INFLUENCE OF THE ENVIRONMENTAL CONDITIONING ON THE FATIGUE BEHAVIOR OF CARBON FIBER/EPOXY/ALUMINUM LAMINATES

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ABSTRACT

Fiber-metal laminates (FML) are a kind of hybrid composites that have imposed themselves as versatile material, principally due to their low weight, stiffness and low crack propagation under fatigue loading. When these materials are used in aircrafts structures, they can reduce in around 25% the aircraft weight, improving its fly performance. This is a reason that can permit these laminates to be used as parts of ships structures, resulting also in a safe of fuel and a increasing the ship performance at sea. CARALL laminates consists of thin layers of carbon fiber/epoxy prepreg sandwiched between aluminum 2024-T3 alloy sheets, resulting in a hybrid composite. Environmental effects such as moisture are so much considered in materials projects, because they can cause changing of the mechanical properties. This work, reports the influence of the seawater conditioning on the fatigue behavior of CARALL laminates. Specimens immersed for a twenty days in artificial seawater are submitted to fatigue tests and the results are compared with dry specimens and with specimens submitted to hygrothermal conditioning (water immersion on 70°C). In order to evaluate the damage mechanisms, optical microscopy techniques were used after the fatigue tests.

1. INTRODUCTION

Composite materials have been used as aircraft structures, due to their low weight and high mechanical performance. Recently, attention has been given to hybrid composites, because their properties can be higher than conventional materials commonly applied [1].

At the beginning of the seventy-decade, a new kind of composite materials were originally developed by the Delft University of Technology. These materials, called fiber-metal laminates (FML), have been imposed themselves as versatile, high-performance and economical materials in aeronautical industry, due to their low weight, stiffness and low crack propagation under fatigue loading. It can be estimated that using FML as a part of the aircraft fuselage, it is possible to reduce in around 25% the aircraft weight. Because of these properties several aeronautical companies have showed themselves interested in use these laminates in their aircrafts manufacturing [2,3].

CARALL laminates consists of thin layers of carbon fiber/epoxy prepreg sandwiched between aluminum sheets, resulting in a hybrid composite. This class of materials offers higher modulus, higher tensile strength and lower density than 2024-T3 aluminum alloy. Figure 1 presents a CARALL composite used in this study as an example of a metal-fiber laminate [2,3].

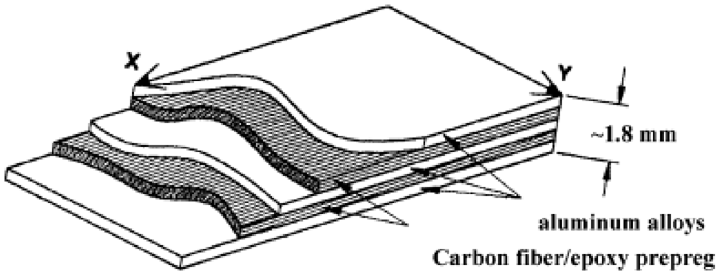


Figure 1: Configuration of CARALL laminate (3/2 lay up).

CARALL laminates show higher strength values, stiffness, and fatigue performance, when compared to ARALL (**A**ramid **R**einforced **AL**uminum **L**aminate) and GLARE (**GL**ass **A**luminum **RE**inforced). Carbon fibers and epoxy resin composites confer low crack growth and propagation rates, and the presence of metal layer in the composite is very favorable for the impact properties [4,5,6].

Composite materials used for aircraft structures are frequently exposed to environmental effects such as changing of temperature, radiation, chemical products attacks, and moisture absorption. These effects must be considered in the project because they can change the mechanical properties of the polymeric composite, such as, interlaminar shear, ultimate tensile, compressive strength, fracture strain and stiffness. There are enough experimental evidences to believe that the presence of water induces swelling of the system and a build-up of residual stresses, rupture of adhesive bonding between the system and a given substrate and modification of the local stress state and creation of microcrazes. The outer sheets of aluminum alloys block the moisture absorption by the surface, allowing absorption just by the free edges [7-10].

