Experimental and Numerical Analysis of Structural Damping of Glass Fiber Reinforced Polymers

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Abstract-*In this study, vibration damping properties of glass fiber reinforced composites are analysed. The study presents an extensive analysis of the damping of unidirectional glass fibre composites as function of frequency and fiber orientation. Damping of glass fiber composites is analysed experimentally using a cantilever beam test specimen and an impulse technique. The present work aims to study the mechanism of damping and its FEA evaluation for GFRP composite beam. This work presents a combined experimental and numerical study of free vibration of GFRP composite plates.The natural frequencies of 8-layered fiber Glass/Epoxy cantilevered composite plates has been determined experimentally and compared with the ANSYS results.*

Keywords: *composite, damping, fiber orientation*

I. INTRODUCTION

In recent days, automobile and construction industries are focus on the light weight, environmental friendly materials with good mechanical properties. Glass fiber reinforced composites have excellent specific properties and are widely used because of reduced mass.

Glass fibers are the most commonly used ones in low to medium performance composites because of their high tensile strength and low cost. Composite structures have been widely used in many engineering examples in aeronautical, astronautically, and marine structures.

Fiber composites are basically constructed with fiber and matrix phases. The mechanical behaviors of the fiber composites are always influenced by the fiber and matrix properties and their microstructures such as fiber array, fiber shape, and fiber volume fraction. In order to design composite materials with desired properties, it is required to understand the relation of their microstructure to the overall mechanical responses. Thus, a composite material is labeled as any material consisting of two or more phases. Many combinations of materials termed as composite materials, such as concrete, mortar, fiber reinforced plastics, fiber reinforced metals and similar fiber impregnated materials.

In addition to the advantages of high strength (as well as high stiffness) and light weight, another advantage of the laminated composite plate is the controllability of the structural properties through changing the fiber orientation angles and the number of plies and selecting proper composite materials. In order to achieve the right combination of material properties and service performance, the dynamic behavior is the main point to be considered. From a theoretical point of view this has led to the development of numerous models of composite plates for the prediction of different parameters including free vibration. To avoid the typical problems caused by vibrations, it is important to determine: a) natural frequency of the structure; b) the modal shapes and c) the damping factors.

1.1 Damping

Damping is an important parameter in the design of composite materials for engineering applications where dynamic response is concerned and vibration control is required. Damping is an important feature of the dynamic behaviour of fiber-reinforced composite structures, involving minimization of resonant and near-resonant vibrations.The dissipation of energy from a vibrating structure that is transformation of vibration energy into other form of energy yielding the removal of energy from vibrating system is called as damping. Damping mechanism in composite material differs entirely from those in conventional metals and alloys.

The damping of an engineering structure is important in many aspects of noise and vibration control, fatigue endurance and so on, since it controls the amplitude of resonant vibration response.

1.2 Classification of Damping:

Damping can be broadly divided into two classes depending on their sources,

(1) Material damping
(2) System damping

Material Damping:

Damping due to dissipative mechanism working inside the material of the member is termed as material damping. The magnitude of material damping in structural metal is low and depends upon the level of stressing. Actual value of stress level for a definite resonant frequency however depends upon the deflection of structural member. Material with best fatigue strength is not necessarily the best material for near resonant loading. Ferro-magnetic material and alloys of magnesium and cobalt exhibits higher damping than common structural material, iron, steel, or aluminum.

System Damping:

System damping involves configuration of distinguishable part arises from slip and boundary shear effects of mating surfaces. Energy dissipation during cyclic stress at an interface may occur as a result of dry sliding (coulomb friction), lubricated sliding (viscous forces) or cyclic strain in a separating adhesive (damping in visco-elastic layers between mating surfaces). System damping to our need is classified as:

(1) Support damping
(2) Damping due to sandwich construction
(3) Damping due to joints

1.3 Problem Definition

Vibration is an element which is hard to avoid in practice. Excitation of resonant frequencies of some structural parts can occur with existence of vibration even it is only a small insignificant vibration. The damping of an engineering structure is important in many aspects of noise and vibration control, fatigue endurance and so on, since it controls the amplitude of resonant vibration response. Estimating damping in structure composed of different materials and processes still remains as one of the most extremely vast challengers; hence it is necessary to study the damping property of the material. In this work we have studied modal properties such as natural frequency, damping factor and mode shapes of the GFRP composite beam with different fiber orientation which are largely used as alternative of conventional metal.

