# Study of damping in composite beams

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**Abstract**

The vibrations produced in the structures or components are the primary source of problems in machine tools, aircraft and automobile structures. Vibration produces detrimental stresses in these components. These problems can be overcome by introducing damping in these structures. Damping is the dissipation of energy stored due to oscillatory motions. This is one of the vital parameters in the design of a dynamic system in order to enhance their service life. A recent method to improve the damping ability of structures is by fabricating these with composites. In addition, composites are found to have superior strength, stiffness, improved corrosion and fatigue resistance. Composite materials, particularly fiber reinforced (FR) composites are widely used in aerospace and automotive applications due to their less weight and high damping characteristics. The damping of FR composites depends on the structure, diameter and orientation of fiber in matrix. Damping at the fiber-matrix interface dissipates a significant amount of energy. In the current investigation, damping of structural composite beams has been studied to estimate the damping ratios and natural frequencies. The various composite beams used are Glass Fibre Reinforced Epoxy (GFE), Glass Fibre Reinforced Polyester (GFP) and Carbon Black Filled Epoxy (CBFE). To accomplish the requirements of the projected investigation, composite beams of 170 mm cantilever length has been used. The cantilever beams are mounted on a heavy and rigid framework. The frame has provisions to hold the fixed end of the beam rigidly, thus ensuring perfect cantilever condition. Forced vibration is imparted to the cantilever beam using a vibration exciter. A contact type accelerometer is used to obtain the signal and feed it to a digital storage oscilloscope (DSO). Logarithmic decrement method is used to evaluate the damping parameters from the obtained amplitude versus time plots. The damping ratio and natural frequency values are found to be 0.2281 and 1664.94 rad/s respectively for CBFE. CBFE has highest damping property as compared to GFE and GFP.

*Keywords:* composite beam; damping ratio; natural frequencies; vibrations

## 1. Introduction

The importance of study of damping is increasing significantly as it is required to avoid the undesirable effects of vibrations. Vibrations are undesirable because position controls, stability, performance, noise reduction in the machine tool structures is highly essential. An undesirable effect of vibration is a matter of concern in huge structures like aircraft and very small structures like in electronics. Various techniques are used to introduce damping to the system. These are: use of viscoelastic layers, un-constrained/constrained sandwich construction, introducing high elastic inserts in the original structure, fabricating jointed and layered structures with riveted/ welded/bolted joints [1]. To overcome friction or other resistive forces, energy is dissipated from a system thereby reducing the amplitude of oscillations. This phenomenon is called damping.

Energy in the vibrating system is dissipated in various ways, and two or even more energy dissipating mechanisms may take place simultaneously. Damping is generally divided into two main groups known as (a) material damping and (b) structural damping. When energy dissipation occurs from the material volume, it is known as material damping. The energy dissipation, in this case is generally associated with the internal re-constructions of macro and micro structures starting from molecular scales to crystal lattice effects, point defect relaxation, thermo-elasticity etc. [2]. Structural damping occurs due to rubbing action between the components as a result of relative motion between them or due to intermittent contact between the joints in the mechanical system [3]. Use of composites to fabricate structures is one of the ways to reduce vibrations. Polymers are better in damping as they possess more viscoelastic property [4]. In an industry like aircraft, one has to always think of reducing the weight of aircraft and this can only be done by replacing the conventional material with the lighter

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material without compromising strength. Composites are one of the options to make structure lighter while taking into account other properties also. The current probe emphasizes on the use of composites to increase damping capacity of structures. Usage of composite also gives the benefits like high specific strength, freedom of shape, better chemical resistance, better thermal isolation, fire retardancy habits, performance at high temperature as well as can absorb radar signals.

Composites are structural materials consisting of more than one insoluble constituents combined at a macroscopic level. One of the components is known as the matrix and part, embedded in matrix is the reinforcing phase. Reinforcing phase material can be particles, flakes or fibers. An example of the composite system is steel rod in concrete. An example of the naturally found composite is lignin matrix reinforced with cellulose fibers. Composites are divided into three groups according to the geometry of reinforcement - particulate, fiber and flake or by the matrix type used- metal, ceramic, polymer and carbon [5].

