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Free vibration and dynamic mechanical properties of basalt fiber reinforced polymer composites

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In this study, the free vibration and dynamic mechanical properties of the surface modified basalt fiber reinforced polymer composites have been investigated. The surface modification of fiber has been carried out with 1N solution. Untreated, acid treated and base treated basalt fiber composites were prepared using Hand layup technique. Fourier transform infrared spectroscopes (FTIR) were used for the study of the effect of surface treatment on fibers. The natural frequencies and damping coefficient of the laminated composites have been analyzed using an impact hammer. The result showed better natural frequencies in the untreated basalt fiber composites than composites prepared with treated fiber. Dynamic mechanical analysis (DMA) was also carried out to find the mechanical properties of the composites as a function of temperature, in this analysis also, Untreated basalt fiber composite were found to possesses good storage modulus, loss modulus and damping factor.

Keywords: Basalt composite, FTIR, DMA, Vibration

Fiber reinforced polymer composites find wide use in engineering applications due to their superior mechanical properties compared to metals. The properties include light weight, high specific strength, ease in manufacture and cost. Synthetic fiber like glass fiber used as reinforcement in polymer finds increasing use due to its high strength compared to natural fiber. However, glass fiber has some limitations such as bio-degradability and damage to the surface of the fiber on alkali treatment. Basalt fiber is a material manufactured from volcanic igneous rock. It is similar to carbon fiber and fiberglass, and has better physicomechanical properties than fiberglass. But significantly cheaper than carbon fiber. In addition to the mechanical properties of the composites, it is essential to study the vibration characteristics and make a dynamic mechanical analysis for the application of composites to understand their appropriateness to suit different environments.

Some researchers have reported that basalt fiber composites have superior mechanical, thermal properties and environmental resistance compared to glass fiber composites[1-3]. Thermal and DMA of the short sisal fiber/ polystyrene composites have been studied by Manikandan et *al*.[1] for various surface treatments of the fiber. Fiber surface treatment has been improved the fiber-matrix adhesion and also made such adhesion thermally more stable than unreinforced composites. Increase in fiber loading causes increase in the modulus of the composites as reported by Manikandan *et al*.[4] The jute fiber reinforced vinylester resin composites were prepared by Ray *et al*.[5] for determining their DMA and making thermal analysis. All the cases considered by them showed a storage modulus decrease with increase in temperature and addition of fiber lowered the damping capacity of the composites. DMA of the banana fiber reinforced polyester composites was carried out to understand the effect of fiber loading, frequency and temperature. The loss modulus and damping peaks were found lowered by the incorporation of fiber while the glass transition temperature associated with the damping peak was seen lowered up-to a fiber content of 30%. The T_g values increased with higher fiber content[6]. DMA of natural rubber and its composites reinforced with short coir fibers had been studied and the effect of chemical treatment of the coir fiber on damping of composites was studied. Composites with untreated fiber were seen tending to dissipate larger volume of energy due to poor interfacial bonding compared to that with treated

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fiber with good interfacial bonding[7]. The mechanical and dynamic mechanical properties of HDPE: jute fiber composites have been investigated. DMA showed an increase in the storage modulus of the treated composites[8]. The viscoelastic behavior of a carbon fiber/epoxy matrix composite material system used for pipeline repair has been evaluated through DMA[9].