II. LITERATURE REVIEW

R. Chandra et. al. (1999) presented review of damping studies in fiber reinforced composites materials and structures. Composite damping mechanism that depends upon the different sources of energy dissipations was described. The study included macromechanical, micromechanical and viscoelastic approaches, and models for interphase damping, damping and damage in composites. It also described the damping model for thick laminates improvement and optimization for damping characteristics of fiber reinforced composites and structures.

Ahmed Maher et. al. (1999) introduced an improved dynamical model for vibration damping in composite structures to investigate the stacking sequence and the degree of anisotropy as a function of the vibration modes. Extensive investigation has been carried out from the fitting of modal measurements with lowest residual errors to establish quasi-uniform mass damping models in terms of normal coordinates system. The analysis of the obtained results proves not only the efficiency of the proposed model but also its applicability in any wide range of frequency spectrum of composites.

R.D. Adams et al. (2003) highlight property of fiber reinforced plastic (FRP) materials which is equally desirable in weight sensitive structural applications, namely their potential for vibration damping. They studied the factors affecting the damping in FRP composites. They also found that the damping properties of FRP composites can be readily predicted.

Jean-Marie Berthelot and youssefSefrani. (2004) extensively analyze the damping of unidirectional fiber composites as function of frequency and fiber orientation. They analyze the damping of glass and Kevlar composites experimentally using a cantilever beam test specimen and an impulse technique. Damping parameters were derived by fitting the experimental Fourier responses with the analytical motion responses. The experimental results compared with literature models: Adams–Bacon analysis, Ni–Adams analysis and complex stiffness model.

Jean-Marie Berthelot (2006) analyzed the damping of unidirectional fiber composites and different laminates. He analyzed damping characteristics of laminates experimentally using cantilever beam test specimens and an impulse technique. He developed the damping modeling of unidirectional composites and laminates using the Ritz method for describing the flexural vibrations of beams or plates. The influences of the beam width as well as the influence of the vibration frequency were considered.

E.C. Botelho et al. (2006) studied the viscoelastic properties such as elastic and viscous responses for aluminum 2024 alloy; carbon fiber/epoxy; glass fiber/epoxy and their hybrids aluminum 2024 alloy/carbon fiber/epoxy and aluminum 2024 alloy/glass fiber/epoxy composites. They compared the experimental results to calculated E modulus values by using the composite micromechanics approach. For all specimens studied, the experimental values showed good agreement with the theoretical values. The damping behavior, i.e. the storage modulus and the loss factor, from the aluminum 2024 alloy and fiber epoxy composites can be used to estimate the viscoelastic response of the hybrid FML.

Jean-Marie Berthelot et al. (2008) developed a synthesis of damping analysis of laminate materials, laminates with interleaved viscoelastic layers and sandwich materials. They studied the Laminate theory including the transverse shear effects combined with a finite element analysis to describe the damping characteristics and the dynamic response of structures constituted of laminates, laminates with interleaved viscoelastic layers or sandwich materials. The results obtained are compared with the experimental results of the frequency response of the structure.

Andrzej Flagaet al.(2008) presented the methods of vibrations damping coefficient determination. The methods, such as collocation method, two energetic methods and half-power bandwidth method concern composite structures. The verification of methods has been taken into account in this work. Two real compound models and two numerical models have been created. They measured and calculated the Time series of vibrations of these models. The comparison of four methods has been made on the basis of obtained results.

Abderrahim El Mahi et al. (2008) analyzed the damping of unidirectional fiber composites, orthotropic composites and laminates. They investigated the damping parameters using beam test specimens and an impulse technique. They developed the damping modeling using a finite element analysis which evaluated the different energies dissipated in the material directions of the layers. The results obtained showed that this analysis describes fairly well the experimental results. The finite element analysis can be applied to complex shape structures.

