EVALUATION OF TEMPERATURE INFLUENCE ON MECHANICAL PROPERTIES OF PEI/GLASS FIBER COMPOSITE

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Abstract *In practical use, composite materials may be subjected to a wide variety of different loading conditions. Woven fabrics provide excellent integrity and conformability as an attractive reinforcement. The effect of temperature on the delamination resistance of composites is quite complex, as reflected by the conflicting data in the scientific literature. The most important conditions are mechanical stresses and environmental attacks. The main environmental attacks are related to temperature, moisture, radiation, and contact with various types of chemical products. These factors can affect the thermal and mechanical properties of the composites in different ways. The thermal environments can significantly degrade the compressive strength of a material. These factors must be understood when designing structures made from composite materials. This degradation can take the form of weakening of the fiber/matrix interface. This way, the purpose of this work is to evaluate the influence of the temperature conditioning on tensile and fatigue properties of PEI/carbon fiber composites. The PEI thermoplastic laminates have been supplied by a Dutch company (TenCate).The results indicate that temperature degrade significantly, the mechanical properties of PEI laminates in both tests, fatigue and tensile tests. The strain rate sensitivity of the woven composites is more significant if the failure is dominated by the resin materials. According to fatigue tests in high cycles this decrease can be reach up to 100% when compared specimens submitted to low and high temperatures. A criterious morfological study have been done in order to understand the fracture propagation as well.*

Keywords*: PEI, glass fiber, mechanical test.*

1. INTRODUCTION

Continuous glass fiber (CGF) composites made of commingled woven or pre-impregnated (“prepreg”) unidirectional plies with a polyeterimide (PEI) matrix have received considerable attention in the last ten years. However, much work still needs to be done to assist end-users in implementing these materials in large-volume markets applications. According to the literature, two subjects deserve to be addressed with high priority: the influence of processing conditions, more precisely of consolidation conditions, and of in-service temperature on the long-term performance of these CGF/PEI composites (Suwanwatana, Gillespie, 2006; Kawagoe *et al*, 2006; Bergeret *et al*, 2001). The influence of processing conditions on the fatigue performance of CGF/PEI composites was recently addressed (Suwanwatana, Gillespie, 2006; Kawagoe *et al*, 2006; Bergeret *et al*, 2001). The fatigue strength of the CGF/PEI composites showed that these consolidation conditions also resulted in different fatigue damage evolution and fatigue life curves (or S-N curves).

Usually, the fatigue results for composite materials emphasized the predominance of the fiber-matrix interface in determining the general mechanical properties and suggest that short-term flexural and short-beam shear tests can be useful empirical indicators of the long-term performance of CGF/PEI composites. The second priority subject identified is the influence of in-service temperature on the fatigue performance of these CGF/PEI composites. The importance of this subject originates from the fact that it is generally believed that thermoplastic CGF composites, as a result of their temperature-dependent mechanical properties, have an inherently less stable behavior with respect to service temperature fluctuations than thermoset CGF composites (Botelho *et al*, 2002; Arici *et al*, 2005; Jang, Kim, 1996).

In the case of PEI-based composites, for which *Tg* is close to 180°C, it is generally thought that room temperature results in higher brittleness due to the glassy state of PEI matrix (Rijswijk *et al*, 2006; Kishi *et al*, 2004; Botelho *et al*, 2003; Perng, 2000). However, few papers have been published in order to investigate the cracking mechanism changed from propagation at the fiber-matrix interface at room temperature.

The general objective of this study is to address the question of the stability of the long-term performance with respect to temperature. More specifically, it is to characterize the mechanical behavior, static and fatigue, of a CGF/PEI composite at different testing temperatures, to compare its behavior with respect to temperature with that of a conventional thermoset CGF composite with similar glass fiber reinforcement architecture and static performance, and finally to demonstrate whether such CGF/PEI composites offer beneficial static and fatigue properties for applications in large-volume markets such as the construction, automotive, transportation, aeronautical, and marine industries.

2. EXPERIMENTAL

Materials

Glass fiber/PEI composites (CGF/PEI) were supplied by TenCate company (Netherlands) and were submitted, as received, to evaluation for optical microscopy, by using a NIKON optical microscope, model EPIPHOT 200.

Glass fiber/epoxy laminates were supplied by EMBRAER company (Brazil) and were also submitted, as received, to evaluation for optical microscopy.

Tensile and fatigue tests

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 CGF/PEI laminate. The tensile tests were performed in an Instron mechanical tests machine according to the ASTM D3039 standard, in room temperature and in 80°C.

