COMPARISON BETWEEN THE ELASTIC MODULUS OBTAINED BY TENSILE AND FREE VIBRATION EXPERIMENTS FOR GLARE MATERIAL

Edson Cocchieri Botelho
Divisão de Materiais, Instituto de Aeronáutica e Espaço, CTA, São José dos Campos, São Paulo, Brazil
Fatigue and Aeronautic Material Research Group - Department of Material and Technology, UNESP - Guaratinguetá/SP/Brazil
ebotelho@directnet.com.br

Mirabel Cerqueira Rezende
Divisão de Materiais, Instituto de Aeronáutica e Espaço, CTA, Praça Mar do Ar Eduardo Gomes n 50 Vila das Acácias, São José dos Campos, São Paulo, 12228-904, Brazil
mirabel@iae.cta.br

Luiz Claudio Pardini
Divisão de Materiais, Instituto de Aeronáutica e Espaço, CTA, Praça Mar do Ar Eduardo Gomes n 50 Vila das Acácias, São José dos Campos, São Paulo, 12228-904, Brazil
lpardini@iae.cta.br

Abstract. *Fiber-metal laminates (FML) are composed of alternating layers of unidirectional fiber-reinforced plastic (FRP) laminae and aluminum-alloy sheets. These materials offer superior mechanical properties, compared to glass fiber/epoxy composites and/or high-strength monolithic aluminum alloys. The specific stiffness and strength in the fiber direction of FML are enhanced over the high-strength aluminum alloys used as the metal layers, which significantly contributes to weight savings in the design of tension-dominated structural components. GLARE is the FML second generation, consisting of glass fiber/ epoxy laminae and aluminum-alloy sheets. The material's elasticity in tension will determine stiffness and load bearing capability and the plastic behavior will give a first indication about brittleness and notch sensitivity. In the FMLs the bond between the reinforcing fiber and the matrix plays a very important role in the transfer of stresses in a composite. The viscoelastic properties of composites can be determined by dynamic mechanical tests. Static mechanical tests are destructive evaluation while dynamic mechanical test offers the advantage of being non-destructive. Nowadays, various experimental methods potentially applicable to determine dynamic moduli and damping of composites (free vibration, rotating-beam deflection, forced vibration response, continuous wave or pulse propagation technique) have been reviewed. This work presents a comparison of elastic properties measured by tensile and by free vibration damping experiments on GLARE laminates. Results were also compared with findings for conventional polymer composite materials. Experiments were done in dry specimens and in specimens submitted to hygrothermal conditioning (specimens exposed at 80°C and 90% RH, during 60 days). Results for the elastic modulus, obtained by tensile testing, and the E' (storage modulus), obtained by free vibration, were similar.*

Keywords: *metal/glass fiber composites; damping; behavior; elastic properties.*

1. Introduction

Fiber Metal Laminates (FMLs) are structural composite materials that consists of thin aluminum alloy sheets bonded alternately with fiber-reinforced epoxy layers. These hybrid materials offer superior mechanical properties, over conventional polymer composite laminates or high-strength monolithic aluminum alloys [Dymácek, 2001; Ünal, 1999; Asundi and Choi, 1997; Vogelesang and Vlot, 2000; Botelho et al., 2004].

One of the most used reinforcement for the composite layer in FML is glass fiber. Glass fiber/metal laminates (GLARE) were originally developed at Delft University of Technology at the beginning of 1980. Their main attribute is fatigue resistance and they are are being used as fuselage components in new on-roll airplanes [Lin and Kao, 1995; Castrodeza et al., 2002; Soprano et al., 1996; Vlot and Gunnink, 2001].

In composite materials applied in aerospace field, is very important the study of the thermal and moisture influence on the materials used in aerospace components. In polymer composite materials, the influence of moisture is most notably present in the matrix that usually absorbs moisture when exposed to humid environments [Vlot and Gunnink, 2001; Naboulsi and Mall, 1997]. This takes place through a diffusion process, in which water molecules are transported from areas of high concentration to areas of lower moisture concentration. However, in GLARE components, basically, only the outer aluminum layers are exposed to the environment as a result of its lay-up pattern. The composite lamina in FML composites is only exposed through free edges of the laminate or holes. Moisture and chemicals however can penetrate the composite through laminate free edges [Vlot and Gunnink, 2001; Naboulsi and Mall, 1997].