Reinforced plastics have also been showed themselves attractive for oceanic applications, such boats and submarine structures and oil industry. The reason is that composite materials provide a combination of high mechanical properties, stiffness, chemical stability and low specific weight. Moreover, when compared with steel alloys, composite materials show higher corrosion strength, and consequently higher useful life. As it was already mentioned, the exposure under humid environments causes modifications in the mechanical properties of composites. When compared to hygrothermal conditioning, the salty water immersion reduces the saturation content in the material after an exposure time, because the salt concentration outer is higher than into the material structure [11-16]. In FML there are not many studies about the seawater effect on the mechanical behavior. It is possible to predict the exposure under salty water environment can cause de degradation of the interfaces between polymeric composite layers and the aluminum sheets, and also to promote the corrosion of the metal. Both can cause considerable reduction of the mechanical properties of the laminate.

The present work reports the influence of the salty water environment and hygrothermal conditioning on the fatigue behavior of CARALL.

2. EXPERIMENTAL PROCEDURES

CARALL laminates were manufactured by using hand lay-up process that consists of stacking alternating laminae of the carbon fiber/epoxy prepregs and the aluminum sheets. The lay up scheme of the hybrid composite was 3/2, as showed in Figure 1. A treatment on the aluminum surface sheets was done in order to promote a good adhesion with the carbon fiber/epoxy prepreg. In this process it was used chromic acid anodization process. After the lay-up process, the laminates were fit inside in a vacuum bag and placed in the autoclave system. The curing cycle was done at a heating rate to 2.5◦C/min until 120 ◦C and this final temperature was held during 1 h. The pressure and the vacuum used were 0.69 and 0.083MPa, respectively.

The hygrothermal conditioning was done by water immersion, where the specimens were submerged during 10 weeks under controlled temperature water. The temperature of water system was set at 70°C. This value is convenient because it is lower than the resin glass transition temperature in order to avoid onset of irreversible damage (swelling and cracks). Each week, the weight of the specimens was measured. By using these measures, it was possible to calculate the weight gain percent and plotting a weight gain percent curve as a function of the exposure time (in days). Both, the fatigue tests and the hygrothermal conditioning were done at Department of Material and Technology, in São Paulo State University, São Paulo, Brazil. 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 20 days.

In order to determine the maximum fatigue load, previous tensile tests were performed. Moreover, the tensile tests permitted to determine both the E-modulus and tensile strength of CARALL laminate. The tensile tests were performed in an Instron mechanical tests machine according to the ASTM D3039 standard.

The fatigue tests were performed according to the ASTM D3479-96 standard. The ratio between maximum and minimum loads was R=0.1 and the frequency of cycling was f=10 Hz. The tests were performed in an Instron mechanical test machine, in São Paulo State University, São Paulo, Brazil. The fatigue tests were performed in dry specimens and in specimens after to be submitted to hygrothermal and seawater conditionings.

3. RESULTS AND DISCUSSION

Figure 2 presents the hygrothermal conditioning results obtained by CARALL laminates. As it was expected, the specimens presented a weight gain during the exposure time, due to the moisture absorption. In this work, it was observed that in 10 weeks of exposure in moisture environment the laminate had around 1.65% of weight gain, but the saturation did not occurred. This behavior happened due probably to interfacial problems between the aluminum and carbon fiber/epoxy laminae (Figure 3). The delamination process (happened after 6 weeks) leads to another diffusion process due to the carbon fiber/epoxy laminate exposition. This process do not happened when is used a hygrothermal chamber with controlled moisture and temperature [7, 17].

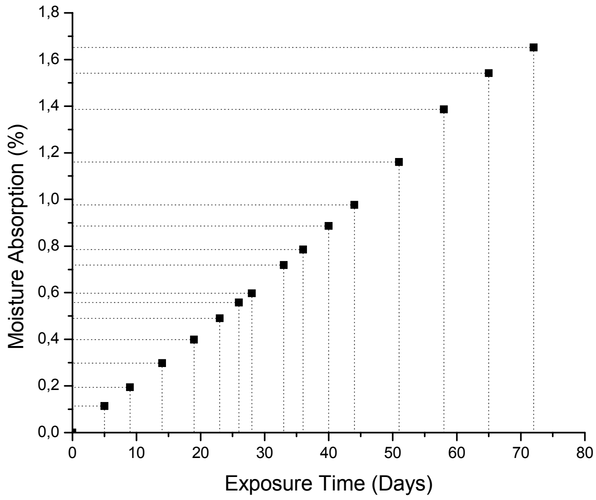


Figure 2: Moisture absorption as a function of the exposure time for CARALL.