Dynamic Mechanical Thermal Analysis was used to determine the glass transition temperature changes of the CGF/PEI composite. The DMTA was performed at a fixed frequency of 1 Hz and a maximum displacement of 10 μm, the temperature was varied from 20 to 250°C at a rate of 3°C/min. The specimens used in the DMTA were 60 x 10 x 2 mm in dimension. These tests were performed on a Thermal Analysis Instruments 2980 DMTA that employs a cantilever bending geometry to displace the specimen.

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 room temperature and in 80°C.

3. RESULTS AND DISCUSSION

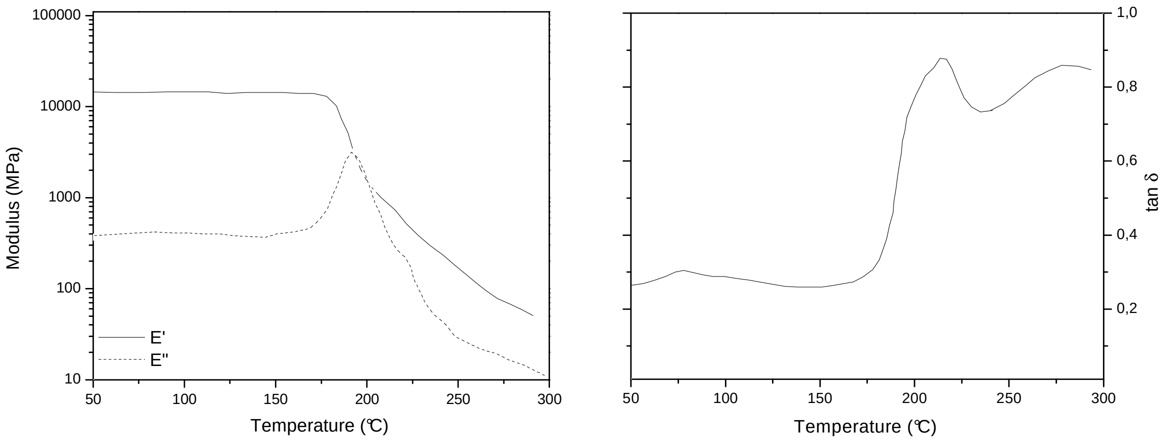
In this work, DMTA investigation was performed in order to evaluate the glass transition temperature of CGF/PEI composites. Representative DMTA results are shown in Figure 1. Table 1, summarize the glass transition temperature for CGF/PEI and epoxy/glass fiber laminates. The maximum of temperature dissipation per strain unit occurs in the temperature where E'' is maximum. So, in this work, the determination of glass transition temperature was done by using the maximum value of loss modulus (E'').

By using this procedure, the glass transition found by CGF/PEI was 192°C, therefore, higher than the values found for aeronautical applications. By using glass transition temperature value, it is possible to find the appropriate service temperature in order to implement this thermoplastic laminates on the aerospace industry. This temperature is generally 25°C to 30°C below of glass transition temperature. This way, for epoxy/glass fiber and CGF/PEI laminates, the service temperatures can be considered as approximately 150°C and 165°C, respectively (Table 1).

With the glass transition temperature value was selected the temperature value to be used on the tensile and fatigue tests. As usually the airplane companies use materials that needs support temperatures between -50°C to 60°C, in this work was used 80°C.

Table 2 presents the tensile results for both laminates studied in this work evaluated at 25°C. As can be observed, in all cases, the obtained values of ultimate tensile stress and young modulus for CGF/PEI was higher than the obtained by epoxy/glass fiber. Table 2 also presents the tensile results on 80°C. However, in this case, due to the difficulty to bond the strain gauges, it was obtained only the tensile stress. As can be observed by using Table 2, a small variation could be observed when it was compared specimens evaluated to 25°C and 80°C (3% for epoxy and 4% for PPS laminates).

Figure 2 presents the fatigue strength results for both studied glass fiber laminates (epoxy and PEI laminates). This graphic shows that in CGF/PEI occurred a decrease more significant on the stress values when analyzed in low cycle, when compared with thermoset laminate. In several regions of the curve can be evidenced the superiority of the thermoset. However, in high cycles, the CGF/PEI laminate presents superior fatigue strength values, presenting a gain up to 15%.



a) b)

Figure 1. DMTA results: a) E' and E" modulus; b) tan delta.

Table 1: Values of T_g and $T_{service}$ of the studied laminates.

Laminate	**T_g (°C)**
CGF/PEI	192
Epoxy/glass fiber (Botelho et al, 2002)	180

Table 2. Tensile results of CGF/PEI laminates.