Mallik et al. [6] have shown that composite material having rigidity and high damping property can be produced by using a small quantity of high damping elastic inclusions with sufficient rigidity in an elastic matrix. Schaller [7] suggested that recent transportation technology needs materials having enhanced damping capacity apart from better mechanical properties and these two opposite requirements can be fulfilled by using metal matrix composite. Chandra et al. [8, 9] have mentioned in their work that damping in composite materials is different from that of conventionally used metals. They reported that the various ways in which energy is drained out from FR composites are-viscoelastic behaviour of matrix or fibers, interphase damping, visco-plastic damping, thermo-elastic damping. They further established an integrated FEM/strain energy approach to determine the loss factor for two and three phase composite with interfacial discontinuity. They have also done research on the theory behind damping mechanism of composite materials such as micromechanical, macro-mechanical and viscoelastic approaches. Chopde et al. [10] have reported that carbon fiber shafts can replace conventional steel drive shaft in an automobile. Damping is a critical parameter associated with the dynamic behaviour of FR composite structures. Adams et al. [11] have estimated the factors affecting damping and property of vibration damping in advanced FR plastic composite materials. Gibson et al. [12] have used the viscoelastic property of a composite material to predict the behaviour of material damping in composites. They showed damping considering micromechanical, macro-mechanical and viscoelastic approaches.

**Nomenclature**

| | |
|---|---|
| GFE | Glass fiber reinforced epoxy |
| GFP | Glass fiber reinforced polyester |
| CBFE | Carbon black filled epoxy |
| FR | Fiber reinforced |
| DSO | Digital storage oscilloscope |

## 2. Experimental details

### *2.1. Microstructural analysis*

Sample of 10mm length each of GFE, GFP and CBFE are prepared for microstructural analysis. Microstructural characterizations of these samples were done using scanning electron microscope (model: JEOL-JSM6480LV). This analysis was done for better understanding of fiber or particulate –matrix orientation at 100x magnification.

### *2.2. Damping in composites*

- Setup and procedure

The composite beam is placed on a frame made of steel by welding process. This frame is joined to heavy concrete base by making use of foundation bolt, and it has slotted guide ways for usage of different lengths of beams. The frame has provision to hold beam tightly and rigidly at one end in order to achieve the cantilever condition. The clamping is done by making use of a mechanical vice. The vice is having base plate and a spindle which in turn has internal and external threads. One arm is attached to this spindle at upper portion. By rotating this arm one can move base plate downwards and impart necessary pressure on beam to achieved required cantilever condition. The base plate prevents the beam from rotating while the load is being applied at the fixed end. One end of composite cantilever beam is fixed. The vibration exciter is placed below the other end of the beam to impart excitations to the beam. Power amplifier is used to withdraw current from distribution box and after amplifying supplies it to vibration exciter. As vibration exciter imparts excitations to composite cantilever beam it experiences some vibrations, these vibrations are sensed by accelerometer and it supplies the excitation to the DSO. The DSO stores this in the form of digital signal and we can get information about vibration from it. Fig. 1 shows schematic diagram of the experimental setup.

The dimensions of the beam specimen used are 5 x 50 x 170 mm (thickness x width x cantilever length). Three varieties of composite plates such as GFE, GFP and CBFE composites are used as test materials. All the experiments are conducted at a frequency of 50Hz to generate forced vibrations at tip of the composite beam. Amplitude versus time plots are obtained from the DSO.

