An Investigation on Dynamical and Mechanical Properties of Hybrid Composite of Epoxy Matrix Reinforced with SglassFiber and Aluminum Sheet

K. Kolahgar Azari[1,*], A. Alizadeh[1], H. Omidvar[2], A. Sayadi Kelemi[3]

[1]*Composite Engineering Institute, Malek Ashtar University of Technology, Tehran, Iran.*
[2]*Department of Materials and Metallurgical Engineering, Amirkabir University of Technology, Tehran, Iran.*
[3]*Department of Materials Science and Engineering, Sharif University of Technology, Tehran, Iran.*
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Abstract

Hybrid composites are a kind of composite produced with two or more different reinforcer. One of the production technologies is using metal-fiber layers in a hybrid composite. In the present study, for the production of Hybrid composite, samples were prepared from glass fiber (S glass), aluminum alloy sheet (2024), and epoxy resin (F grade) using Resin Transfer Molding (RTM) process. Thus, three samples were considered, not strengthened matrix samples, samples with two layers of glass and samples with two layers of glass and two layers of aluminum. Then amounts of rigidity, strength and density of the samples were calculated considering fibers volume fraction. The results indicate that the presence of aluminum layer leads to an increase in toughness and plasticity of the composite, and thus causes more resistance to damage. Besides ultimate strength and strain, Natural frequency of the samples also increases by addition of the aluminum layer.

Keywords: Fiber Reinforced Composites, Aluminum Sheet, Dynamic Mechanical Analysis.

1. Introduction

Polymer-based composites are an important type of composites that are used in different fields of the industry such as aerospace, shipbuilding, and automotive. In recent years, high mechanical strength and low cost as well as good corrosion and chemical resistance of polymer composites have led to the replacement of these materials instead of metal sheets [1]. Fiber metal laminate (FML) Composites are a new kind of polymer-based composites made of sheet metal and fiber-reinforced polymer composites. Various types of FML have been developed to reduce the weight of products for replacing aluminum alloys with FML composites in automotive and other relative applications [2, 3]. High impact resistance, convenient repair conditions and high fatigue resistance, low density, and relatively good stiffness of FML composites have led to the creation of materials with desirable mechanical and physical [4]. Aluminum, titanium, magnesium, and steel alloys are suitable candidates for the metal layer in FML. Among these candidates, Magnesium alloys are superior due to their low density and excellent corrosion resistance, however, Magnesium alloys demonstrate low fatigue resistance under static loads, and for long periods they are likely to fail. Titanium alloys offer good properties in fatigue, impact, and stiffness, but their high density and low flexibility, as well as high cost, make them less attractive in the FML composites material selection procedure [4, 5]. Various aluminum alloy grades such as 2024 and 7075 are used in FML composites. Superior mechanical properties such as high fracture toughness, good strength, and low cost of these types of alloys have led to their widespread applications in FML composites [4, 6].

However, placing the glass fiber (which has little plasticity) within the polymer matrix increases the mechanical properties, but it reduces the structural flexibility and toughness with increasing of fiber volume fraction and causes the vibration properties and impact resistance be reduced. One of these technologies, is using the metal layer -fiber hybrid composite (Fiber Metal Laminates) .[1-3]

In this study, in order to production of hybrid composite (Sglass Aluminum epoxy) resin transfer molding (RTM) method was used. RTM process under low pressure and in the closed mold be done using fiber reinforcer and a thermostat resin to produce composite parts with a variety of dimensions and with high dimensional precision [7-9]. After the fiber is installed into the mold, a premixed catalyst and resin is injected into the closed mold cavity encapsulating the fiber within. RTM has the inherent advantage of low-pressure injection that usually does not exceed 100 psi of resin injection pressure during the mold-fill process [8]. Various types of resin including epoxy resin polymer, unsaturated polyester and vinyl esters

*Corresponding author
Email address: k.k.azari@mut.ac.ir

could be used in this process. In this study, vibration and dynamic analysis of samples were performed by the Modal analysis as a theory-experimental method. In the experimental measurements of structural vibrations, a series of relevant peak frequencies. Peak-Picking can be a reliable are present in the response. These sharp peaks include detectable central frequency that are known as resonance of structure. The behavior of a structure could be analyzed by the diagnosis and evaluation of both resonances and modes existing in the response in time and frequency domains. Modes are inherent properties of a structure, and are determined by the material properties (mass, damping and stiffness), and boundary conditions of the structure. Each mode is defined by a natural (modal or resonant) frequency, modal damping, and a mode shape (i.e. the so-called "modal parameters"). If either the material properties or the boundary conditions of a structure change, its modes will change. A simple way of doing modal analysis from the response-only data is based on a Peak-Picking technique applied to the auto and cross-spectrum of the response signal. This is a Single-Degree-Of-Freedom (SDOF) method, which involves selecting peaks in the spectra corresponding to resonance approach when the modes of the system are well separate and when the damping associated with each mode is low so that the influence each mode on the dynamical behavior can be considered independently. This method is based on singular value decomposition (SVD) of the matrix of power spectra.

