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The Influence of Borax Filler Addition on Damping and Vibration Response of S-glass/epoxy Composite Laminates

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Abstract - This study aims to examine the influence of borax addition on damping and vibration response of S-glass/epoxy composite laminates. Natural frequency and damping response of particle filled composite laminates cantilever beam are determined with different mass ratios between borax and epoxy resin with hardener. Borax particles were used as replacement material with epoxy resin and their particle loadings (the ratio between mass of the borax over total mass of the epoxy with hardener+borax filler) of the samples were 0 (plain), 5, 10, 15 and 20 mass %, respectively. Vibration properties of samples were experimentally determined by using modal analysis procedures. For damping responses, half power band-width method was employed with first natural frequency value. The results indicated that the replacement of boron particles with epoxy resin by 5 mass % of particle loading" significantly increased the damping and natural frequency and further increase of borax content caused a reduction in damping and vibration values.

***Keywords*:** Damping, free vibration, borax

1. Introduction

Modern composite materials have been extensively used in high-performance structural applications, such as the aeronautical, automotive and marine industries due to their high specific strength/stiffness, high corrosion resistance, long fatigue life and good design flexibility [1]. Their dynamic performance is a significant factor for safety of the structures in service. There is a particularly strong need for improvement of damping and natural frequency in lightweight structural composite materials so that they may be more effectively used in the design of high performance structures and machines [2-5].

Particulate filled polymer composites generally consist of micro- or nano-fillers of different sizes and shapes combined with polyester or epoxy resin. The physical and mechanical properties of the composite can be modified by adding organic or inorganic solid fillers to the matrix in the composite production. It has been observed that by incorporating filler particles in fiber reinforced polymer composites, strength, overall stiffness, impact energy absorption, fracture toughness, wear resistance, thermal durability, vibration characteristics may be changed.

Mechanical properties of composite materials have been improved by using microscale fillers such as graphite and rubber. However, recently the nanoscale particles such as carbon nanotube (CNT), nano-silica and nano-clay as alternative additives have gained a significant attraction for composites [6-7]. Huang and Tsai [8] studied vibration damping response of composite laminates including silica nanoparticles and rubber particles. Half-power method was used to measure vibration damping and flexural stiffness of the composite beams. Results indicated that addition of rubber particles and silica nanoparticles enhanced damping properties of nano-composites. Alva and Raja [9] conducted vibration tests to characterize the dynamic behavior of hybrid epoxy composites reinforced with nano-alumina and carbon nanotube particles. Favorable stiffness and damping properties were obtained with hybrid and non-hybrid composites. It was noted that the hybrid reinforcements could be optimally designed to obtain improved stiffness and damping properties of the structures. Sankar et al. [10] investigated the effect of natural rubber particle inclusions on the mechanical and damping properties of epoxy-filled glass fiber composites. It was observed that damping ratio varied with inclusion of natural rubber particles and that 0.25 mm particle inclusions improved damping better than the other selected particle sizes without greatly affecting the stiffness in the case of cantilever beams and fixed edge free plates. Khan et al. [11] studied the damping and vibration behavior of nanocomposites and carbon fiber reinforced polymer composites containing MWCNTs. It is found that the loss modulus of nanocomposites and CFRP composites increases as the nanotube contents increase. Arumuga Prabu et al. [12] studied influence of redmud on the mechanical, damping and chemical resistance properties of banana fiber/polyester hybrid composites.

Based on literature survey, it appears that the effects of various amounts of micro and nano-scale particle filler addition on the mechanical properties have been extensively investigated.. However, no study was encountered investigating the damping and vibration properties of S-glass/epoxy composite laminates with additions of borax particles in the open literature. Present study aims to show the variation of damping and vibration properties of S-glass/epoxy composite laminates with microscale particulate borax content (5, 10, 15 and 20 mass % of particle loading).

2. Materials and Procedures

2.1. Material production

Woven plain S-glass fiber plies with areal density of 200 g/m^2 was used as reinforcement in the lamina of physical properties given in Table 1. An epoxy resin (MOMENTIVE-MGS L285) with hardener (MOMENTIVE-MGS H285) at a stoichiometric ratio of 100:40 was used as the matrix.

Table 1. Mechanical properties of S-Glass/epoxy composite laminate [13].

