sulfide (PPS) as matrix material in order to improve the mechanical properties, when compared with thermoset matrix, for aerospace applications. Due to the high cost and high processing temperatures of this and other aromatic high performance polymers the applications are limited to fields in which the price is of little importance, such as in military aircrafts and space vehicles. The great advantages of thermoplastic composites in processing, such as the long shelf life of prepregs and zero emissions during processing, have led to the development of thermoplastic fiber composites in many different prices and performance classes [1-6].

Polyphenylene Sulfide (PPS) is a highly crystalline polymer recognized for its unique combination of properties, including thermal stability, chemical resistance, and fire resistance. PPS polymer crystallizes very rapidly at temperatures above its Tg and usually has a crystallinity content in the range of 50-60%. PPS exhibits intermediate mechanical properties and temperature tolerance. Its excellent corrosion resistance is attributed to its inertness to organic solvents, inorganic salts, and bases. PPS composites are not affected by aircraft fluids [7].

Polymeric composite materials in practical use may be subjected to mechanical stresses and environmental attacks. The main environmental attacks are related to temperature, moisture, radiation, and contact with several kinds of chemicals. Mechanical properties, such as interlaminar shear strength (ILSS), ultimate tensile strength, compressive strength, fracture strain and stiffness are the primary static mechanical properties, which normally decrease with the increase of moisture content [8-10].

Environmental agents that usually cause damage to composites are electromagnetic effects, fire, and high temperatures; lightning and electrical discharges, ozone (chemical degradation); ultra-violet radiation; out-gassing at high-vacuum; erosion by rain, sand, etc.; low-energy impacts that induce barely visible impact damage; moisture uptake and contact with organic liquids such as fuels, lubricants and de-icing fluids. During normal service aircraft are exposed to all these agents in a time-variable manner [11-14].

The purpose of the present work is to evaluate the effect of the hygrothermal and salt conditionings in the shear behavior of glass fiber/PPS laminates. In this work, specimens of glass fiber/PPS after to be submitted to hygrothermal conditioning were evaluated by Iosipescu and short beam shear tests. In order to compare the seawater effect with the hygrotermal conditioning it was used ILSS test.

2. EXPERIMENTAL PROCEDURES

Laminates of PPS/glass fiber were supplied by TenCate Company (from Netherlands) having as reinforcement a 5HS fabric (64% volume content).

For each test, ten specimens were dried at 50ºC under vacuum atmosphere, for 48 hours. After this procedure, five specimens were weighed and immersed in hot water with controlled bath temperature in 80ºC and maintained in this condition during 8 weeks. The weight gain was evaluated twice per week. Another five specimens were conditioned in a salt water bath. The environmental conditioning by salt water immersion was conducted according to ASTM D1141-98. This standard describes the procedures of preparing substitute seawater, in laboratory. The pH of the solution was adjusted to 8.2, similar to seawater. The specimens were immersed in a recipient containing seawater. In this test, the exposure time was 30 days.

The interlaminar short-bean test method (ILSS) was done according to ASTM D-2344 normative. The Iosipescu method was done according to ASTM D-5379 normative. All tests were accomplished in an Instron test machine, using speed test of 0.5mm/min and a load cell of 500 Kgf.

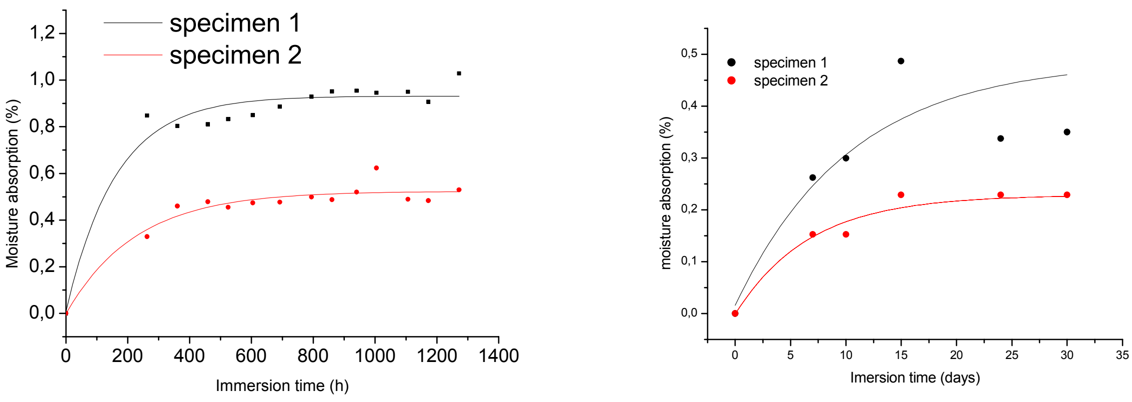
In order to obtain the shear modulus its necessary assuming that both, stress and strain are uniformly distributed in the test region of the specimen used. In this case, the apparent in-plane shear strain, γ at the cross-section along two notch tips can be obtained by:

$$\gamma = \varepsilon^{+45°} - \varepsilon^{-45} \qquad \text{equation 1}$$

In this work, shear strain was measured by bonding strain gages at ± 45°, placed at the mid-section between the two notch tips. The uniformity of shear stress and corresponding strain in the test region need to be examined to assess the accuracy of the shear modulus determination. Due to difficulties in fix strain gauges in wet specimens, it could not possible to obtain the shear modulus for specimens after to be submitted to hygrothermal conditioning.

3. RESULTS AND DISCUSSIONS

Figure 1 presents the hygrothermal and seawater conditioning results obtained by glass fiber/PPS laminates. As it was expected, in both cases the specimens presented a weight gain during the exposure time, due to the moisture absorption. In this work, it was observed that in four weeks of exposure in moisture environment the laminate presented a saturation point in around 0.6% and 0.35 (average values) of weight gain for hygrothermal and seawater conditioning, respectively.



a) b)

Figure 1. Moisture absorption of the glass fiber/PPS laminate: a) hygrothermal conditioning; b) seawater conditioning.

Table 1 presents the average values of maximum interlaminar shear strength and shear modulus obtained by Iosipescu and ILSS tests. This test has been done only in order to compare the dry and the hygrothermal conditioned specimens. This test has presented a characteristic of non-catastrophic fracture profile of shear strength x deformation. As it was commented before, due to difficulties in fix strain gauges in wet specimens, it could not possible to obtain the shear modulus for specimens after to be submitted to hygrothermal conditioning.

Table 1. Results of the Iosipescu test.

Conditioning	σ_{ult} (MPa)	E (GPa)
Dry	97.4±2.9	13.7±0.7
Hygrothermal	73.4±9.6	-----

Table 1 shows that after the hygrothermal conditioning approximately 25% reduction in the shear stress of the laminate. This effect can be attributed to the plasticizing effects of water diffused through the amorphous regions of the polymeric matrix. This behavior is still associated with the interface degradation between polymer/glass fiber due to the moisture presence.

The short beam shear test has been used to measure the apparent interlaminar shear strength (ILSS) of a composite material. This method is not suitable for design information, but data generated from this test method is being used to obtain design allowables, primarily because of the lack of any alternative test methods for measuring interlaminar strength.

Table 2 shows the interlaminar shear strength results for glass fiber/PPS composite. By using this Table, it was observed that the ILSS values decreases when exposed to hydrothermal and seawater conditions. Wet conditioning induces strong matrix plasticization.

Table 2. Results of the ILSS test.

Conditioning	σ_{ult} (MPa)
Dry	38.9±0.8
Hygrothermal	24.0±7.9
Seawater	35.2±1.2

According to the Table 2, the interlaminar shear strength values for glass fiber/PPS composite shows a decrease of 37% and 10% after being submitted to hygrothermal and seawater conditioning. The hygrothermal effects on the mechanical properties of composites are described in detail in the literature [3-5] but there is not a general agreement over the magnitude of this effect. The difficulty is to evaluate the influence of both moisture absorption and temperature at the same time on the mechanical properties. The difference between both conditioning is due to the diffusion process to be accelerated with increase of the temperature

Figure 2 presents the morphology of the failure mode aspect in seawater conditioning glass fiber PPS composites specimens after being submitted by ILSS test. It can be observed that the composite exhibit multiple delaminations having interlaminar cracks at horizontal and vertical positions. This behavior was observed in all specimens (dry, hygrothermal and seawater conditioning). The ILSS test in general provoked an interlaminar fracture in the specimen, as shown in Figure 2, characterized for parallel failure of the laminated. 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.

