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Evaluation of Modal Damping of Graphite/Epoxy Laminated Composites

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ABSTRACT

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. Damping in fiber-reinforced composite materials is highly tailorable with respect to constituent properties, fiber volume fractions and ply orientation angles. To this end an experimental analysis of the damping of unidirectional graphite reinforced epoxy composites was carried out. Damping characteristics of laminates are analysed experimentally using impulse technique. Composite laminate were made using the traditional hand-lay-up process. Experimental dynamic tests were carried out using specimens with different fiber orientations and three different boundary conditions and different thickness.

Keywords: *Composite materials, FFT, Graphite, Modal Damping, Modal Testing.*

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I. INTRODUCTION

Graphite fiber reinforced composites have been widely used in many industrial fields, especially leisure/sports and aerospace, for their strength, light weight, and other mechanical properties. Despite all these advantages, graphite fiber reinforced composites are vulnerable to destruction by the shock and the vibration due to their inherent low vibration damping ability. The damping mechanisms of composite materials are completely different of those ones of conventional materials.

There is much literature published on vibration damping. Bert [1] and Nashif et al [2] had done survey on the damping capacity of fiber reinforced composites and found that composite materials generally exhibit higher damping than structural metallic materials. Gibson et al [3] and Sun et al [4] assumed visco-elasticty to describe the behaviour of material damping of composites. Suarez et al [5] has utilised random and impulse techniques for measurement of damping in composite materials. The random and impulse techniques utilize the frequency-domain transfer function of a material specimen under random and impulse excitation. Gibson et al [6] utilised the modal vibration response measurements to characterize, quickly and accurately the mechanical properties of fiber-reinforced composite materials and structures. Koo KN et al. [7] studied the effects of transverse shear deformation on the modal loss factors as well as the natural frequencies of composite laminated plates by using the finite element method based on the shear deformable plate theory. Adams et al. [8], Adams and Bacon [9, 10] used symmetric free-free flexural modes of vibrations for measuring the damping. Abderrahim et al., [11] evaluated damping of unidirectional fibre composites, orthotropic composites and laminates using beam test specimens and an impulse technique. Damping modelling is developed using a finite element analysis and predicted the different energies dissipated in the material directions of the layers. Damping characteristics of laminates are analysed by Berthelot [12] experimentally using cantilever beam test specimens and an impulse technique. Damping modelling of unidirectional composites and laminates is developed using the Ritz method for describing the flexural vibrations of beams or plates. From the above literature, it can be observed that much of the work on damping is limited to either viscoelastic or structural damping on single fiber system. Hence, this work is extended to different fiber system and also to study the influence of boundary conditions on the modal damping of laminated composites.

II. EXPERIMENTAL PROCEDURE

2.1 Materials Required for Fabrication of Laminates:

The constituent materials used for fabricating the composite plates are: unidirectional graphite fiber as reinforcement, Epoxy as resin, Hardener as catalyst (10% of the weight of epoxy), polyvinyl alcohol as a releasing agent.

2.1 Fabrication Procedure:

The composite plate specimens used in this work were made from unidirectional graphite fiber with epoxy matrix. Specimens were fabricated by hand layup vacuum bagging technique**.** The first layer of uni-directional graphite fiber cloth ranging from 0.25 mm to 0.35 mm is laid and resin is spread uniformly over the cloth by means of brush. The second layer of the cloth is laid and resin is spread uniformly over the cloth by means of brush. After second layer, to enhance wetting and impregnation, a teethed steel roller is used to roll over the fabric before applying resin. Also resin is tapped and dabbed with spatula before spreading resin over fabric layer. This process is repeated till all the 7 layers 2 mm thickness and 14layers 4 mm thickness are placed. No external pressure is applied while casting and curing because uncured matrix material can squeeze out under high pressure. This results in surface waviness non-uniformed thickness in the model material. The casting is cured at oven temperature of about 100º C up to 2 hrs & finally removed from the mould to get a fine finished composite plate as shown in the fig -1 below.

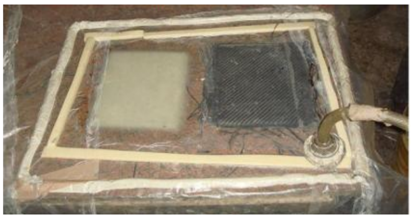

Fig: 1 Vacuum Bagging Technique

*2.3 Experimental Setup and Test Procedure for Modal Test***:**

To simulate different boundary conditions, vibration test fixture was designed and fabricated as shown in fig - 2 . Vibration test fixtures are required to allow mounting of the test specimen to the fixture as well as to allow for testing in all the three orthogonal directions. The design of vibration test fixtures is critical to avoid errors in equipment test response due to any resonances of the impact hammer, table and the fixture itself. Ideally the laboratory mounting should replicate the physical conditions observed in service such as the stiffness, mass and the consequent resonant responses of the actual service installation. The test specimen was mounted for different test conditions such as cantilever, two sides fixed and all sides fixed.