2. Materials and Methods

2.1. Materials

In this study pre-preg layers with specification of DIN7735, HGW 2372.4, ISO: EPGC4, NEMA: G11 (properties according to Table. 1.) including epoxy resin with viscosity of 460-640cp and woven textile glass fiber S type (Sglass) with aluminum sheet (Al2024 T3) with the thickness of 0.7mm were used.

Table. 1. The properties of pre-pregs.

Bulk Density(g/cm^3)	1.7-1.9
Flexural strength at 23 (N/mm^2)	450
Flexural strength at 150 (N/mm^2)	220
Impact strength(KJ/m^2)	150
Tensile strength(N/mm^2)	360
Compression strength parallel to layers(N/mm^2)	300
Compression strength perpendicular to layers(N/mm^2)	500
Modulus of Elasticity(N/mm^2)	18 10_3
1 Minute Test Voltage (kv)	40
Mass percentage of Fiber glass	60%
Delamination strength(N)	2500

The samples without reinforcing were also prepared in order to compare the results of the tests. Table. 1. given the properties of pre-pregs. Schematic of layer arrangement is shown in Fig. 1. and the characteristic of different samples is given in Table. 2.

Table. 2. The properties of samples.

Symbol of sample	Thickness (mm)	Properties
1	4.5	Not strengthened matrix(pure epoxy resin)
2	4.5	18 layers of pre-preg (thickness of per layer is 0.2mm) -1 layer of aluminum sheet with 0.7 mm thickness - Residual thickness is filled with resin
3	4.5	15 layers of pre-preg (thickness of per layer is 0.2mm) -2 layers of aluminum sheet with 0.7 mm thickness per layer Residual thickness is filled with resin

2.2 Procedure of Sample Preparation

RTM method was used for production of composite samples. For proper adhesion of the aluminum sheet to the composite, aluminum sheet surface was roughened.

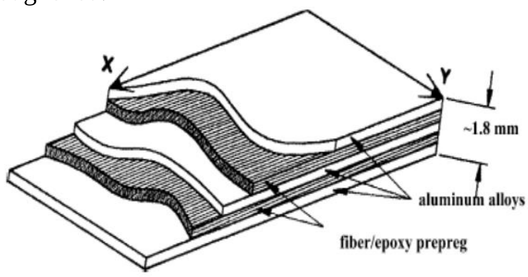

Fig. 1. The schematic of layer arrangement.

2.3. Test methods and analysis

The fiber volume fraction was calculated [10] and based on these values, the amounts of stiffness, strength and density of samples were obtained as given in Table. 3.

Table. 3. The volume fraction, yield strength and rigidity of the composite samples.

Sample	Thickness (mm)	Volume fraction of reinforcer	Yield strength (MPa)	Rigidity (GPa)
1	4.5	0	86	8
2	4.5	0.187	580	32.8
3	4.5	0.245	640	36

2.3.1.Modal Analysis

Dynamic analysis was done using the Frequency Response Method [11]. This method is usually used for vibration measurements in which the system is stimulated by using harmonic impulse, so that its frequency could be changed, and then its response within the desired frequency is recorded. Using advanced -Attention to orthotropic direction of the measurement instruments and computer, impulse method is accepted more and more in vibration test [12]. One of these methods to obtain structural natural frequency is modal analysis which has been used in this study. If the natural frequency of structure is the same as exciting frequency, all of the incoming energy is used to increase the amplitude, and resonance will occur and thus system will collapse.

In fact, the environment continuously changes to few degrees of freedom. 30 points were considered on the samples. There are many tools available for performing vibration analysis and testing. The frequency response function is a particular tool that expressed in the frequency domain. Consider a linear system as represented by the diagram in Fig. 2.

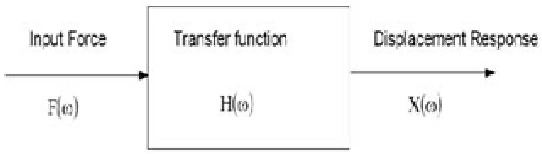

Fig. 2. linear system as represented by the diagram.