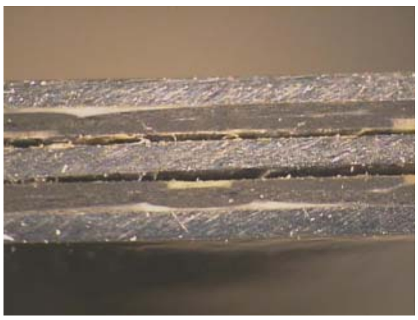
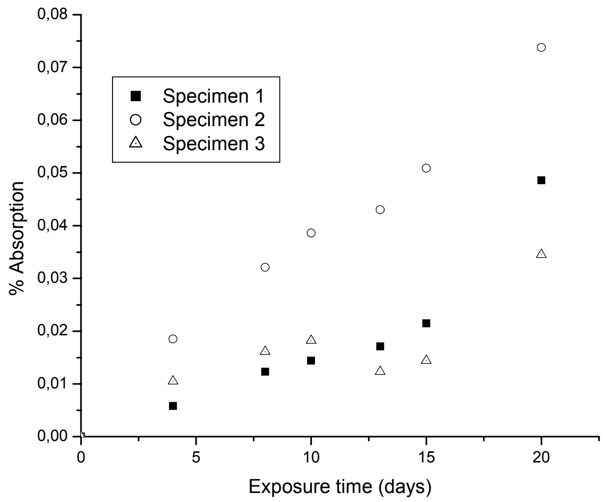
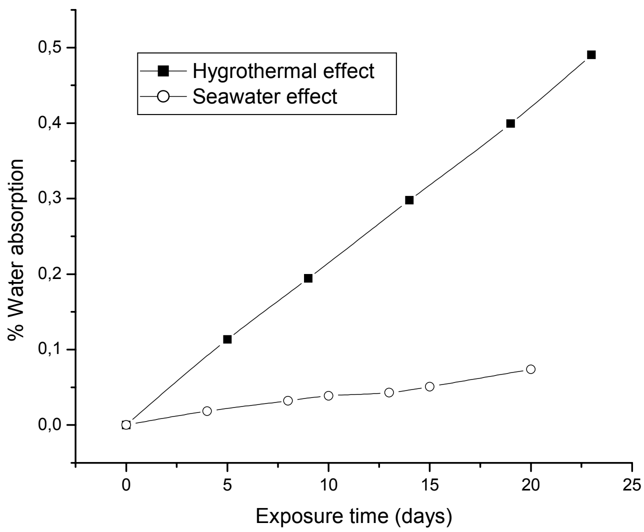


Figure 3: Delamination regions after 10 weeks of hygrothermal conditioning.

Figure 4a presents the seawater absorption content for the three controlled specimens, obtained by the measure of the gain weight of the specimens. It is possible to be observed that after 20 days of exposure time, all specimens presented a low gain of weight due the seawater absorption, reaching the maximum moisture content in around 0.06 ± 0.02. Figure 4b present the difference between the water absorption percent for the hygrothermal and salt water immersion conditioning, considering the same exposure time (around 20 days). The difference between both absorption behaviors is due principally to: first, the diffusion process is accelerated with increase of the temperature; second: the salt concentration of the solution can induces a decrease of the saturation point into the composite material. It is important to say that until this exposure time (20 days), both of specimens do not presented delamination problems due to the aggressive atmosphere.



a)



b)

Figure 4: Seawater absorption percent for CARALL laminate (a); comparison between the specimens under hygrothermal and seawater conditioning (b).

Table 1 presents the tensile test results for CARALL in dry condition and also for CARALL submitted to environmental conditioning.

Table 1: The tensile tests results of CARALL laminates.