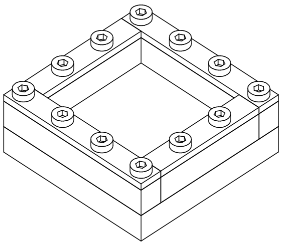

Fig-2: Vibration Test Fixture

2.4 Modal Testing:

The damping characteristics of the materials were obtained by subjecting plates to flexural vibrations. The equipment used is shown in Fig-3. An impulse hammer is used to induce the excitation of the flexural vibrations of the composite plate and the resulting vibrations of the specimens on the selected points were measured by an accelerometer mounted on the specimen by means of special wax. Next, the excitation and the response signals are digitalized and processed by a dynamic analyzer of signals. This analyzer associated with a PC computer performs the acquisition of signals, controls the acquisition conditions and next performs the analysis of the signals acquired Fourier transform, frequency response, mode shapes.

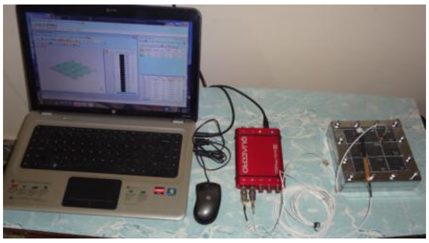

Fig-3: Experimental Set-up

III. EXPERIMENTAL RESULTS:

Table 1: Results of Graphite/Epoxy for 0 degree fiber orientation

Boundary Conditions	**Damping Ratio (%)**							
	2 mm thick laminate				**4 mm thick laminate**			
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 1	Mode 2	Mode 3	Mode 4
One end fixed	0.726	1.93	1.45	2.99	0.258	0.495	0.669	1.54
Two ends fixed	0.675	0.657	0.468	2.42	0.529	0.675	0.808	1.73
All sides fixed	0.784	0.745	0.757	0.816	0.902	1.16	0.839	1.64

Table 2: Results of Graphite/Epoxy for 45 degree fiber orientation

Boundary Conditions	**Damping Ratio (%)**							
	2 mm thick laminate				**4 mm thick laminate**			
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 1	Mode 2	Mode 3	Mode 4
One end fixed	0.826	0.39	1.88	2.13	0.463	0.584	1.19	1.781
Two ends fixed	1.1	1.15	0.573	0.85	1.35	0.79	0.78	0.975
All sides fixed	1.02	0.81	0.749	0.89	0.77	0.786	1.45	1.79

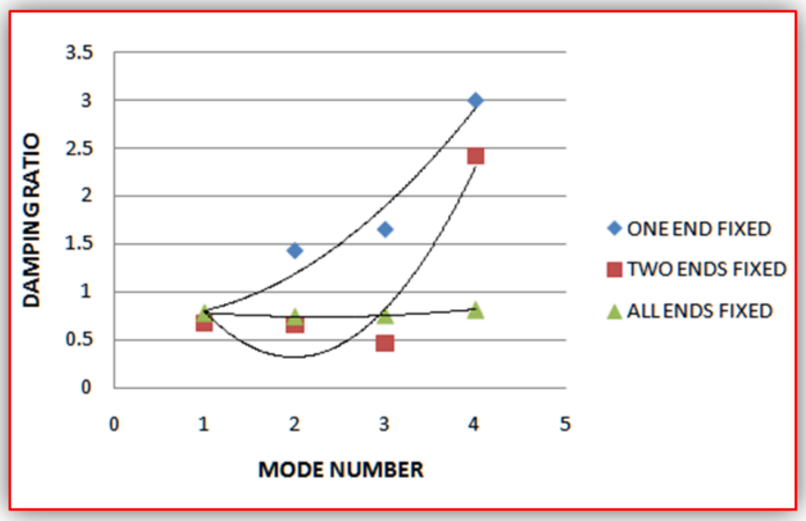

Fig - 4: Variation of damping ratio with respect to Mode number, for Graphite/Epoxy laminate, 2mm thickness, 0 degree orientation