In this study, equipment were calibrated before the modal test. After calibration of analyzer equipment, hammer and amplifiers, the completely free boundary conditions was selected. The relations between various components of the modal analysis are shown in Fig. 2. schematically. The modal analysis was performed according to the following steps Eq. (1).:

$$\mathbf{X(\omega)= H(\omega) \times F(\omega)} \qquad \text{Eq. (1).}$$

Substituting the convention terms into Eq. (2).:

$$\mathbf{H(\omega)= X(\omega)/ F(\omega)} \qquad \text{Eq. (2).}$$

Summation of forces in the vertical direction and Considering a Multiple-Degree Of-Freedom (MDOF) system, the linearized equation of motion assuming viscous damping can be can be written as Eq. (3).:

$$\mathbf{M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = F(t)} \qquad \text{Eq. (3).}$$

Consider a single-degree-of-freedom system subjected to a force excitation Eq. (4).:

$$\mathbf{\ddot{x}+(c/m)\dot{x}+ (k/m)x = F/m} \qquad \text{Eq. (4).}$$

where M, C, K are the mass, damping and stiffness matrices respectively; $\ddot{x}$, $\dot{x}$ and x the corresponding acceleration, velocity and displacement and F is the force applied to the system. By convention,

$$\mathbf{(c/m) = 2\xi\omega_n(k/m) = \omega_n^2} \qquad \text{Eq. (6).}$$

where ω_n is the natural frequency in (radians/sec), and ξ is the damping ratio. Eq. (4).:

$$\mathbf{\ddot{x}+ 2\xi\omega_n\dot{x}+ \omega_n^2x = \omega_n^2F/k} \qquad \text{Eq. (7).}$$

The Fourier transform of each side of Eq. (7). may be taken to derive the steady-state transfer function for the absolute response displacement. After many steps, the resulting transfer function is Eq. (8).:

$$\frac{X(\omega)}{F(\omega)} = \left[\frac{1}{k}\right] = \left[\frac{\omega_n^2}{\omega_n^2-\omega^2+j(2\xi\omega\omega_n)}\right] \qquad \text{Eq. (8).}$$

This transfer function, which represents displacement over force, is sometimes called the receptance function. Creation of base boundary conditions. The completely free conditions were selected since it's simulation is easier. These conditions can be provided by two methods: a-laying the sheet on a linen sheet that has a little damping. b-hanging of pieces. In this study, b condition was considered. Stimulating of samples and measuring frequency response. By moving an accelerometer over the surface, the mode may by using the ratio between these two signals be recorded and plotted. Excitation by an impulsive load (impact force) will produce a transient response consisting of a superposition of all the modes of vibration and their corresponding natural frequencies. To extract the frequency response there are two methods: a-The exciting point is fixed and the accelerometer spot can be moved through the points. In fact accelerometer is moved and impact test is repeated at as many points where a mode is desired. b- The exciting point is variable and the accelerometer on a fixed point is considered (b condition was considered in this study). The accelerometer stood at point 23 and impulses were done at the other points up to required number (5 to 85). The excitation and response signals have been sent to the double channel analyzer in order to measure these values. The analyzer alters the signals which are received in the time domain to frequency domain and the frequency response function is regularly made There are two methods to extract the natural frequencies:

a-Visual inspection by monitoring of results with attention to the resonance peaks in the frequency responses (which in this study, this case was considered). b-Sending the frequency responses to STAR software and crafting. -Determining the frequencies and viewing the modes: In this section the modal index of a natural frequency with a special mode could be detected by considering the number of nodal lines, nodal points and the mode of slope, so that the counts of lines per node are equal to the modal index plus 1 for that direction.

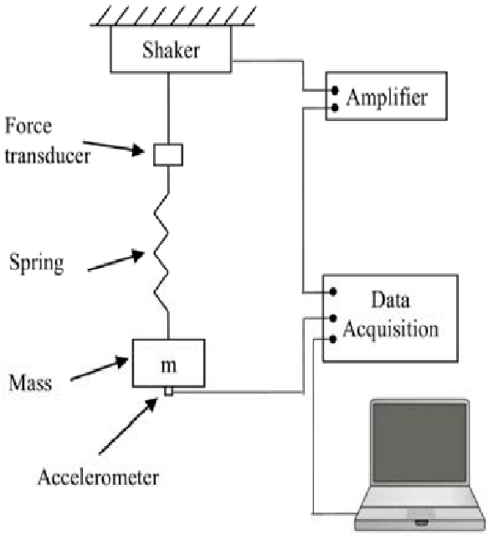

Fig. 3.The schematic of modal analysis.

2.3.2. Tensile and Impact tests

The tensile test was done on the machined samples according to ASTMD 3039 standard with displacement rate of 2mm/min. The impact test was also done according to ASTMD256 standard. Finally, to ensure proper performance of composite parts in working conditions, the loading test was performed.