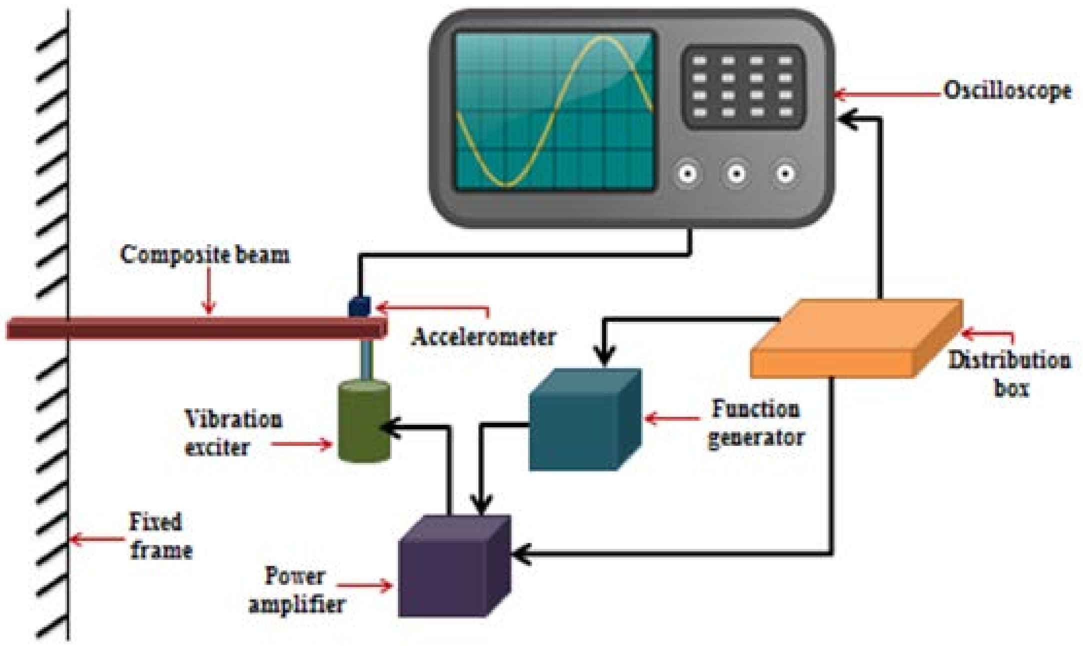


Fig. 1. Schematic diagram of the experimental set-up

- Estimation of damping ratios and natural frequencies

Logarithmic decrement values for damping of composites are then calculated by using the amplitude values obtained from oscilloscope. First cycle ($x_1$), last cycle ($x_{n+1}$) and number of cycles ($n$) of the steady signal are measured and used in Eq. (1) to calculate logarithmic decrement. Logarithmic decrement: It is the natural logarithm of the ratio of amplitudes of any two consecutive peaks.

$$\delta = \frac{1}{n}\ln\left(\frac{x_1}{x_{n+1}}\right) \quad (1)$$

Zeta (ζ) is a damping ratio which is the proportion between damping coefficient to critical damping coefficient.

$$\zeta = \frac{\delta}{\sqrt{(4\pi^2 + \delta^2)}} \quad (2)$$

$\omega_d$ is the frequency of damped vibration.

$$\omega_d = \frac{2\pi}{\Delta T} \quad (3)$$

$\omega_n$ is the natural frequency. If a system vibrates or oscillates in the absence of any external driving force or resisting force then that frequency is known as natural frequency and is given by,

$$\omega_n = \frac{\omega_d}{\sqrt{(1-\zeta^2)}} \tag{4}$$

### 3. Results and discussions

- Damping in composites

The amplitude-time graph shown in Fig. 2 is plotted after extracting the vibration signal from the DSO during experiments. From Fig. 2 it is observed that the maximum amplitude of GFE is more as compared to other two materials as well as the signal is more fluctuating in case of GFE as evident from the more number of peaks compared to GFP and CBFE. Amplitude of vibration is decreasing slowly to form logarithmic decrement. In case of CBFE, number of peaks is less and the decrease in amplitude becomes almost steady. For GFP maximum amplitude is less among three. Also we can see that decrease in amplitude takes place in steady manner. From Fig. 2, we can also see that in case of CBFE, after few peaks amplitude remains almost steady and therefore it possess highest damping.