Conditioning	**σ_{ult} (MPa)**	**ε (%)**	**E (GPa)**
Dry	568 ±17	1.48±0.10	69.3±1
Hygrothermal	462±15	2.46± 0.02	48.0±10
Seawater	538 ±12	1.56 ±0.07	66.0 ± 2

In general, up to the initial cracking of the matrix in polymer composite it is reasonable to assume that both fibers and matrix behave elastically. The specimens were tested as received (room temperature dry – ETD) and after hygrothermal conditioning (elevated temperature wet – ETW). According to this table, after the hygrothermal conditioning a ~21% reduction in the tensile strength of the composite is observed. 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/carbon fiber and polymeric composite/aluminum due to the moisture presence. On the other hand, the changes in the properties observed for the laminates, after seawater conditioning, are negligible (reduction of 5%), which is an evidence of the shielding effect of the aluminum skin layers in this material. A similar behavior can be observed by the E modulus and strain stress (ε**).** It's necessary to remember that the seawater conditioning have been done during only 20 days.

Figure 5 shows the fatigue strength curve for the laminates studied in this work (under hygrothermal and seawater conditioning). It is also possible to observe that there was a higher difference (about 100%) between the fatigue strength of non-conditioned and hygrothermal conditioned CARALL. The reason for the dry specimens have so higher fatigue strength can be explained by two facts: first, during the moisture absorption, epoxy resin absorbs the moisture resulting in plasticization process of the matrix polymer and degradation of the interface between the fibers and matrix, and degradation of the interface between carbon/epoxy composite layers and aluminum sheets. All these facts result in a decreasing of the mechanical properties of the metal/fiber laminates; second, after 10 weeks of conditioning the specimens presented some delamination regions through the layers. These problems could have been occurred due to the severe environment that the specimens were exposed with heat and high moisture level. Delamination in the structure of the composite can be one of the causes for the decreasing in the fatigue strength, once it becomes easier the crack propagation through layers of the laminate, and the interface between fibers and matrix.

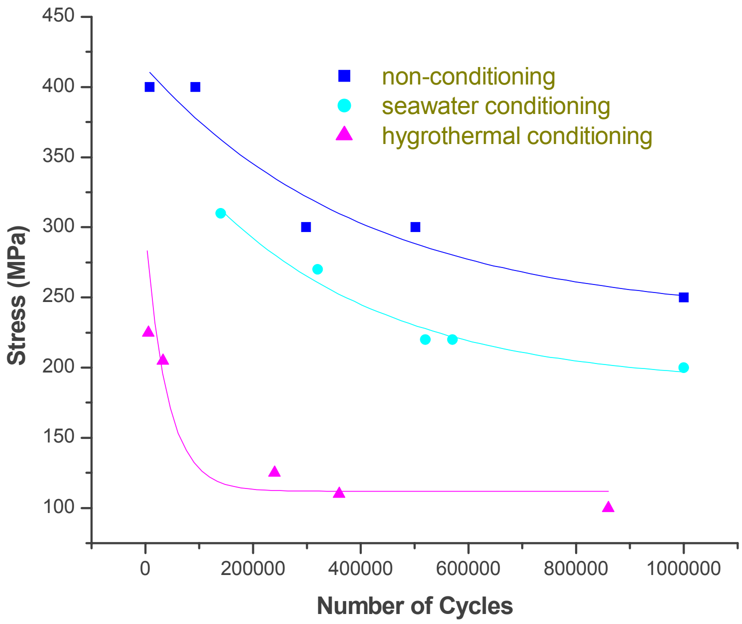


Fig. 5. Fatigue strength of CARALL laminate.

Therefore, when compared seawater conditioned and dry specimens, can be observed that both curves presented a similar behavior. The salt water conditioning generates only around 20% of stress fatigue decrease. Since during this test there is no delamination, only the free edges of the composite laminate are exposed to moisture attack.

CONCLUSIONS

According to this work, it was possible to conclude that environmental effects can cause considerable changes on the mechanical properties of composite materials used in aeronautical structures. In this study, it was observed that one of the methods used (water immersion in 70°C) for moisture absorption test was very severe. The weight gain was higher than it was expected and it made the fatigue strength having a high decrease (about 100%) when compared with the fatigue strength of the non-conditioned CARALL. But by using seawater condition, it was observed that this conditioning method was much less aggressive than the hygrothermal conditioning. This behavior happened due to temperature and exposition time difference between these two different methodologies.

This work intends to contribute with the aeronautical and naval applications, in order to create a datasheet showing the influence of moisture absorption on mechanical properties that should be considered structural materials projects.

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