Fiber Type	$E_1 = E_2$ (GPa)	$E_3 = 0.6\ E_1$ (GPa)	$G_{12} = G_{13} = G_{23}$ (GPa)	ν_{12}	$\nu_{13} = \nu_{23} = 0.6\ \nu_{12}$
S-Glass/epoxy	19.650	11.790	3.800	0.140	0.084

The anhydrous borax (Etibor-68) supplied by Etibor A.Ş., Bandırma, Turkey, passing 45 µm sieve was used in this study (Table 2). Borax filler and epoxy resin were mixed with a mixer at constant speed (800 rev/min) in a bowl before hardener was added at a ratio of 0.285 by mass of epoxy. The epoxy-borax matrix mixture was then applied on woven glass fiber with paint brush, using a vacuum supported production unit. Mixing ratios between matrix and borax particles are given in Table 2.

Table 2. Matrix and borax content in the specimens.

Particulate material content (mass %)	Mass of epoxy with hardener (g)	Mass of borax particle (g)
0	100	0.00
5	95	5
10	90	10
15	85	15
20	80	20

Laminated fabrics of 16 plied woven glass fiber (of 220 mm × 220 mm size) were first laid on the flat mold and subjected to 0.4 MPa pressure for 1 h curing time at 80 °C. Then, composite laminates were cooled to room temperature under pressure. The filler contents of the composite plates were taken as 0 (plain), 5, 10, 15 and 20 % of particle loading. Each vibration test specimen was 200 mm long and 12.7 mm wide. The free beam length was kept at 155 mm. The thickness of specimens was measured as 3.5±0.3 mm.

2.2. Vibration tests

Dynamic characteristics of composite laminates were measured using an experimental set-up as shown in Fig. 1 (a). In the experiments, a general purpose PCB 352C03 ceramic shear ICP ® accelerometer, a PCB 086C03 general purpose modal impact hammer and a National Instrument product NI 9234 with LABVIEW software were used for output signal acquisition, stimulus force signal and data acquisition, respectively. In order to measure damping responses, half power bandwidth method was used for first natural frequency modes of the specimens. The damping ratio was measured according to the half-bandwidth method as shown in Fig. 1(b), according to Equation 1.

Table 3. Producer's specification for chemical composition of anhydrous borax (Etibor-68) [14].

Component	Unit	Content
B_2O_3	%	68.00 min.
Na_2O	%	30.27 min.
SO_4	ppm	300 max.
Cl	ppm	105 max.
Fe	ppm	150 max.
Insoluble in Water	ppm	920 max.

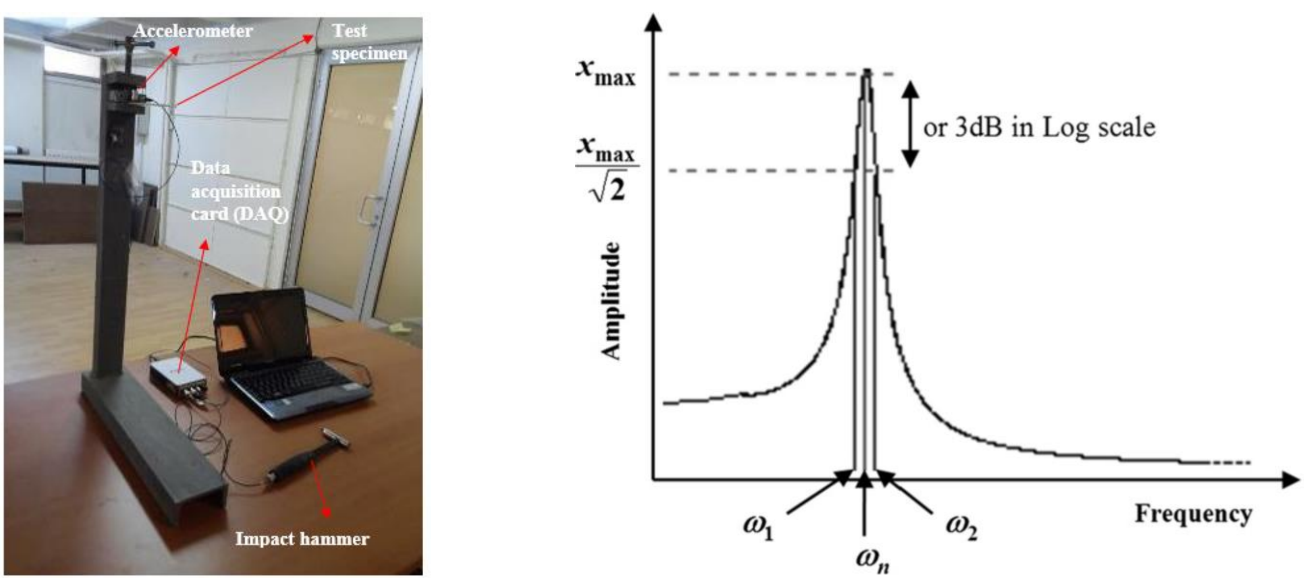
$$\xi = \frac{\omega_2 - \omega_1}{2^*\omega_n} \tag{1}$$