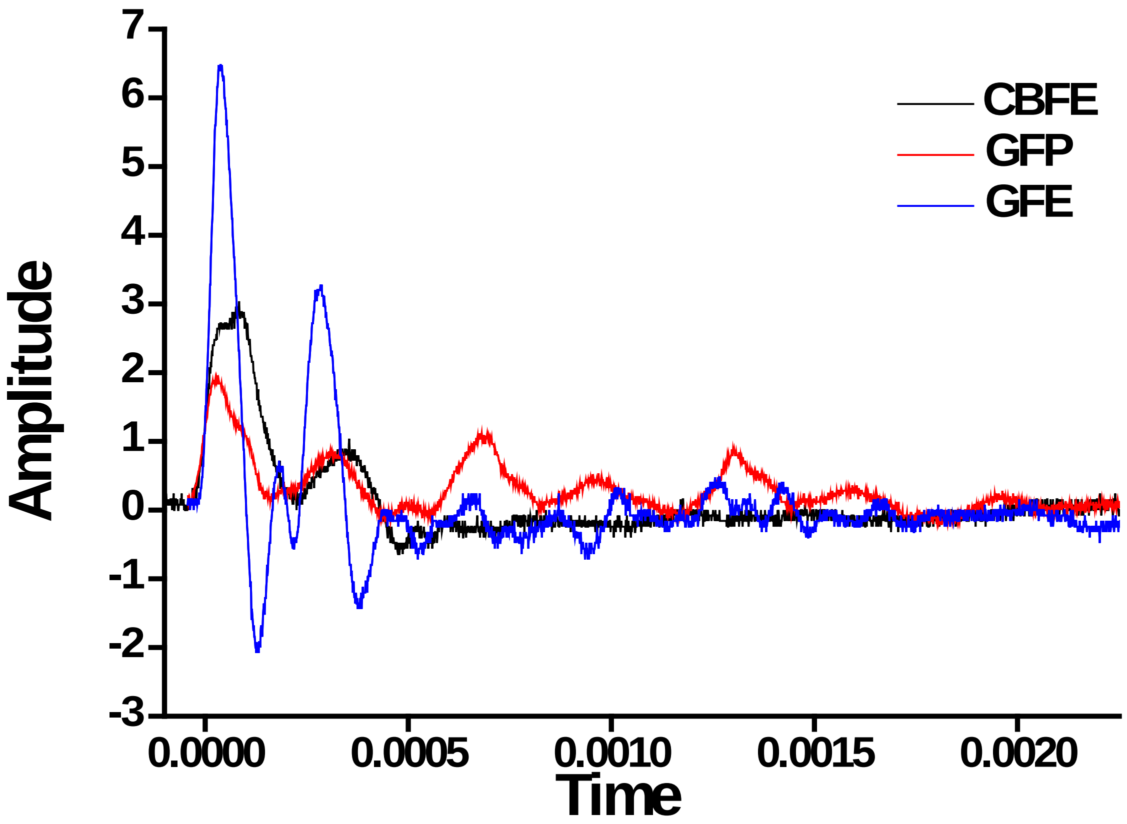

Fig.2. Comparison of vibration signal for different composites

From the above graph, the values of amplitude, time and n for three different materials is obtained. Using these values the above mentioned parameters are calculated. Table 1 lists the values of logarithmic decrement, damped natural frequency, damping ratio and un-damped natural frequency.

Table-1: Results from experiments

| Material | Δ | $\omega_d$, rad/sec | ζ | $\omega_n$, rad/sec |
|---|---|---|---|---|
| GFE | 0.4112 | 2895.31 | 0.0653 | 2901.50 |
| GFP | 0.3579 | 3127.56 | 0.0569 | 3132.64 |
| CBFE | 1.4722 | 1621.04 | 0.2281 | 1664.94 |

From the above table we can see that damping ratio of CBFE is more as compared to GFE and GFP, so it can be said that CBFE possess good damping properties among three.

