Effect of Silicon Carbide as Filler Reinforcements on the Mechanical and Damping Properties of Glass Fiber/Epoxy Composites

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Abstract

Fiber reinforced composites are widely used nowadays owing to their cheap availability, light weight and high damping properties. These found applications in areas such as aerospace, automotive and marine industries. Therefore, it is necessary for these materials to possess higher strength as well as stiffness. The objective of the current research is to study the effect of addition of Silicon carbide (SiC) particulates in various weight ratios on the mechanical and damping properties of Glass fiber reinforced epoxy (GFE) composites. The influence of weight percentage of SiC particulates with an average particle size of 250 µm on damping as well as mechanical properties of GFE composites is studied. Mechanical properties such as tensile strength and elongation are obtained experimentally to study the effect of change on varying SiC particulates content (0%, 2.5%, 5% and 7.5%). The tests are done as per corresponding ASTM standards. Further, the effect of SiC reinforcements on damping properties of GFE is also studied. It is observed that damping properties, as well as tensile strength of SiC particulates, filled GFE composites are superior to unfilled GFE composites. However, the percentage elongation of the samples is found to be decreasing with increasing SiC content.

Keywords: Silicon Carbide, Glass fiber reinforced epoxy, Damping properties, Tensile strength, Elongation.

1. INTRODUCTION

Fiber reinforced (FR) composites are used in automotive and aerospace industries owing to their lighter weight, high strength and damping properties. Among these FR composites, glass fiber reinforced epoxy (GFE) composites are commonly used because these are cheap, readily available and easily manufactured. These found wide industrial applications such as automotive, aerospace, marine, medical, sports, machine tools and various other structures. However, the composites reinforced with both fiber and filler have better strength and damping property compared to FR composites. Therefore, SiC particulates are reinforced in the FR composites to enhance the mechanical and damping properties. Agarwal et al. [1] have shown the effect of addition of SiC particulates on the thermo-mechanical properties of GFE composites. Suresha et al. [2] have demonstrated that filling glass epoxy composite with graphite particulates improves the mechanical properties such as hardness, tensile strength, tensile modulus, percentage elongation as well as wear resistance.

Nagasankar et al. [3] have shown that the damping of composites depends on fiber diameter and orientation. Berthelot et al. [4] reported that the energy dissipation in FR composites occur due to damping at the fiber matrix interface, fiber orientation and viscoelastic nature of the matrix. Chandra et al. [5] 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 dissipated from FR composites are-viscoelastic behaviour of matrix or fibers, interphase damping, visco-plastic damping and thermo-elastic damping.

Various techniques are used to measure damping parameters of a material but it is quite difficult to accurately assess the damping parameters. Therefore, wavelet transform has evolved as a new signal processing tool. In wavelet transform, a time series is decomposed into a time-frequency space, thus providing more localized information about time and frequency. This detailed study of time varying features of the signal was not possible using conventional methods such as Fourier transform, Hilbert transformation, etc.

Lardies et al. [6] have used Morlet wavelet transform to analyse the free response of a vibrating system and estimate the damping properties. Chen et al. [7] have developed wavelet transform technique to effectively extract inherent modulation information for fault diagnostics. Le [8] has used Morlet wavelet in combination with frequency-scale domain decomposition to estimate the modal damping parameters without considering the effect of ridge extraction phase. Nakamura et al. [9] have found that flexural strength and tensile strength increases with decrease in particle size of silica in silica-filled epoxy resin composites.

Therefore, the present focuses on the evaluation of effect of SiC particulate reinforcements on the mechanical and damping properties of GFE composites. Further, Morlet wavelet technique is used to estimate the damping parameters of the composites and validate the results obtained experimentally. Moreover, the best composite is identified which can be used as a substitute for structures in automotive and aerospace industries as well as various structural applications.