Where ξ is the damping ratio, ω_n is the natural frequency of first mode and $\omega_2 - \omega_1$ is the bandwidth. The loss modulus ($E^{'}$) and storage modulus ($E^{''}$) of the specimens were obtained from equations 2 and 3.

$$\omega_1 = \frac{1.875^2}{2\pi L^2}\sqrt{\frac{E^{'} I}{\rho A}} \tag{2}$$

Where ω_1 is the natural frequency of first mode, L is the free length of the beam, ρ is the density of beam material, E' is the storage modulus, I is the moment of inertia of the given cross-section of beam and A is the cross-sectional area of the beam. Similarly, loss modulus of the beam can be found using storage modulus. Relationship between loss and storage moduli is given in Eq. 3:

$$E^{''} = E^{'}(\omega)\,\mathrm{Tan}\,(\delta) = 2E^{'}(\omega)\xi(\omega) \tag{3}$$



(a) (b)

Fig. 1. Vibration test mechanism. (a) Overall view of set-up, (b) Half power band-width method.

3. Results and discussions

The frequency response curves recorded in the vibration tests are given in Table 3 and illustrated in Fig. 2, respectively. Storage and loss moduli distributions are given in Fig.3. It is observed that the first mode natural frequency was definitely dominant for all borax contents. The natural frequency increased with increasing borax content while the maximum amplitude decreased. With the addition of 5 mass % borax, natural frequency increased by 17 % in all S-glass/epoxy samples. The samples with 20 mass % borax content exhibited the highest natural frequency and storage modulus, while samples with 5 mass % borax content specimen had the maximum loss modulus. Due to direct proportional correlation of stiffness and natural frequency according to equation 2, it is concluded that stiffness of the specimens increases as the borax content increases. The variations of damping ratios can be attributed the matrix dislocations during the fabrication [15]. Liang et al. indicated that the increase of effective damping ratio could be result in the reduction of energy dissipated and responses by means of amplitudes. [16]. Similarly, Chandradass et al. [17] investigated the effect of nanoclay addition on vibration properties of glass fiber reinforced vinyl ester composites with different nanoclay contents (0, 1, 3 and 5 wt.%). It was concluded that addition of organically modified clay in the hybrid laminates increased the natural frequency due to the increased modulus. In addition, enhancement in damping factor nanoclay filled laminates was observed up to 3% by weight of organically modified clay. This was attributed the stiffness mismatch between the matrix, fibre and second phase nanoclay reinforcements [18].

Table 3. Measured vibration properties of samples.

Particulate material content (mass %)	**Natural frequency, ω_n (Hz)**	**Storage modulus, $E^{''}$ (GPa)**	**Loss modulus, $E^{'}$ (GPa)**	**Damping ratio**
0	88.061	10.774	19.474	0.276
5	103.424	15.776	22.228	0.355
10	102.452	12.711	20.972	0.303
15	105.470	8.149	18.886	0.215
20	108.548	10.052	18.517	0.271

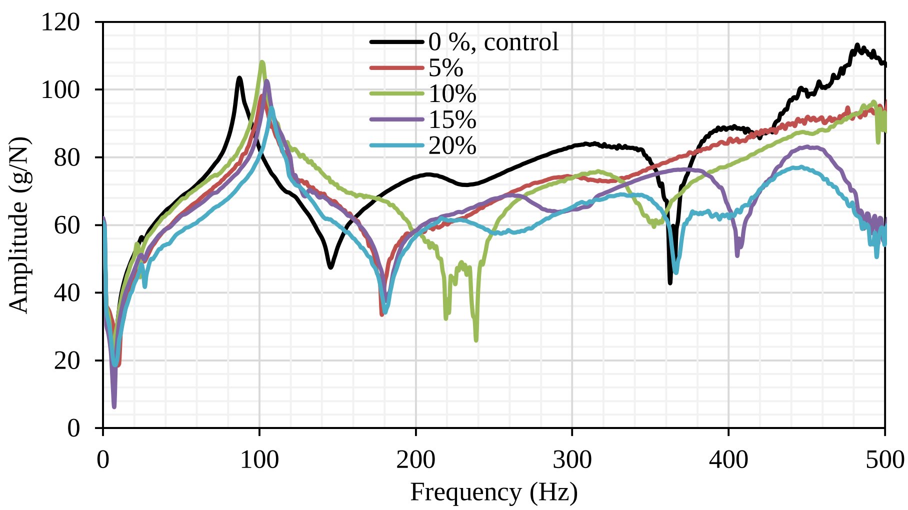


Fig. 2. Frequency versus amplitude response of samples.