2.3.3 Loading test Description

The equivalent load on the specimen is 23 bars and loading time is about 2 minutes. The test is done in ambient temperature. The purpose of the test is surveying the structure strength. The equipment include fixtures and loading devices. The loading continuously resumed to 23 bars (3.3 KN) to achieve a much higher reliability coefficient. Before loading, during loading and after that, the strains and changes in shape were recorded. The failure load and location of any failure were detected. Both visual inspection and evaluation of the results of strain gauge were performed. In two following conditions this test is acceptable: -There isn't any damage in structures. -No significant deformation should be observed. Fig. 3. shows the sample under loading test.

Fig. 3. sample under loading test.

3. Results and Discussions

The ratio of stiffness, yield strength, failure strength and toughness values of samples than sample 1 are shown in Table. 4. As shown, the reinforcement polymer composite with glass fibers, has a good effect on the mentioned quantities. The amount of toughness has been increased 9 times with addition of glass fiber and aluminum to matrix (sample 3). Presence of the aluminum sheet instead of using glass fiber alone has more effect on the increase of impact because the existence of much natural strength and toughness of the composite. The ultimate failure strength and failure strain for the final composite have been increased by increasing the reinforcer. The role of the aluminum sheet on the ultimate properties is more effective, so that for sample 3 with the reduced glass fiber and the increased aluminum, the ultimate failure strength is 5 times more. Table. 5. compares the results of impact test for different samples, showing that the energy absorption for the reinforced samples is higher than that of sample 1, so that for the aluminum sheet reinforced sample this value is 7 times higher.

Table. 4. The ratio of rigidity, yield strength, fracture strength and toughness for different samples than sample 1.

Sample	Rigidity ratio	Yield strength ratio	Fracture strength ratio	Toughness ratio
2	4.1	6.74	4.5	7
3	4.5	7.44	5	9.8

Table. 5. The energy absorption of samples.

Sample	Dimension (mm)	Absorbed energy per unit Surface(KJ/m^2)	Energy ratio than sample 1
1	4.6*10.2	50	1
2	4.6*10.2	295	5.9
3	4.6*10.2	357	7.4

Frequency, the amplitude was adjusted between 0 to 400HZ, so that the natural frequencies at lower amplitudes were obtained with more accuracy [13]. The vibration is an important problem at the low weight of spatial structure that causes failure in parts due to the fatigue. On the other hand the vibration causes additional stress that wastes the heat energy even though the effect of the fatigue is disregarded [11]. The frequency of composite is changed with the fibers direction variations. Optimization of fibers direction has a great importance in the design of composite structures to reach the maximum frequency response. The increase of natural frequency is due to less fluttering of the parts under vibration conditions.

In fact, reducing vibration energy with higher frequency response results in less vibration and more tolerance in higher vibration frequency. In this study as shown in Table. 4., samples reinforced with aluminum sheet (sample 2) have a higher natural frequency. In fact, with increasing natural frequency, the minutes. The reliability coefficient was higher vibrating mode of structures occurred in high frequencies and besides the good toughness and flexibility, the vibration is also suitable. It should be mentioned that the natural frequency response of the parts due to the error sources, is also higher than the results listed in Table 6. One of these error sources is effect of the environment since the sample is hung in the air, so the frequency measurement is also done at the same experimental environment and the air damping reduces the experimental frequencies [13].

Table. 6. The results of modal analysis, the first 5 natural frequencies of the samples.

Sample	Mod1	Mod2	Mod3	Mood4	Mod5
1	111	122	150	161	172
2	132	157	167	174	189
3	257	322	378	394	443

The loading test was performed on samples 2 and 3. Sample 2 fractured at the junctions (screws) after loading to 30 bars (Fig. 4.a). For the test sample 3 the loading resumed to 60bars (7.6kN), no destruction was found (Fig. 4.b) and the loading time continued to 6 than 2 in termes of time and applied load.

Fig. 4. Hybrid composite after loading on a.sample2 , b.sample3 without any fracture.

4.Conclusion

In this study hybrid composite samples was prepared using pre-pregs and aluminum sheets layers. Addition of aluminum sheet to epoxy matrix has efficient effects on dynamical and mechanical properties of composite. The results are concluded as follow:

1. According to Modal analysis results, composite samples reinforced with aluminum sheets contain higher natural frequency.
2. Addition of glass fiber and aluminum sheet to epoxy matrix results in 9 times increase in toughness. The presence of the aluminum sheet instead of using glass fiber alone has more effect on the increase of yield strength and toughness of the composite.
3. The energy absorption is increased about 7 times as a result of the presence of the aluminum sheet.

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