Hameed *et al.*[10] have studied the DMA of the composites with E-glass fiber used as reinforcement. The study showed thermoplastic modification as effective for improving the dynamic mechanical and thermal properties of composites. Bamboo and glass fibers hybrid composites were prepared and the results showed an increase in storage modulus (E_0) indicating a higher stiffness in the case of hybrid composites compared with untreated composites and virgin matrix[11]. Hybrid composites of polypropylene (PP) reinforced with short sisal and glass fibers were prepared by a twin-screw extruder, followed by injection molding. Storage modulus of sisal/glass reinforced PP hybrid composites (SGRP) showed maximum improvement as a result of the treatment with MAPP[12]. A study of the hybrid composites of bamboo/glass fiber, banana/glass fiber and curaua/glass fiber composites was made to determine the DMA of the composites. The results showed an increase in storage modulus (E') indicating higher stiffness in case of hybrid composites compared with untreated composites and virgin matrix[13-15]. The mechanical and high-temperature performance of four glass fibers reinforced phenolic resins composites were studied with different matrix materials. Increases in the crosslink density and the interfacial bonds between the fibers and the resin matrix by post cure was seen, an increase in their mechanical and high-temperature properties was also seen[16]. The DMA of oil palm empty fruit bunch (EFB)/woven jute fiber reinforced epoxy hybrid composites was fabricated. The conclusion was that hybridization of EFB composite with Jute fibers enhanced the dynamic mechanical and thermal properties[17]. The experimental study on the static and dynamic mechanical and visco-elastic properties of short hemp fiber polypropylene composites was made for finding their interfacial bonding of the composites. The results indicated increases in storage modulus of the composites with increase in short hemp fiber content upto 40 wt%. Further increase in fiber content resulted in fiber agglomerations and voids[18]. The development of a recycled poly (ethylene terephthalate) (PETr) reinforced with surface treated date palm leaf fiber (DPLF) composites had been studied and dynamic mechanical analysis indicated an increase in the toughness in the composites as a result of an addition of DPLF to the PETr matrix[19]. Rajini *et al.*[20,21] have studied the DMA and free vibration behavior in chemically modified coconut sheath/nano-clay reinforced hybrid polyester composite. The mechanism of chemical modifications improve the natural frequencies of the composites and the resultant improvement in the temperature dependence mechanical properties has also been reported. Enhanced vibration properties have been observed upto 3 wt% of clay dispersion in hybrid composites. The free vibration analysis and modal stress analysis of an adhesively bonded composite single lap joint having unidirectional laminated narrow plates and subjected to clamped-free condition have been carried out[22]. Chandra *et al.*[23] have provided a review on the damping characteristics of synthetic fiber reinforced composites and concluded that the major contribution of damping is due to the visco-elastic nature of the matrix. The surface treatment of the fiber and the hybridization influences the dynamic stiffness of the structures and hence, it is important to analyze the free vibration characteristics of composites. In the present investigation a study of the basalt fiber reinforced polyester composites with different surface modification of the fiber has been done. The effect of the surface modification of the fiber has been analyzed on the basis of the dynamic mechanical analysis and free vibration characteristics of the composites.

Experimental Procedure

Materials

Basalt plain woven fabric fiber (220 g/m^2) was purchased from ASA.TECH, Austria and unsaturated polyester resin, methyl ethyl ketones peroxide (MEKP) and co-napthenate were purchased from GVR traders, Madurai, India. Sodium hydroxide and sulphuric acid were purchased from the United Scientific Company, Madurai, India.

Treatment of fiber

The basalt fiber was cut to a size of 35 × 35 cm and treated by soaking in two solutions, 1 N NaOH and 1 N H_2SO_4, separately for 24 h at room temperature. Following this, the fibers were washed with distilled water to remove any NaOH and H_2SO_4 from the surface of the fibers. Finally, the fibers were dried at room temperature for 24 h before the preparation of the composites.

Fabrication of composites

Basalt fiber reinforced polymer matrix composites were fabricated using the hand lay up method and unsaturated polyester resin was used in the matrix. Cobalt naphthenate and methyl ethyl ketone peroxide were used as an accelerator and a catalyst, respectively for ensuring a proper chemical reaction. Twelve layers of basalt fiber mats were cut and weighed for determining the corresponding 1:1 amount of unsaturated polyester resin. Polyester resin was used for curing by incorporating 1 vol% of the methyl ethyl ketone peroxide (MEKP) acting as catalyst and 1 vol% cobalt naphthenateacting as accelerator was also added. A stirrer process was carried out for achieving a homogenous mixture. Resin mixture was used for fabricating the basalt fibers composites using the hand lay up technique with a roller. The fabricated samples were cured for 24 h at room temperature. A similar procedure was adopted for the preparation of the acid-treated basalt, the base-treated basalt, the untreated glass, the acid-treated glass and the base-treated glass fiber reinforced polymer composites.