2. WAVELET ANALYSIS FOR SYSTEM IDENTIFICATION

Wavelet analysis is used to verify the value of damping ratio and natural frequency obtained experimentally. Morlet wavelet is used for accurate evaluation of natural frequency and damping ratio of the composites taking forced response of the source signal as the input. Let us consider a single degree freedom system consisting of rigidly connected mass, spring and damper. A harmonic force of frequency ω and magnitude F is used to act upon it. The equation of motion due to displacement of mass through x is given by:

$$m\ddot{x} + c\dot{x} + kx = F\sin(\omega t) \quad (1)$$

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where m, c, k and $F\sin(\omega t)$ are the mass, damping constant, stiffness and excitation force respectively. Eq. (1) can be expressed in terms of natural frequency, ω_n and damping ratio, ξ as:

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2 x = f\sin(\omega t) \quad (2)$$

where, $\omega_n=(k/m)^{0.5}$, $\zeta= c/2\sqrt{mk}$ and $f = F/m$.
The solution of Eq. (2) is given by:

$$x(t) = A_0 e^{-\zeta\omega_n t}\cos(\omega_d t - \phi_0) + A\sin(\omega t - \phi) \quad (3)$$

Here A_0 and ϕ_0 are the amplitude of vibration and phase angle respectively which depend on initial conditions.

$$\omega_d = \omega_n\sqrt{1-\xi^2},$$

$$A = \frac{f}{\sqrt{(2\zeta\omega\omega_n)^2 + (\omega_n^2 - \omega^2)^2}} \text{ and}$$

$$\phi = \tan^{-1}\frac{2\zeta\omega_n\omega}{\omega_n^2 - \omega^2}$$

According to Chen et al. [10], the Morlet wavelet transform of the forced response of the system is given by:

$$W_g x(a,b) \approx \frac{\sqrt{2\pi a}}{2} A_0 e^{\{-\zeta\omega_n b - \frac{1}{2}[(1-2\zeta^2)\omega_n^2 a^2 - 2\omega_0\omega_d a + \omega_0^2]\} + i\{\omega_d b - \phi_0 + \zeta\omega_0\omega_n a - \zeta\omega_n\omega_d a^2\}} \quad (4)$$

where a, b and ω_0 is the scaling or dilation parameter, translation parameter and central wavelet frequency respectively. Assuming a constant value of dilation parameter $a = a_0$, the value of logarithmic magnitude and argument of the wavelet transform is obtained as:

$$\ln|W_g x(a_0,b)| \approx -\zeta\omega_n b + s_1 \quad (5)$$

$$\angle W_g x(a_0,b) \approx w_d b + s_2 \quad (6)$$

where the values

$$s_1 = -\frac{1}{2}[(1-2\zeta^2)\omega_n^2 a^2 - 2\omega_0\omega_d a + \omega_0^2] + \ln\frac{\sqrt{2\pi a}}{2} \text{ and}$$

$$s_2 = -\phi_0 + \zeta\omega_0\omega_n a - \zeta\omega_n\omega_d a^2$$

are independent of translation parameter, b. From Eqs. (5) and (6), it is evident that slopes of logarithmic modulus and argument of wavelet transform with respect to b will give the values of natural frequency, ω_n and damping ratio, ζ.

3. EXPERIMNETAL DETAILS

3.1 Materials and Methods

Woven glass fiber mat and SiC particles are used with epoxy resin and hardener with trade-name Bisphenol A Diglycidyl ether and tri-ethylene tetra-amine respectively. The average size of the SiC particulates is 60 mesh or 250 µm. The matrix material comprises of epoxy and hardener, mixed in the weight ratio of 10:1. The hand lay-up technique is used to fabricate the GFE composites as the process is the most simple and inexpensive. Mould relieving spray and mould relieving sheet is used to cover the surface of the rectangular mould. 15 layers of woven glass fiber mat are used for fabrication of each GFE composite. The weight of epoxy, hardener and SiC particulates are calculated depending on the required composition of the composite. Then these materials are divided in to 14 equal portions and mixed together thoroughly. Each mixture is applied on a glass fiber mat. Care is taken to ensure thorough mixing of the epoxy, hardener and SiC particles as well as proper matrix coating on the glass fiber surface. The fiber surface is frequently rolled with a hand roller to remove any trapped gas bubble or tangled glass fibers. Each cast composite is first cured by applying a load of about 400 N for a period of 24 hours and then cured in air for 24 hours. Utmost care is taken to maintain homogenous distribution of fiber, particles and matrix material and to avoid any defect in the final composite structure.

Four different compositions of composites are prepared by varying the SiC particulates reinforcement with fixed weight percentage (wt. %) of woven glass fiber reinforcement. The combinations of weight percentage of the various components used for manufacturing composites are given in Table 1.