- Microstructural analysis

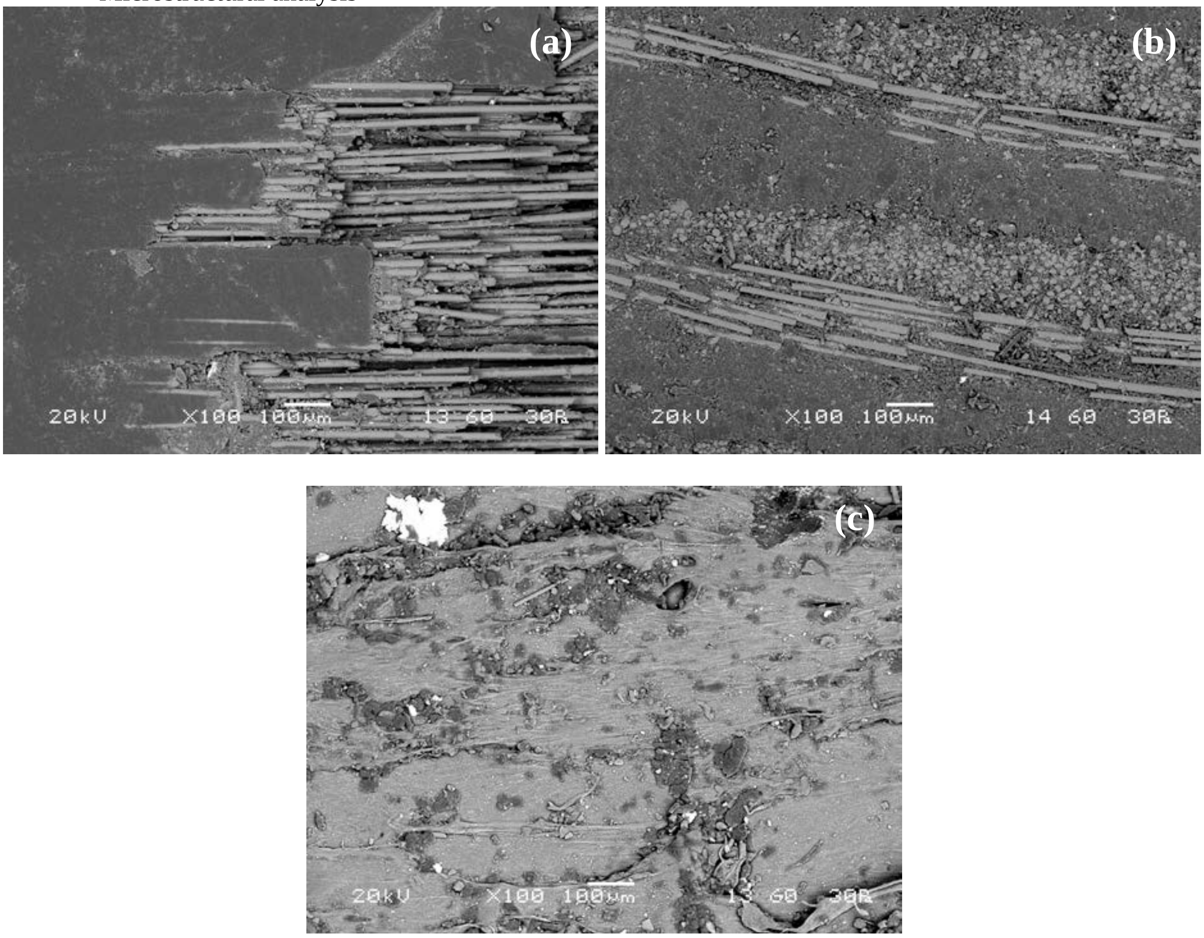


Fig. 3. SEM microstructure of (a) GFE; (b) GFP and (c) CBFE

The microstructures of GFE, GFP AND CBFE are shown in Fig. 3 (a), (b) and (c) respectively. It can be seen from Fig. 3 (a) and (b) that fibers are reinforced in matrix smoothly. In GFE, fibers are bounded well with the matrix compared to GFP. In Fig. 3(c) carbon black powder can be easily seen, also we can see some void spaces in this specimen.

As in GFE, fibers are more strongly bounded with matrix it possesses more damping property compared to GFP. However, in case of CBFE, the carbon particles-epoxy interface acts as energy dissipater and thus, it possess highest damping property due to presence of large surface area of the micro particulate-matrix interface.

## 4. Conclusion

Study of damping of GFE, GFP and CBFE were done and the following conclusions are drawn

(1) CBFE has highest damping property while GFP having lowest damping property and GFE possess in between the above two composites.
(2) As GFE possess more damping capacity than GFP, therefore epoxy has better damping properties than polyester matrix with common glass fibers as reinforcements.
(3) From microstructural analysis, we can notice that in CBFE, the micro carbon black particles possess more surface area as compared to fibres so they help to dissipate more energy as compared to fibres therefore possess more damping than the other two.

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