ELASTIC BEHAVIOR OF CARBON FIBER/EPOXY/TITANIUM LAMINATES

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Abstract: Continuous fiber composite materials have been widely used in the field of aerospace as well as in the area of high technology products. Polymeric composites materials offer many advantages compared to metals, mainly because their high strength and stiffness to weight ratio, excellent fatigue properties and corrosion resistance. On the other hand, they have some disadvantages such as low interlaminar fracture toughness and moisture absorption. Hybrid composite materials have received attention for structural applications over the last 20 years, particularly in the aerospace field. Fiber/metal laminates (FML) have been lately introduced as structural composite materials for high-performance aerospace applications such as Airbus aircraft fuselage; aircraft lower wing skin and internal parts of the airplanes. In fiber/metal laminates, the properties of polymer matrix composites depend strongly on the type of the reinforcing fibers. For instance, aramid-epoxy composites have good specific strength, specific modulus and high impact resistance, but they have poor compressive strength. Carbon-epoxy and glass-epoxy composites exhibit high specific modulus but relative low values of specific strength, strain to failure and impact resistance in relation to aramid/epoxy composites. In recent years, developments in carbon fiber with titanium alloys laminates have increased. In this work, the tensile behavior of carbon fiber/epoxy/titanium laminates was evaluated, showing high values when compared with the conventional metal-fiber laminates.

Keywords: *metal-fiber laminates, elastic behavior, advanced composite materials*

1. INTRODUCTION

Fiber-metal laminates (FMLs) consisting of alternating plies of metal and fiber-reinforced polymer-matrix composites combine the high fracture toughness properties of composites with the superior impact resistance of many metals [Silva, R. A., 2006]. It is well-documented that hybrid laminates such as these offer excellent impact properties, a superior fatigue performance, an impressive environmental resistance and an elevated damage tolerance [Dymácek, P., 2001]. Current FMLs such as ARALL (Aramid fiber-reinforced aluminum laminate) and GLARE (Glass fiber-reinforced laminate) are being considered for a wide range of aerospace applications. It is likely however, that future aerospace applications will require advanced materials can able of withstanding relatively high temperatures for long periods of time. Clearly, hybrid laminates for use in such applications should be based on materials offering a high temperature capability. In principle, a titanium alloy and a composite based on a matrix such as epoxy or poly-ether-imide (PEI) could satisfy these requirements [Vermeeren, C., 2002].

In the early nineties, a large investigation was carried out into carbon/titanium laminates. An advantage of these laminates is their combination of high stiffness, high yield strength, good fatigue and good impact properties at both room and elevated temperatures. For a laminate made from titanium, carbon fibers and epoxy adhesive, the tensile ultimate stress is almost twice that Glare. Compared to Glare, the yield stress is a factor three higher [Vlot, A., D., Gunnink, J. W.].

In this work, the tensile behavior of carbon fiber/epoxy/titanium laminates was evaluated, showing high values when compared with the conventional metal-fiber laminates.

2. MATERIALS

The FML were manufactured from a 0.35 mm thick textile carbon-fiber/epoxy prepreg (CF-E) having a fiber volume fraction of 60%, and a 0.3 mm thick titanium alloy sheets (Figure 1). The lay-up scheme of the hybrid composites was 3/2, having 3 aluminum layers and 2 CF-E layers. After the lay-up process, the laminates were fit inside in a vacuum bag and placed in the autoclave for curing. The curing cycle was performed at a heating rate of 2.5°C/min up to 120°C, and held at this final temperature for 1 hour. The pressure and the vacuum used were kept at 0.69MPa and 0.083MPa, respectively.

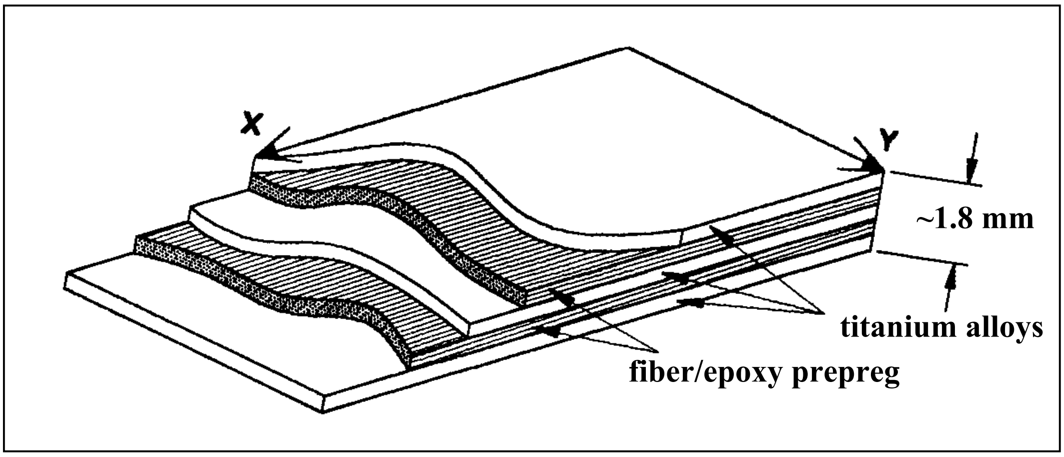

Figure 1. Configuration of continuous fiber/metal/epoxy hybrid composite (3/2 lay up).