Table 1

Material designation and compositions

Designation	Composition (wt%)		
	Glass fiber	Epoxy	SiC
C1	50	50	0
C2	47.5	50	2.5
C3	45	50	5
C4	42.5	50	7.5

3.2 Mechanical and Damping Properties

In order to evaluate the tensile property of these four composites, flat specimens are prepared as per ASTM D3039-76 standards. The effective lengths of the specimens for tensile tests are maintained at 150 mm with an average thickness of 5 mm. The tests are performed in a Universal Testing Machine (Instron, UK/ SATEC 600KN) at a crosshead speed of 2 mm/min. The schematic configuration of specimen for tensile test is shown in Fig. 1.

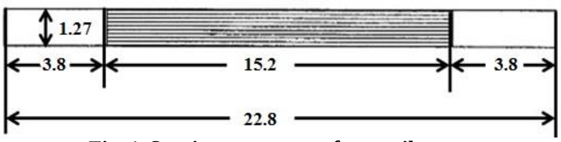

Fig. 1. Specimen geometry for tensile tests

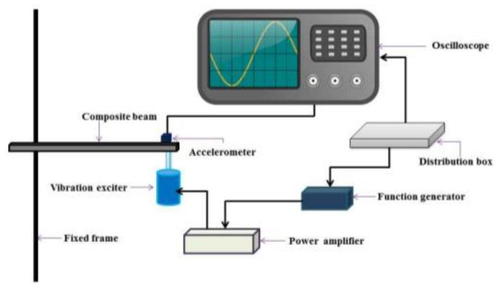

Fig. 2. Schematic diagram of experimental setup

Test samples of 350×50×5 mm dimensions are cut from the cured GFE samples using a diamond cutter. An experimental setup consisting of a heavy and rigid frame has been prepared to hold the fixed end of the cantilever beam as shown in Fig. 2. In order to ensure negligible support damping, the composite beams are stiffly fixed to the frame to avoid any rotation and to achieve required cantilever condition. Vibration exciter is placed below the free end of the cantilever beam to impart forced excitations to the beam. A contact type accelerometer is placed on the free end to sense the signals and supply it to the digital storage oscilloscope (DSO). Function generator is used to apply required loading frequency for excitations. Logarithmic decrement method is used to calculate the damping parameters from amplitude versus time graph obtained from DSO.

4 RESULTS AND DISCUSSIONS

4.1 Mechanical Properties

Flat composite samples are prepared for tensile tests as mentioned in previous section and the value of ultimate tensile strength (UTS) and percentage elongation are calculated for each composite sample. Fig. 3 shows the graph of tensile strength vs. the wt.% of SiC reinforcement. The tensile strength of the composite samples are found to increase with increase in wt.% of SiC reinforcement. This is due to the fact that these SiC particles act as a barrier in transferring stress from one point to another. However, if the wt.% of SiC reinforcement increases beyond 10%, the tensile strength decreases because with increase in filler content, bonding surface area increases thereby reducing bonding strength. This leads to ineffective transfer of load from one end to another (Agarwal et al.).

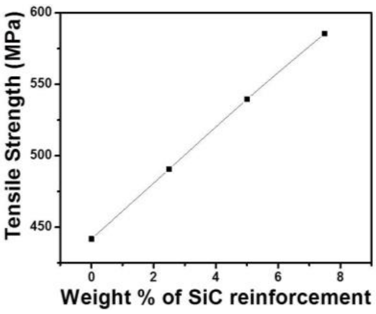

Fig. 3. Plot of Tensile strength vs. wt. % of SiC reinforcement

However, the percentage elongation of the GFE samples is found to decrease with increase in wt. % of SiC reinforcement. The distribution of SiC particles in the matrix hinders the propagation of failure along the loading direction. Therefore, the stresses will tend to propagate in the directions where the concentration of filler reinforcements is less leading to reduction in elongation. The effect of wt. % of SiC reinforcements on the percentage elongation of GFE composite samples is shown in Fig. 4.