Laminate	***σ_{ult} (MPa) 25°C***	***σ_{ult} (MPa) 80°C***	***E (GPa) 25°C***
CGF/PEI	580±23	310±12	36.4±1.6
Epoxy/glass fiber	532±18	301±8	34.2±1.8

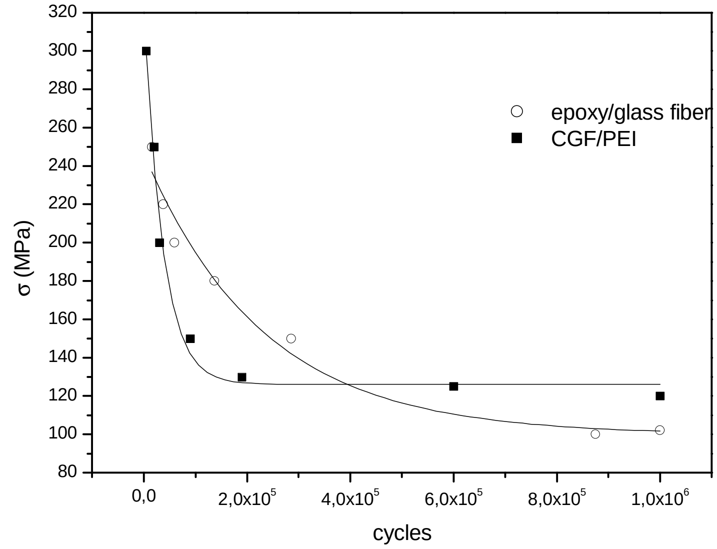


Figure 2. Fatigue life of the studied laminates.

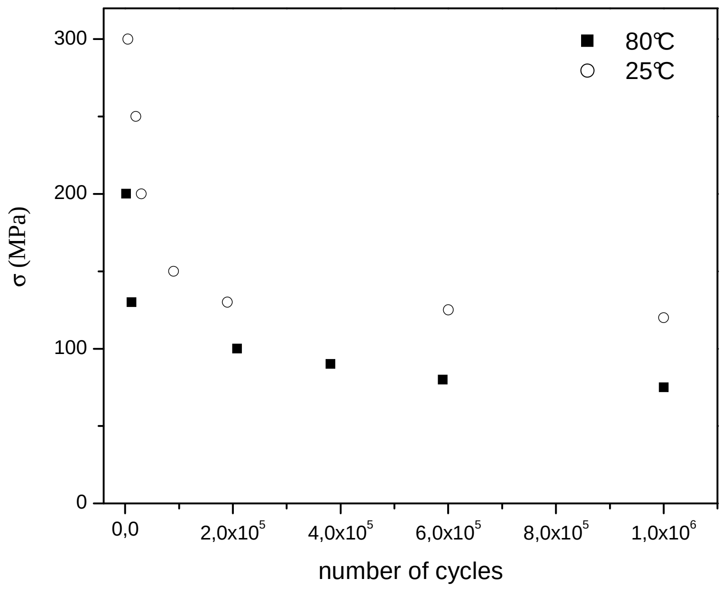


Figure 3. Temperature effects on fatigue behavior of CGF/PEI.

As it is well known, the fatigue damage results in strength and rigidity changes where the damages behavior are associates with several loads. The failure growing depends of tension level that can affect significantly the damage. If the fiber rupture occurs in low tension due to the presence of structural defects, the damage tends to lead to interface split instead of the failure on the matrix. The tensile-tensile fatigue of composites that present elevate volumetric content of reinforcement are dominated by the fatigue properties of the fibers.

However, the ratio of matrix/fiber is also important since the matrix is sensitive to fatigue and this can suffer the significant influence of service temperature. In this work, both composites presented 61% of volumetric reinforcement content. If this ratio is not enough elevate, the matrix deformation become critical. Above of this deformation level, the microcrack on the matrix occurs. This behavior is associated with the temperature when the residual tensions generate by the thermal expansion can influence the poisson ratio and consequently the fatigue behavior of the composite materials will be prejudice (Figure 3).

4. CONCLUSIONS

According to the results obtained in this work, can be verified that thermoplastic composites present a great potential to be used instead of thermoset laminates in aerospace applications. The fatigue strength found by CGF/PEI, when analyzed in high cycles, were superior of the results found by a conventional thermoset composites (epoxy/glass fiber). This gain was aproximately 30% higher. When evaluate the fatigue stress considering high temperature (80°C), have been observed a decrease of around 30 - 40% on this mechanical property. This behavior is due probably to the existence of thermal stress on the interior of the laminates as a result of the difference between the expansion thermal coefficients during the heating of the laminate.

5. ACKNOWLEDGEMENTS

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