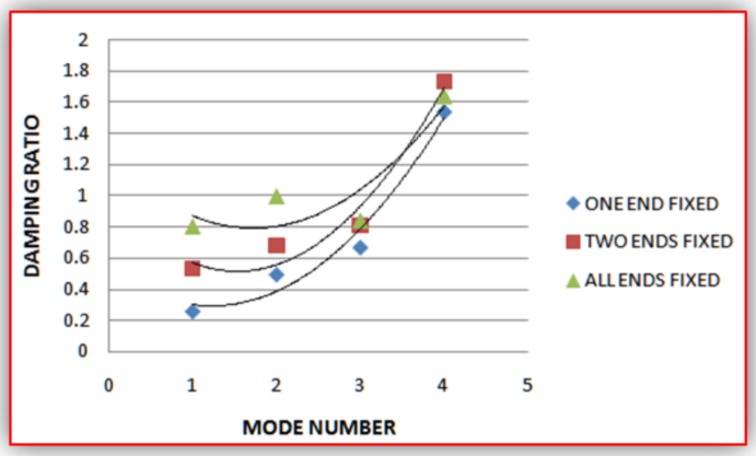

Fig - 5: Variation of damping ratio with respect to Mode number, for Graphite/Epoxy laminate, 4 mm thickness, 0 degree orientation

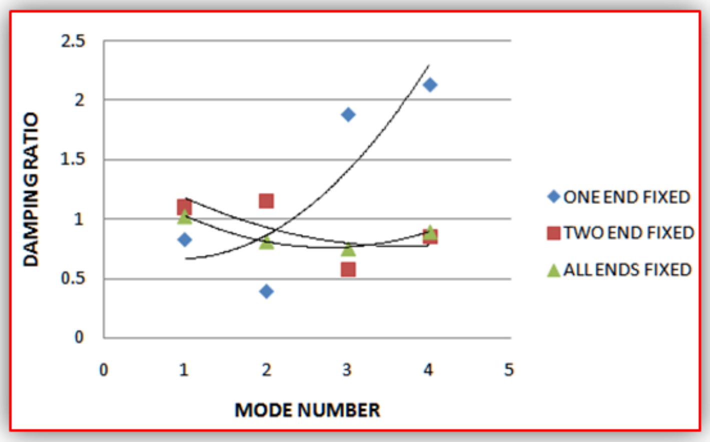

Fig - 6: Variation of damping ratio with respect to Mode number, for Graphite/Epoxy laminate, 2mm thickness, 45 degree orientation

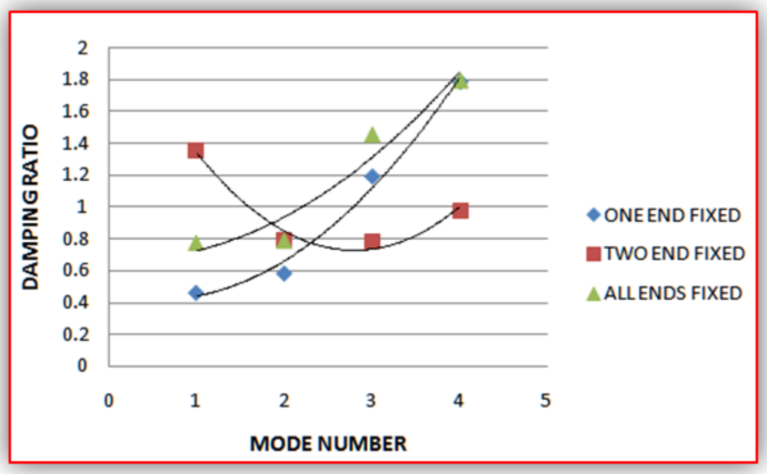

Fig - 7: Variation of damping ratio with respect to Mode number, for Graphite/Epoxy laminate, 4 mm thickness, 45 degree orientation

Figs 4,5, 6 & 7 depicts the graphs of mode number and percentage modal damping obtained through modal testing for graphite laminates for three different boundary conditions. It can be observed that for graphite laminates of 2mm thick there seems to be increasing trend in the modal damping, whereas in case of 4mm thick laminates there is a decreasing trend. This can be observed for both 0^0 and 45^0 fiber orientations. Table 1 & 2 well indicates the modal damping for 2mm and 4mm thick laminates, and it is found that modal damping is weak as the laminate thickness is increased. Further, the influence of boundary conditions too plays an important role in the prediction of damping characteristics as it is evident from the figures 4, 5, 6 & 7 the damping has increased by 9.7% in case of cantilever one end fixed when compared to two ends fixed condition. Similar variation can be observed for the other configuration also.

IV. CONCLUSIONS

Experimental Modal Testing of graphite/epoxy composite specimens with two thicknesses 2mm and 4mm with three different boundary conditions was investigated and the results are tabulated. For the laminated composite specimens, the change in the vibration properties is more significant with change in boundary conditions, but it is less sensitive for thickness consideration. The adoption of modal test seems to be very simple, effective and justified. Also, the modal damping depends on geometry & mechanical properties of the laminates under test. Thus, it can be concluded that evaluation of modal damping through experimental modal technique is simple and effective.

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