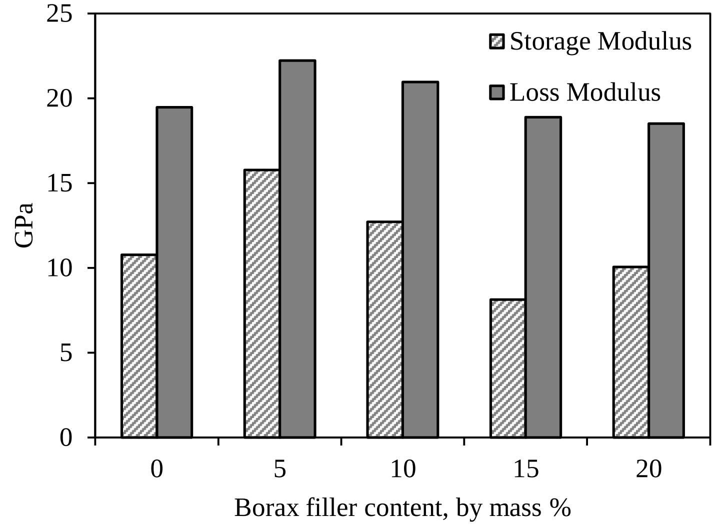
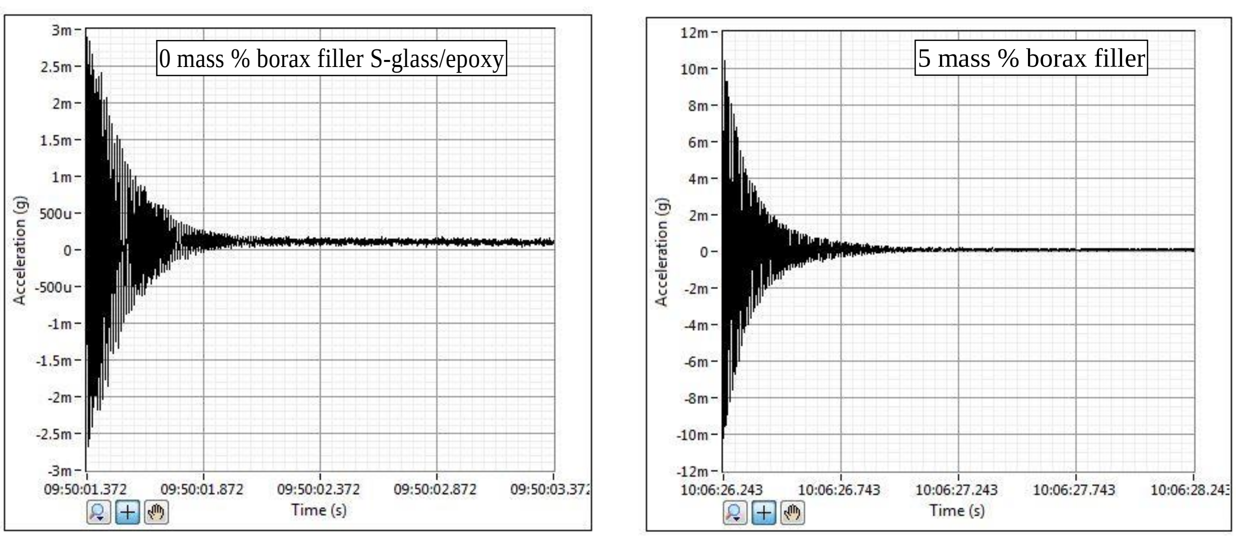


Fig. 3. Storage and Loss moduli versus borax filler content.

Fig. 4 illustrates the influence of borax addition on the displacement versus time records. Amplitude-time decaying curves were recorded within the same time intervals (2 seconds) in order to compare damping properties of the samples. It was found that the increase in borax content in S-glass/Epoxy composite laminates effected a significant increase in damping ratio even at only 5 mass % of particle loading, then followed by a decreasing trend. This may be attributed the large stiffness variation between matrix and fiber [19] and interlaminate shear strength which causes the increase in damping factor [18].