E. Sarlinet al.(2012) studied the damping properties of laminated structures consisting of steel, rubber or epoxy adhesive and glass fiber reinforced epoxy composite. They investigated the damping properties of the structures through the loss factors. The loss factors of the hybrid structures and the constituent materials were determined by frequency and time domain test methods. By using the loss factor results of the constituent materials, the loss factor of the hybrid structures were estimated by the rule of mixtures and the results were compared with the experimental results. They observed that the use of weight fractions instead of volume fractions in the rule of mixtures provides a good average estimation of the damping behaviour of the hybrid structure and the results of rule of mixtures method can be used as rough estimates during the design phase of hybrids.

S.Prabhakaran et al.(2014). In this paper, they studied the sound absorption and vibration damping properties of flax fiber reinforced composites and compared with the glass fiber reinforced composites. They experimentally observed that the sound absorption coefficient of flax fiber reinforced composites has 21.42% & 25% higher than that of glass fiber reinforced composites at higher frequency level (2000 Hz) and lower frequency level (100 Hz). From the vibration study they observed that the flax fiber reinforced composites have 51.03% higher vibration damping than the glass fiber reinforced composites. The specific flexural strength and specific flexural modulus for flax fiber reinforced composites also good. These results suggest that the flax fiber reinforced composites could be a viable candidate for applications which need good sound and vibration properties.

F. Duc, P.E. Bourban et. al. (2014) compared the mechanical and damping properties of unidirectional (UD) and twill 2/2 flax fiber (FF) reinforced thermoset (epoxy) and thermoplastic (polypropylene (PP) and polylactic acid (PLA)) composites containing 40 vol% of fibers with those of carbon (CF) and glass (GF) fiber reinforced epoxy composites. The composites reinforced with FF showed improved damping as reflected by dynamic mechanical analysis with respect to composites reinforced with synthetic CF and GF. The addition of UD FF to epoxy led to an approximately 100% increase in loss factor with respect to both the matrix and GF reinforced epoxy. FF/PP showed the highest damping at 25 _C and 1 Hz of all the composites investigated (tan d ¼ 0:033). However the best compromise between stiffness and damping was obtained with FF reinforced semi-crystalline PLA.

H. Abramovich et al. (2015) investigated the damping characteristics of composite laminates made of Hexply 8552 AGP 280 5H (fabric), used for structural elements in aeronautical vehicles, using the hysteresis loop method and compared to the results for aluminum specimens (2024T351). They found that the loss factor η, obtained by the hysteresis loop method was linearly dependent only on the applied excitation frequency and was independent of the preloading and the stress amplitudes. For the test specimens used in tests series, they found that the damping of the aluminum specimens is higher than the composite ones for longitudinal direction damping, while for bending vibrations the laminates exhibited higher damping values.

Mustapha Assarar et. al.(2015) evaluated the damping properties of flax–carbon twill epoxy composites. The effects of stacking sequence and hybridation on damping property were estimated using beam test and impulse technique. The dynamic characteristics of the composite materials were derived from vibration testing. It is reported that the damping coefficients are higher than the carbon fiber composites. The dynamic and mechanical properties were found to be highly dependent on stacking sequence of flax and carbon layer.

A. Treviso et. Al. (2015) presented discussion on test methods, damping phenomenon, material constituent's orientation and stacking sequence, temperature and frequency effect on damping property of different composite materials. It also described the damping models such as

1. Linear viscoelastic model
2. Complex modulus and loss factor
3. Strain energy model
4. Physics based model

Himanshu Mevada and Dipal Patel. (2016) estimated the damping in structure composed of different materials (steel, brass, aluminum).The damping characteristics is estimated in terms of natural frequency and damping ratio. The modal analysis is carried out experimentally and by using ANSYS. The damping ratio was determined by using half power bandwidth method. It was reported that harmonic analysis is an effective method for estimating the damping characteristics of structural material.