Micrographs of the cross section of the hybrid composites were observed by scanning electron microscopy (MEV) in order to evaluate how homogeneous was the lamination and the delamination after mechanical tests. The morphological evaluation was done in a Digital Scanning Microscopy from Zeiss Company, model 950.

Static tensile tests were performed according to ASTM-D 3039-76. Ten specimens were tested for each type of material (Glare, Carall and titanium/carbon fiber/epoxy laminate). The dimensions of the sample were 247.0 x 25.4 x 2.00 mm (length x width x thickness). The tests were performed in an Instron mechanical testing machine. The cross-head speed was 1.27 mm/min. Tensile strain was measured by an optical system constituted by a double laser signal close to the two tabs. According to the tensile test, they were measured the tensile strength and tensile modulus.

3. RESULTS

Tensile tests were carried out in order to investigate the elastic behavior of the metal-fiber laminates. In general, until the initial cracking of the matrix it is reasonable to assume that both fibers and matrix behave elastically.

Table 1 presents the tensile results for Glare, Carall and titanium/carbon fiber/epoxy laminates used in this work. According to this Table, the initial cracking for Glare, Carall and titanium/carbon fiber/epoxy occurred at strains of about 1.70%, 1.48 and 1.53, respectively.

As can be observed in this Table, titanium/carbon fiber/epoxy laminates presents 67% and 34% ultimate tensile stress values higher than Glare and Carall laminates, respectively. The difference between these values is due to the addition of the titanium instead of aluminum alloy. This good mechanical properties, combined with low density, damage tolerance aspects and manufacturing possibilities means that these laminates can be considered for applications where metals or composites are used.

The stiffness of titanium/carbon fiber/epoxy laminate studied in this work was around 90 GPa, 29% and 68% higher than Carall and Glare. Both, tensile strength and modulus for fiber-metal laminates depend strongly on the continuous fiber orientation angle. With increasing fiber orientation angle, both tensile strength and modulus are reduced.

Table 1. Tensile results for metal/fibers laminates.

Laminate	**σ (MPa)**	**E (GPa)**	**ε (%)**
Glare	445 ± 23	53.3 ± 2.3	1.70 ± 0.2
Carall	568 ± 17	69.3 ± 1.1	1.48 ± 0.1
Titanium/carbon fiber/epoxy	742 ± 38	89.3 ± 3.4	1.53 ± 0.3

The analysis of failure photomicrographs with a scanning electron microscopy (SEM) conduces to a better understanding of damage mechanics and quality of interface between reinforcement-matrix of the composite. Figure 1 shows the failure behavior of Glare laminates submitted by tensile test. In this case, can be observed that glass fiber broke catastrophically, creating voids regions inside of the laminate. The study of this damage is complex since there are three different constituents forming Glare laminate: glass fiber, epoxy resin and aluminum 2024-T3, both can be observed in Figure 1 that the fracture happened in the same region of the specimens, forming a flat damage surface. Both, conditioned and non-conditioned specimens presented the same morphology after to be study by SEM. The same behavior happened by Carall and titanium/carbon fiber/epoxy laminates.

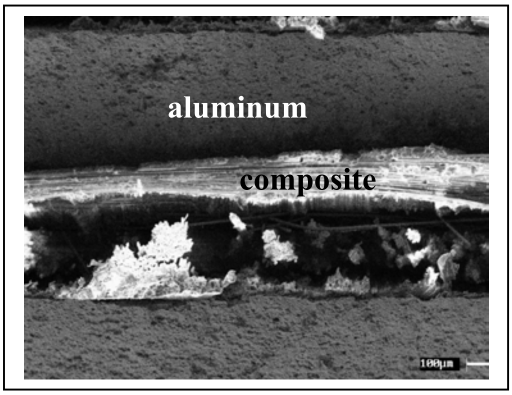

Figure 2. Tensile failure behavior of Glare.

4. CONCLUSIONS

In this work, the elastic properties for Glare, Carall and titanium/carbon fiber/epoxy laminates were evaluated. It was observed that titanium/carbon fiber/epoxy laminates presented higher tensile properties when compared with the others metal-fiber laminates studied. This behavior is due to the titanium contribution instead of the use of aluminum alloys. According to these results, can be concluded that titanium laminates proved to be very attractive structural materials for several applications in space structures.

6. ACKNOWLEDGEMENTS

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