4. Conclusions

The damping and vibration properties of S-glass reinforced composite laminates were investigated by incorporating different contents (5, 10, 15 and 20 % by mass of particle loading) of borax filler and compared with plain S-glass/epoxy composite laminates. Borax filler has been used as additive material. The results showed that the replacement of borax filler particles with epoxy resin by 5 mass % of particle loading significantly increased the damping and first mode frequency of the samples. On further increase in borax content, trend is followed by increase in natural frequency, but resulting the decrease of the damping ratio. The variation of storage and loss modulus has shown the decreasing trend by increasing in particle loading of borax. The sample with 20 mass % borax filler exhibited the highest natural frequency. The sample with 5 mass % borax filler had maximum damping ratio and loss modulus.



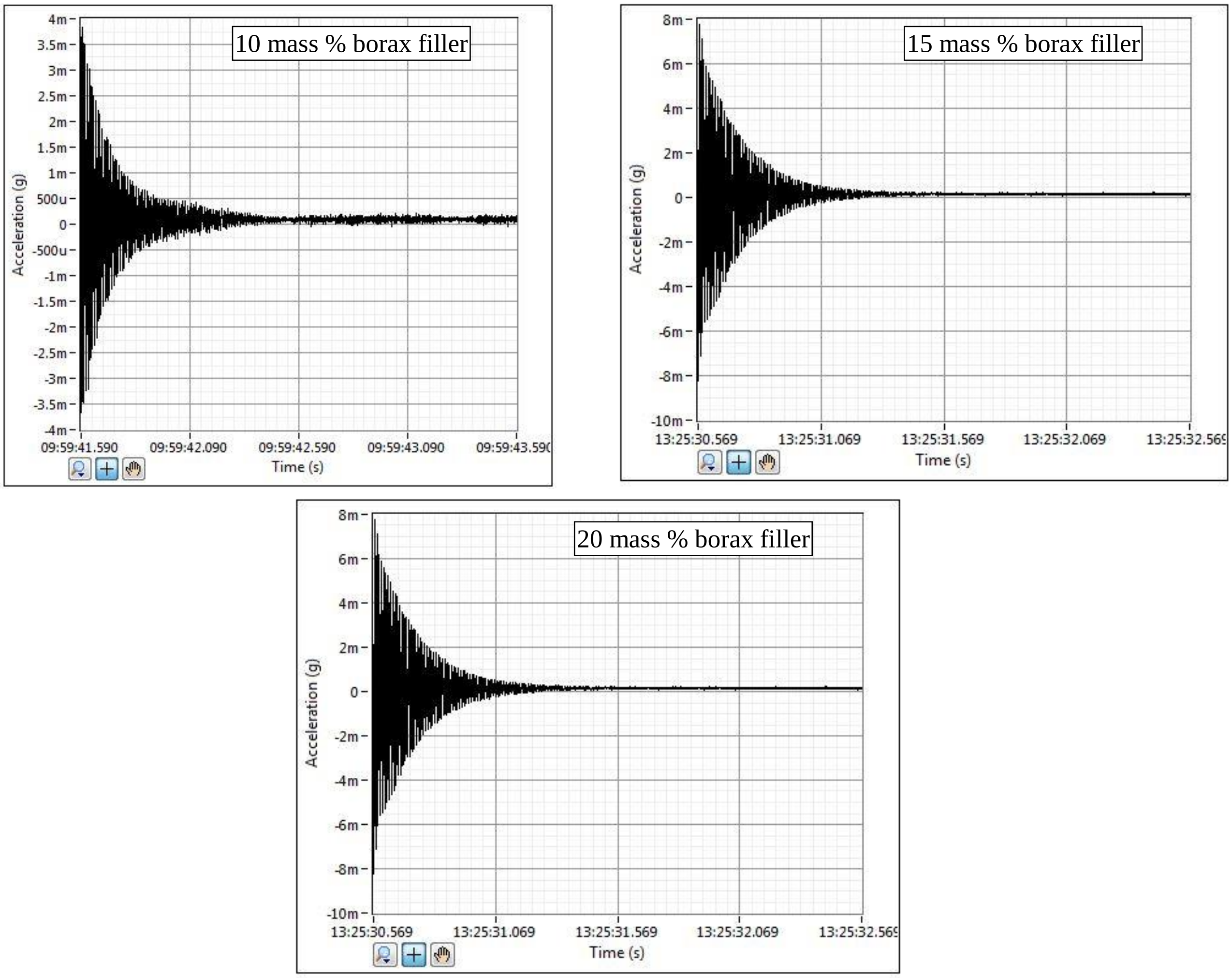


Fig. 4. Time dependent acceleration responses of samples

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