III. EXPERIMENTAL SETUP OF CANTILEVER BEAM

An experimental setup is as shown in Figure 3.1. First a beam of test material is to be fixed at one end. An Accelerometer has been attached to the cantilever beam at free end to sense the acceleration data of vibration. Impact hammer is used to disturb the frequency or to oscillate the beam. After impact the beam will be oscillated, so accelerometer sense data and signal generated by DAQ device. To calculate the natural frequency of the cantilever beam experimentally, experiment is conducted the with the specified cantilever beam specimen to record the data of time history (Acceleration-Time), and FFT plot. The natural frequencies of the system can be obtained directly by observing the FFT plot. The location of peak values corresponds to the natural frequencies of the system. [15]

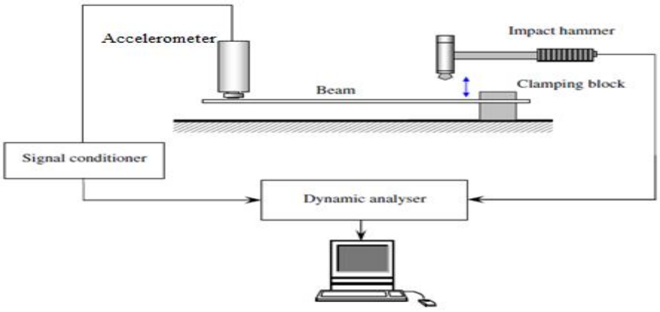

Figure 3.1- Experimental setup of cantilever beam.

3.1 EFFECT OF FIBER ORIENTATION ON NATURAL FREQUENCY

Variation of natural frequencies with 'θ' (angle) for an 8-layered GFRP cantilevered composite plate; the experimental and numerical values are tabulated in Table 3.1.1

Table 3.1.1- Natural frequency of composite with different orientation

Orientation	0		45		90	
	EXPT	ANSYS	EXPT	ANSYS	EXPT	ANSYS
I Mode	30.2913	24.553	21.7476	22.9207	20.1942	15.689
II Mode	151.607	153.75	133.592	143.34	86.2136	97.776
III Mode	397.67	430.71	382.136	400.87	275.728	264.48

Here, the effect of fiber orientation on the natural frequency of composite beam is analyzed. The variations in natural frequency with different fiber orientation are shown in the following Figure 3.1.2 to3.1.4:

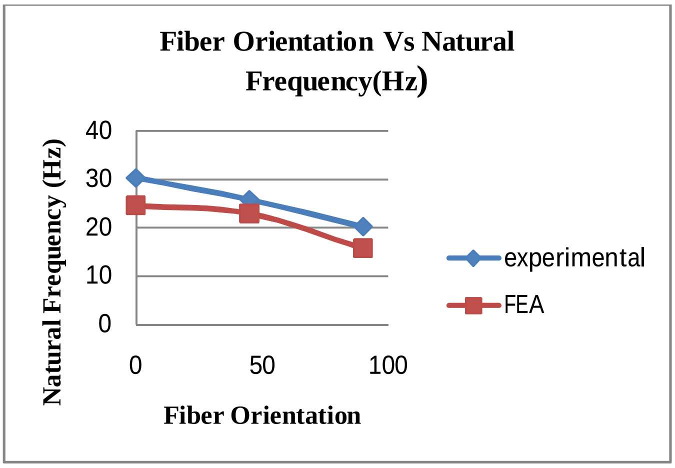

Figure 3.1.2- Fiber orientation vs First Mode Natural Frequency

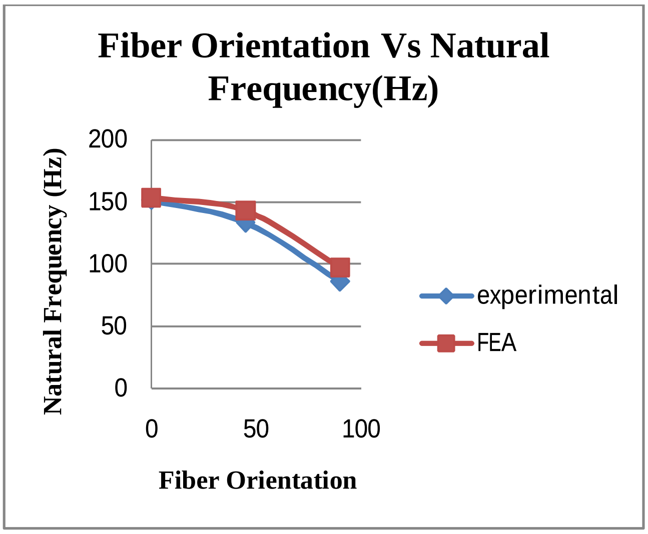

Figure 3.1.3- Fiber orientation vs Second Mode Natural Frequency

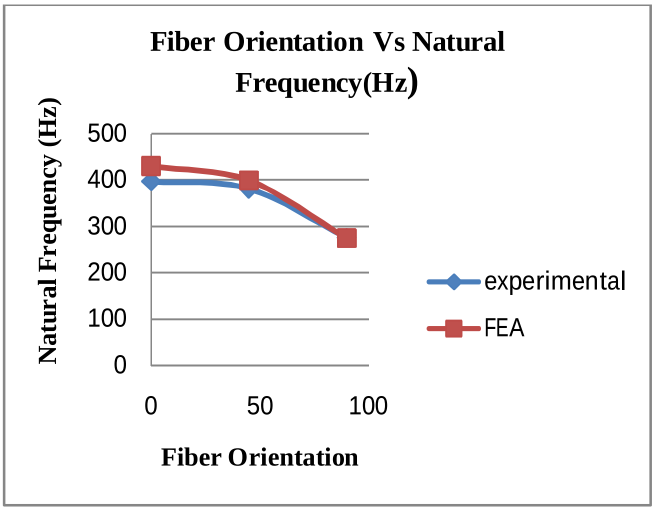

Figure 3.1.4 - Fiber orientation vs Third Mode Natural Frequency

The natural frequency from ANSYS is compared with experiment results. The ANSYS value is closely agreed with the experimental one. Percentage error of experimental valueand ANSYS value is within 15%. The natural frequency decreases with increase of fiber orientation.

3.2 EFFECT OF FIBER ORIENTATION ON DAMPING FACTOR ξ

3.2.1 ANSYS Result

Graph of the Material beam frequency vs displacement are obtained from the ANSYS result which are as below Frequency vs Amplitude for 0° fiber oriented GFRP is as in Figure 3.2.1.

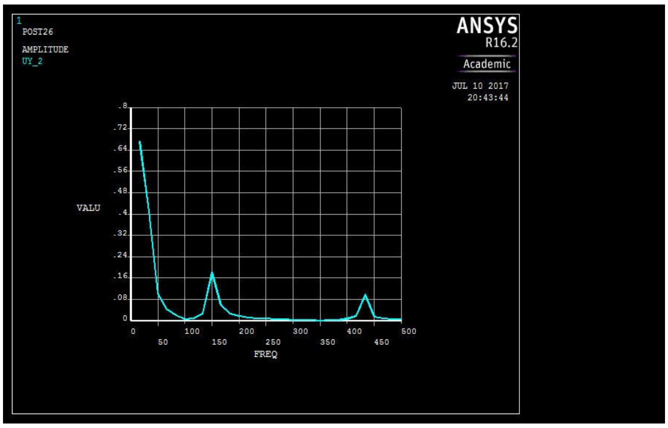

Figure 3.2.1- Frequency vs Amplitude for 0° fiber oriented GFRP

Frequency vs Am plitude for 45° fiber oriented GFRP is as in Figure 3.2.2.

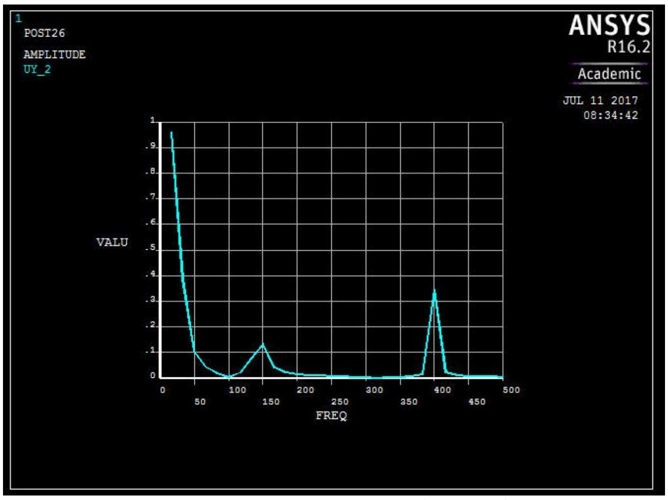

Figure 3.2.2- Frequency vs Amplitude for 45° fiber oriented GFRP

Frequency vs Amplitude for 90° fiber oriented GFRP is as in Figure 3.2.3.