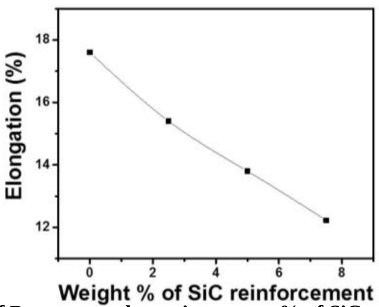

Fig. 4. Plot of Percentage elongation vs. wt. % of SiC reinforcement

4.2 Damping Properties

The amplitude vs. time plots obtained from DSO is used to calculate the damping ratio and natural frequency of the above mentioned composites. The experimental values of amplitude and phase angle are used to calculate the magnitude of wavelet transform of the acquired signals. The central wavelet frequency for Morlet wavelet, ω_0 is taken as 10. The Morlet wavelet transform is calculated from Eq. (4) for translation parameter b ε [0.125; 5] and dilation parameter a ϵ [1; 40]. Specialized MATLAB programs have been developed for signal processing as well as calculation of damping parameters. The wavelet transform of forced vibration plotted against *a* and *b* for composite sample C4 is shown in Fig. 5. The constant vale of dilation parameter a_0 is taken at the peak value of the $|W_g x(a,b)|$ matrix. From the MATLAB program, the value of dilation parameter corresponding to the peak value of magnitude of wavelet transform for all the 4 composites is obtained.

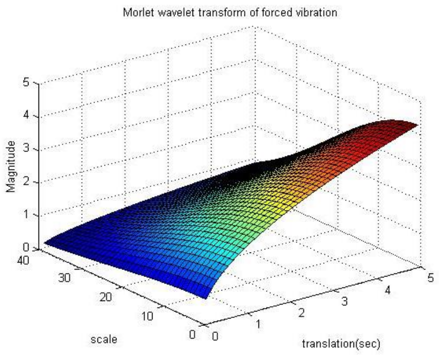

Fig. 5. Morlet wavelet transform of forced vibration for composite C4

Using the value of a_0, the logarithmic magnitude $ln| W_g x(a,b) |$ and argument $\angle W_g x(a,b)$ are calculated for the composites as given in Eqs. (5) and (6). Further, the slopes of $ln| W_g x(a,b) |$ vs. b and $\angle W_g x(a,b)$ vs. b are computed using MATLAB curve fitting software with linear interpolation and the values of $-\zeta\omega_n$ and ω_d are obtained. The values of ζ and ω_n thus obtained from wavelet analysis are compared with the experimental ones and are shown in Table 2. Also the error values for both damping ratio and natural frequency are in well agreement with the error values published in literature. Further, the damping ratio of all these four composites is plotted against wt. % of SiC particulate reinforcements in Fig. 6. From the figure, it is evident that damping in GFE composites increases with increase in wt. % SiC reinforcements.

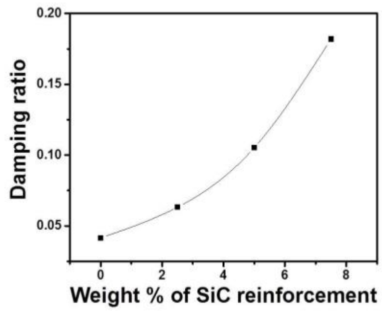

Fig. 6. Plot of damping ratio vs. wt. % of SiC reinforcement

Table 2: Comparison of the experimental and wavelet results for b ε [0.125, 5], $a_0 = 1$ and $\omega_0 = 10$.

Composite Designation	Experimental results		Wavelet analysis results		Percentage Error (%)	
	ζ	ω_n	ζ'	ω_n'	ζ'	ω_n'
C1	0.0416	161.44	0.04161	161.40	-0.024	0.025
C2	0.06321	100.96	0.06318	101.002	0.0475	-0.0614
C3	0.10528	162.67	0.105283	162.70	-0.0028	-0.0184
C4	0.18196	328.36	0.181953	328.38	0.0038	-0.0061

7 CONCLUSIONS

The study of the effect of SiC reinforcements on the mechanical and damping properties of glass fiber epoxy composites has resulted in to the following conclusions:

1. Tensile strength and elongation of these GFE composite samples increases and decreases respectively with increase in wt. % of SiC reinforcements as the particulates hinders the stress transfer along the loading direction.
2. Damping of the GFE samples increases with increase in SiC reinforcements as these particles act as site for energy dissipation in the composite matrix.
3. The damping parameters obtained from wavelet analysis is found to be in good agreement with the experimental ones.

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