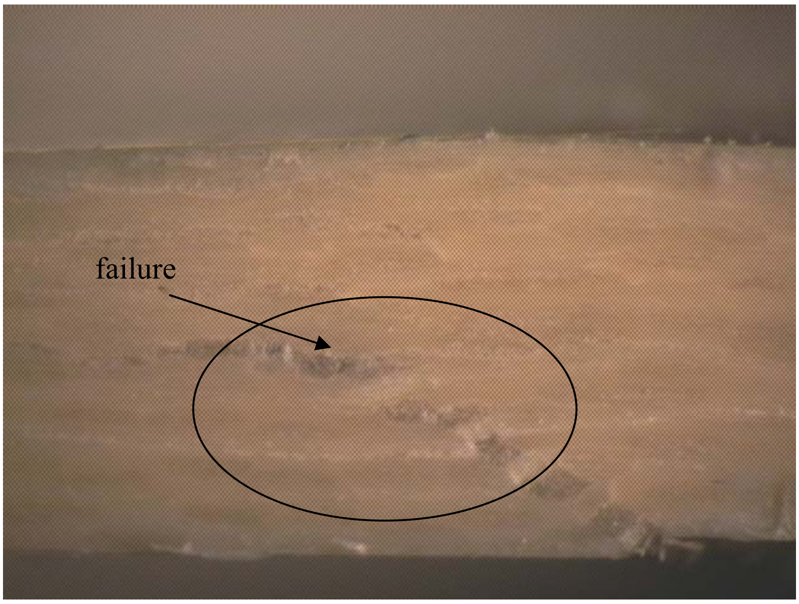


Figure 2. Representative fracture observed by ILSS test.

CONCLUSIONS

The influence of hygrothermal and seawater conditionings in shear properties of glass fiber/PPS composites have been investigated. It was observed that this laminate absorbed 0.6% and 0.35% of moisture after the saturation point (after 6 weeks and 3 weeks, respectively), when submitted to hygrothermal and seawater conditionings, respectively.

For all specimens studied the ILSS values decrease when exposed to environment conditioning. Moisture uptake always induced resin plasticization and, consequently, reduces of the shear strength values of the laminates. When compared the ILSS results obtained by hygrothermal and seawater conditioning, it was found a difference of around 25%. This difference is due to the diffusion process to be accelerated with increase of the temperature and the presence of several salts in seawater.

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REFERENCES

1. Botelho E.C., Pardini L.C., Rezende M.L., Almeida R.S.; "Evaluation of Adhesion of Continuous Fiber-epoxy Composite/aluminum laminates", *Journal of Applied Adhesion Technology*, 2004:18:1799 – 1813.
2. Botelho E.C., Pardini L.C., Rezende M.L., Costa M.L.; "Processing and Hygrothermal Effects on Viscoelastic Behavior of Glass Fiber/Epoxy Composites", *Journal of Material Science*, 2005:40:3615-3623.
3. Botelho E.C., Pardini L.C., Rezende M.C.; "Evaluation of hygrothermal effects on the shear properties of CARALL composites", *Materials science & engineering*, 2007:452 – 453:292 - 301.
4. Chiang M.Y.M., He J., "An analytical assessment of Using the Iosipescu Shear Test for Hybrid Composites", *Composites Part B*, 2002:33:461-470.
5. Costa M.L., Almeida S.F.M., Rezende M.C.; "The Influence of Porosity on the Interlaminar Shear Strength of Carbon/Epoxy and Carbon/Bismaleimide Fabric Laminates", *Composites Science and Technology*, 2001:61:2101-2108.
6. John N.A.S., Brown J.R.; "Flexural and Interlaminar Shear Properties of Glass-Reinforced Phenolic Composites", *Composites Part A*, 1998:29:939-946.
7. Balley C., Davies P., Yves G., Dolto G.; "Application of Interlaminar Tests to Marine Composites. A Literature Review". *Applied Composite Materials:* 2004: 11: 99–126.
8. Burakowski L.; "Estudo da Interface de Compósitos Termoplásticos Estruturais Processados a partir de Fibras de Carbono com Superfícies Modificadas" Master

degree dissertation, Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil, 2001.

9. Botelho E.C., Pardini L.C., Rezende M.C.; “Evaluation of hygrothermal effects on the shear properties of Carall composites”, *Materials Science and Engineering*; 2007.
10. Costa M.L. “Efeito do conteúdo de vazios no comportamento mecânico de compósitos avançados carbono/ epóxi e carbono/ bismaleimida”. PhD thesis, Instituto Tecnológico de Aeronáutica, São José dos Campos, Brazil, 2002.
11. Cunha J.A.P., Costa M.L., Rezende M.C.; “Influência de Diferentes Condições Higrotérmicas na Resistência à Tração de Compósitos de Fibra de Carbono/Epóxi Modificada”, *Polímeros: Ciência e Tecnologia*, 2006:16(3):193-201.
12. Botelho E.C, Pardini L.C., Rezende M.L., Costa M.L.;“Processing and Hygrothermal Effects on Viscoelastic Behavior of Glass Fiber/Epoxy Composites”, *Journal of Material Science*, 2005:40:3615-3623.
13. Zenkert D.; “Strength of Sandwich Beams with Interface Debonding”, *Composite Structures*, 1991:17:331-338.
14. Sala G.; “Composite Degradation due to Fluid Absorption”, *Composites Part B*, 2000:31:357-373.