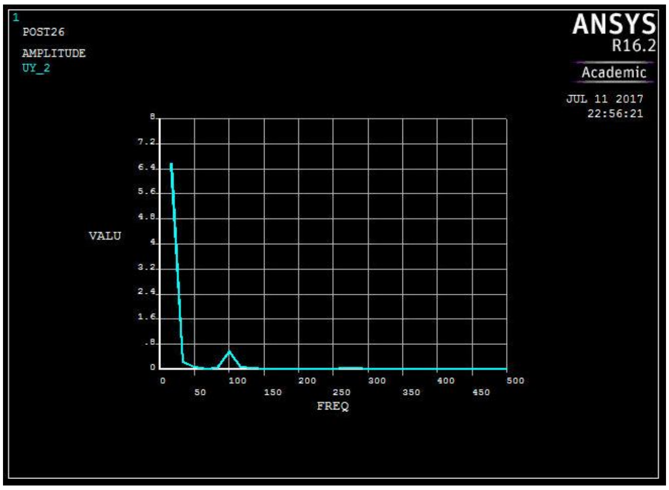

Figure 3.2.3- Frequency vs Amplitude for 90° fiber oriented GFRP

3.3 EFFECT OF FIBER ORIENTATION ON DAMPING FACTOR OF THE UNIDIRECTIONAL BEAM

Tables 3.3.1shows the mode wise change in the damping factor with change in fiber orientation and they graphed as in Figure 3.3.1

Table 3.3.1- Effect of Fiber orientation on Damping Factor

	Damping Factor (ξ)		
Orientation	**0°**	**45°**	**90°**
I Mode	0.0441818	0.0502	0.0399736
II Mode	0.050458	0.0625	0.05037
III Mode	0.015773	0.016187	0.015301

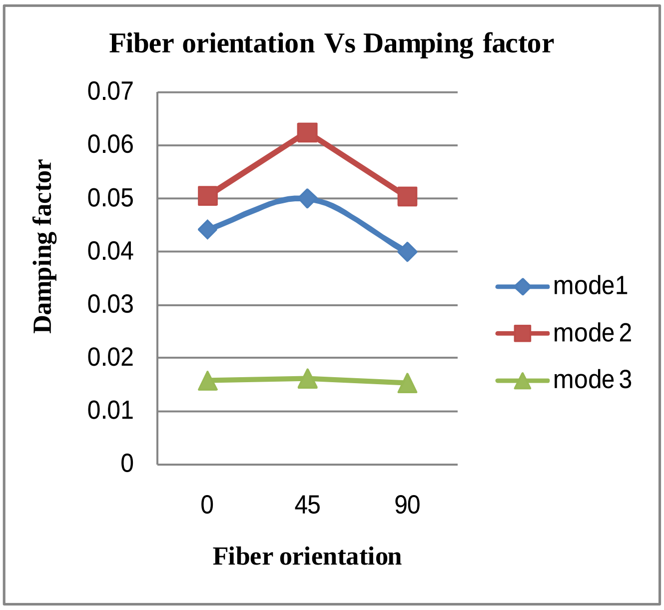

Figure 3.3.1- Effect of Fiber orientation on Damping Factor

IV. CONCLUSION

In this section of the report, series of reasonable observations were made and discussed below. The dynamic investigation of a fiber reinforced polymer beam was carried out in this work. The modal analysis was performed to the natural frequencies and mode shapes. The fundamental frequency for cantilever beam condition was estimated in experimental and numerical ways.

Material damping of continuous fiber organic matrix composites was experimentally determined using cantilever beam test specimen geometry and an impulse excitation technique.

- The damping factor for 0, 45 and 90 degree glass fiber reinforced polymer are measured. Damping is found to be effected by fiber orientation.
- In general, the damping factor increases with increasing fiber orientation upto 45° and is seen to be decreases as the fiber orientation increases above 45.
- The natural frequency also affected by the fiber orientation. As fiber orientation increases from 0 to 90 the natural frequency decreases.
- The finite element analysis (ANSYS) tool is successful tool to investigate the effect of fiber orientation on the natural frequency of GFRP beam.
- Finally, there are fair agreements between experimental results and numerical which was the target of this research work.

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