For this kind of material, the bond strength between aluminum and epoxy/continuous fiber layers plays a very important role in the stress transfer mechanisms of FML laminates [Rastogi, Soni and Nagar, 1998; Lee and Holl, 1996; Verpoest and Springer, 1988; Lee and Peppas, 1993]. There are several kinds of tests that can be used in order to study the stress transfer at the fiber/resin interface of the composite material and at the composite laminae and the aluminum. Static mechanical tests are destructive while dynamic mechanical tests offer the advantage of being non-destructive. For the determination of the elastic constants and damping properties, analysis of free vibrations can be applied [Lee and Peppas, 1993; De Wilde and Frolkovic, 1994; Carlsson and Gillespie, 1995, Zhang and Mason, 1999]. Nowadays, various experimental methods potentially applicable to determine dynamic moduli and damping of composites (free vibration, rotating-beam deflection, forced vibration response, continuous wave or pulse propagation technique) have been used [Lee and Peppas, 1993; De Wilde and Frolkovic, 1994; Carlsson and Gillespie, 1995, Zhang and Mason, 1999].

In the present study the influence of hygrothermal effects on mechanical properties of GLARE were studied using a free vibration damping and tensile tests, in order to compare the elastic and viscous response of these materials.

2. Materials

Glass fiber/epoxy (G/E) prepreg with F155 specification was used for composite preparation. It was supplied by Hexcel Co. The pattern design of the fiber reinforcement was plain weave. Aluminum alloy 2024-T3 sheets was supplied by Empresa Brasileira de Aeronáutica (EMBRAER). The hybrid composite (GLARE) was prepared by stacking alternating laminae of the glass fiber/epoxy prepreg and the aluminum sheet. The lay-up scheme of the hybrid composites was 3/2, as depicted in Figure 1.

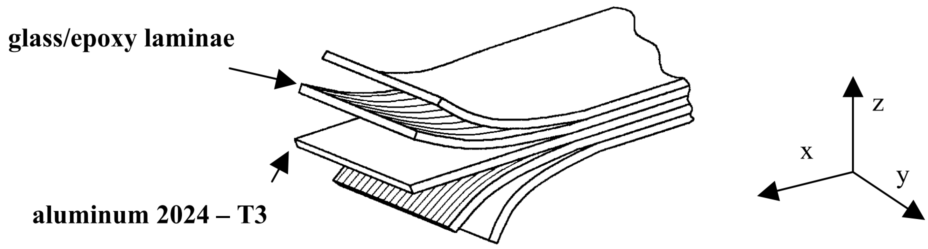

Figure 1. Lay-up scheme of GLARE material.

In order to assess the influence of the environmental conditioning on the damping behavior, the glass/epoxy and GLARE specimens were exposed to a combination of temperature and humidity in an environmental conditioning chamber. The condition selected to saturate the specimens before the mechanical tests were based on Procedure B of ASTM D 5229 M-92.

The dynamic elastic modulus was determined by vibration damping measurements. The vibration measurements used a 0.6g accelerometer attached to the end of the rectangular beam (dimensions shown in Table 1). The vibration test gives as a result the free vibration damping decay and the frequency response function (FRF), simultaneously.

Table 1. Dimensions and weight of specimens used in damping tests.

Specimen	Length – b (m)	Width – b (m)	Thickness - h (m)	Weight (g)	Inertia (m^4)
G/E	0.210	0.020	23.1×10^{-4}	19.0×10^{-3}	13.3×10^{-12}
Aluminum	0.211	0.020	10.4×10^{-4}	12.4×10^{-3}	1.90×10^{-12}
GLARE	0.211	0.021	17.2×10^{-4}	16.8×10^{-3}	10.2×10^{-12}

Using the vibration damping results, the storage modulus (E') was obtained according to equation 1 [Botelho et al., 2004].

$$E' = \frac{4\pi^2 f^2}{3I} \cdot \left[M + \frac{33}{140} m \right] \cdot L^3 \cdot \left[1 + \frac{\Delta^2}{4\pi^2} \right] \qquad \textbf{(1)}$$

where: E'= elastic modulus; f = natural frequency (first mode of vibration); I = inertial moment; M = accelerometer mass; m = specimen mass; L = specimen lenght and Δ = logaritmic damping.

The tensile test was done according to ASTM-D 3039-76. The tests were performed in an Instron mechanical testing machine using a test speed of 1.27 mm/min. Tensile strain was measured by bonding one strain gage type Rosette at ±45°, placed at the mid-section between the tabs (Figure 2). The surface center of composite was treated in order to allow a good adhesion between the strain gage and the composite surface.

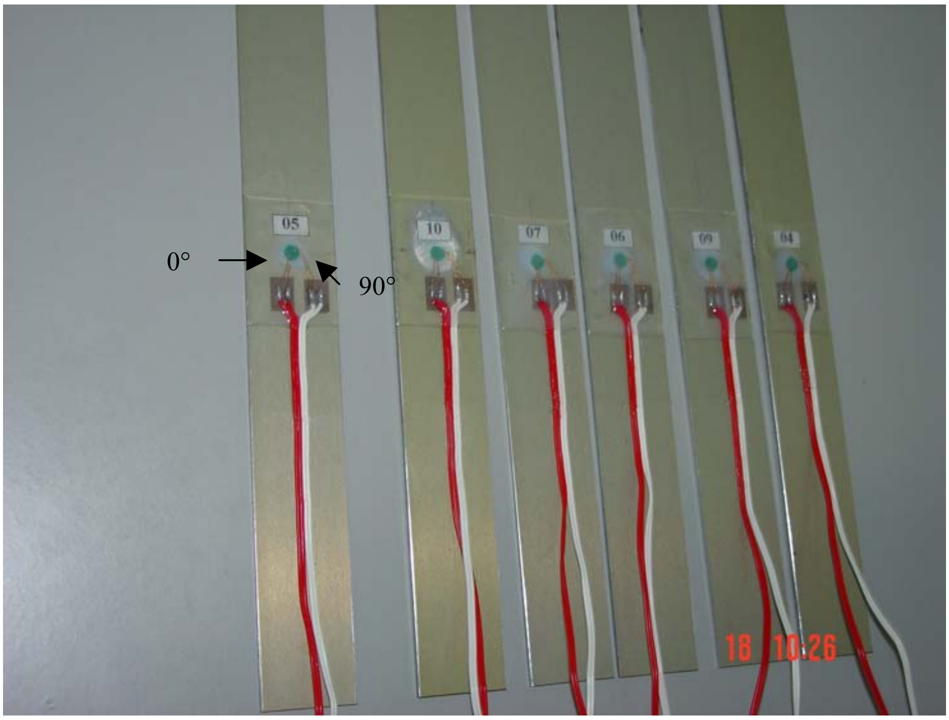

Figure 2. One strain gage type Rosette bonded at ±45°.

Results of the elastic modulus for polymer composite (G/E) obtained by the vibration tests were compared to the values calculated by using the Fabric Geometry Model software [Pastore and Gowayed, 1994]. The FGM software allows predicting the stiffness of composite materials having spatially oriented reinforcements, from constituent material properties using composite micromechanics approach.

3. Results

Figure 3 shows a graph of moisture absorption for glass fiber/epoxy (G/E) composite, GLARE and aluminum 2024-T3 specimens exposed to 80°C and 90% RH. It is observed in Figure 3 that moisture absorption in aluminum and GLARE composites are negligible in relation to the G/E composite. There is a steady increase in moisture absorption for G/E composite up to the saturation point (6 weeks), reaching a moisture absorption around 1.5%/mass. Like other polymers, epoxies can absorb moisture when exposed to humid environments. Moisture absorption in polymers takes place through of a diffusion process, in which water molecules are transported from areas with high concentration to areas with lower moisture concentration. Figure 3 shows that GLARE composites absorbed less than 0.1% of moisture up to the polymer composites saturation point (after 6 weeks).

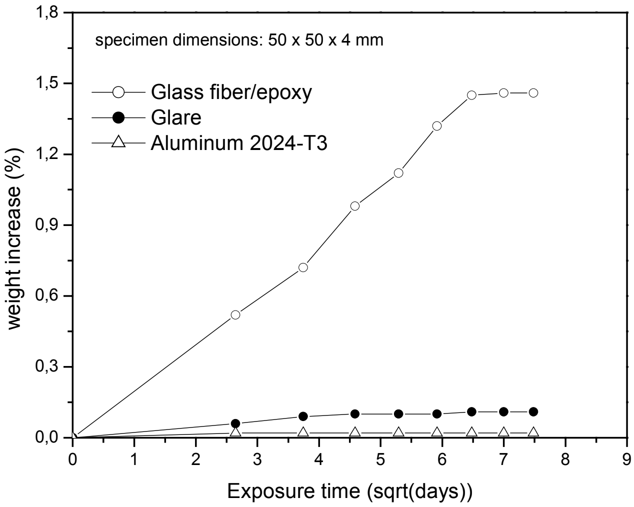

Figure 3. Moisture absorption of the materials studied.

Composite elastic constants calculations where performed using the FGM software, in order to compare with the elastic constant changes after hygrothermal conditioning. Results for theoretical elastic constants calculated by using composite micromechanics approach are shown in Table 2. Due to the elastic behavior of these composite materials, it can be assumed that the E' value found by vibration test is close to the E_x value found by theoretical calculations.

Table 2. Calculated theoretical engineering constants.

Specimen	Fiber content (%)	Al content (%)	E_x (GPa)	E_y (GPa)	G_{12} (GPa)	G_{13} (GPa)	ν_{12}
G/E	60.0	0.00	30.6	30.6	6.03	5.72	0.15
Aluminum*	0.00	100	70.0	70.0	28.0	28.0	0.33
GLARE	25.3	57.9	54.8	54.8	18.8	18.6	0.25

* obtained in the literature [Vlot and Gunnink, 2001].

Table 3 presents the storage modulus (E') as a function of the number of days exposed to humidity/temperature conditioning for aluminum, G/E and GLARE laminates, obtained by free vibration damping. Comparing the results presented in Table 2 with the results of Table 3, it was observed that the elastic modulus for G/E, Aluminum and GLARE, before to be conditioning, decreased 9%, 5% and 8%, respectively. Experimental measurements of elastic modulus of composites tends to exhibit different values from the theoretical calculations from micromechanics approach, because ideal bonding between fiber/matrix interface, perfect alignment of fibers and absence of voids and other defects are considered in the last. So, the differences between E' experimental and calculated E modulus (Table 2 and Table 3) are expected.

Table 3. Damping factor (E') and elastic moduli (obtained by tensile test – E) values.

Specimen	**E' (GPa)**	**E (GPa)**
G/E		
0 days	26.7	28.1
60 days	24.7	26.8
Aluminum		
0 days	65.3	66.1
60 days	65.4	66.0
GLARE		
0 days	49.7	50.2
60 days	48.0	49.1

In this work, it was observed that the G/E composite reduce the E' modulus value when exposed to humidity/temperature conditioning (Table 3). After 60 days of hygrothermal conditioning, the specimen reach moisture saturation and the E' values remain constant at ~25 GPa. As mentioned before, for G/E specimens, moisture uptake always induced resin plasticization and, consequently, reduces the E' modulus of the laminates. In Table 3 it was observed that the aluminum present the same E' value due to the moisture absorption for this specimen to be negligible.

For GLARE specimens, it was observed a lower decrease of E' modulus due to the effect of aluminum layers on the material.

These results are similar with the results obtained by tensile tests. According to Table 3, it is observed that elastic modulus from the GLARE composite, glass fiber/epoxy composite and aluminum in dry condition were: 28.1, 66.1 and 50.2, respectively, and in wet condition were: 26.8, 66.0 and 49.1, respectively.

4. Conclusion

The viscoelastic properties (E') and (E) moduli were measured for G/E composite, aluminum 2024 alloy; and for a GLARE laminate (aluminum 2024 alloy/glass fiber/epoxy composite). The specimens were tested using the vibration damping method and tensile test. Changes in the viscoelastic properties were measured during higrothermal conditioning up to the saturation point (8 weeks). The G/E composite absorbed more than 1.5% of moisture uptake up to the saturation point, while moisture absorption in GLARE laminates and aluminum were negligible. Results obtained by tensile and vibration tests agreed well, showing that both techniques (damping tests and semi-static tensile tests) can be used in order to investigate the viscoelastic properties of composite materials.

5. Acknowledgements

The authors acknowledge financial support received from FAPESP under grants 02/01288-3 and 03/04240-4. The authors are indebted to Mr. Rogério A Silva and Dr. José Maria Marlett from EMBRAER and to Divisão de Ensaios from IAE/CTA for helping to process the composite materials used in this work and in the vibration tests, respectively.

6. References

ANNUAL AMERICAN STANDARD TEST METHODS, Standard Hygrothermal Conditioning Test Method. Philadelphia, PA: American Society for Testing and Materials, 1988. (ASTM-D 5229 M-92).

ANNUAL AMERICAN STANDARD TEST METHODS, Standard Tensile Test Method. Philadelphia, PA: American Society for Testing and Materials, 1988. (ASTM-D 3039-76).

Asundi, A., Choi, A.Y.N. 1997, Journal of Materials Processing Technology 63, 384-394.

Botelho, E.C., Silva, R.A., Pardini, L.C., Rezende, M.C., 2004. Journal of Adhesion Science and Technology, 18, 1799-1813.

Carlsson, L.A, Gillespie, J.W. 1995. Marine envoronmental effects on polymer matrix composite. Composite Materials: Fatigue and Fracture, Fifth Volume, ASTM STP 1230, RA Martin, American Society for testing and materials, Philadelphia, 283-303.

Castrodeza, E.M., Bastian, F.L., Yawny, A., Ipiña, J.E.P.2002. Journal of Composite Materials 35, 1-14.

De Wilde, W.P., Frolkovic, P. 1994. Composites, 25, 119-27.

Dymácek, P. 2001. Fiber-Metal Laminates Steel-C/Epoxy. PhD thesis, Institute of Aerospace Engineering, Faculty of Mechanical Engineering of Brno University of Technology, Czech Republic.

Lee, B.L., Holl, M.W. 1996. Composites Part A 27A, 1015-1022.

Lee, M.C., Peppas, N.A. 1993. Journal of Composite Materials, 27, 1146-71

Lin, C.T., Kao, P.W. 1995. Materials Science & Engineering A. 190, 65-73.

Naboulsi, S., Mall, S. 1997. Theoretical and Applied Fracture Mechanics 26, 1-12.

Pastore, C.M., Gowayed, Y.A.1994. Composites. Journal of Composites Technology & Research, 16, 32-36.

Rastogi N., Soni S.R., Nagar A. 1998. Advances in Engineering Software, 29, 273-281.

Soprano, A., Apicella, A., D'Antonio, L., Schettino, F., 1996, Int. J. Fatigue, 18, 265-272.

Ünal Ö., Barnard D.J., Anderson I.E., 1999, Scripta Materialia 40, 271-276.

Verpoest, I, Springer, G.S. 1988. Journal of Reinforced Plastic and Composites, 17, 130-138.

Vlot, A., Gunnink, J.W. 2001. Fibre Metal Laminates. Kluwer Academic Publishers, Delft, Netherlands.

Vogelesang, L.B., Vlot, A. 2000. Journal of Materials Processing Technology 103, 1-5.

Zhang, M., Mason, S.E. 1999. Journal of Composite Materials, 33, 1363-1374.

7. Responsibility notice