Testing of composites

Free vibration

Figure 1 shows the investigation setup used for carrying out the modal analysis of composite laminates with an impact hammer. The accelerometer (Kistler model 8778A500) was attached at the end of the rectangular plate (200 mm × 20 mm × 3 mm) using wax. The modally tuned impact hammer (Kistler model 9722A500) with sharp hardened tip was chosen for obtaining higher frequencies. The displacement signal from the accelerometer was recorded in a personal computer through the data acquisition system.

Dynamic mechanical analysis (DMA)

Dynamic mechanical properties namely storage modulus and loss tangent were measured using the SIIEXSTARDMS 6100 – DMA instrument. Rectangular composite specimens of size 50 mm × 10 mm × 3 mm were used. The test was conducted using a 3-point bending mode. The samples were tested in a nitrogen atmosphere in a fixed frequency mode of 20 Hz with a heating rate of 2 °C/min. The measurements were taken over a temperature range of 20°C-300°C.

FTIR spectroscopy

The IR spectra of the untreated, acid and base treated basalt fiber composites are shown in Fig. 2. The IR broad spectra found to be 2360 cm^{-1} for the acid treated basalt fiber. It is a characteristic band for O=C=O stretches. The stretching asymmetric and symmetric vibration of CO_2 were observed appearing in the spectra for fiber comprising cellulose and lignin filler. The FTIR spectra for the base treated composite peak was observed at about 2900 cm^{-1}. It is the characteristic of CH stretching, vibration which results in the removal of hemicelluloses from the fiber during base treatment.

Results and Discussion

Free vibration analysis

A study of the experimental natural frequency and damping factor analysis carried out on untreated, acid treated and base treated basalt fiber and similarly for the glass (treated or untreated) fiber was made. The rectangular specimen of size 200×20×3 mm was clamped at a rigid support to a length of 30 mm. Free vibration was excited on the specimen with the help of a modally tuned impact hammer. Dewetron 43 data acquisition system was used for storage and analysis of the data. Table 1 shows details of the influence of surface treatment of both basalt and glass fiber composites. The basalt fiber composite showed better natural frequency and damping than glass fiber composites. The maximum increase in natural

Fig. 1 — Setup for modal analysis

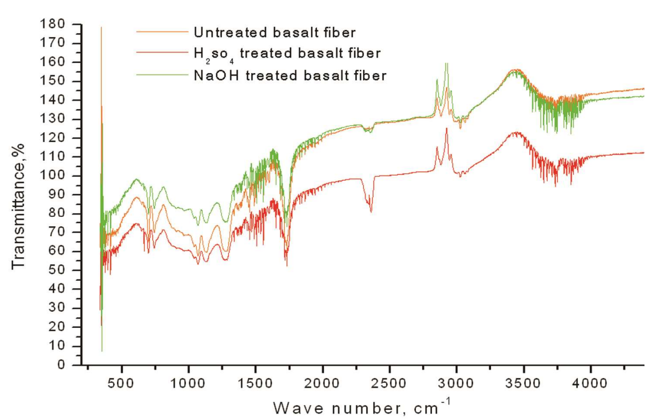


Fig. 2 — Basalt fiber FTIR spectra for treated composites

frequency was observed in acid treated basalt fiber composites. The chemical treated leading to a good interfacial bonding between fiber and matrix[1,27] was evident. The layering and weaving of the composites was also seen as influencing the natural frequency of the composites[28,29]. SEM micrograph of surface modified basalt fiber is shown in Fig. 3.

Dynamic mechanical properties (DMA)

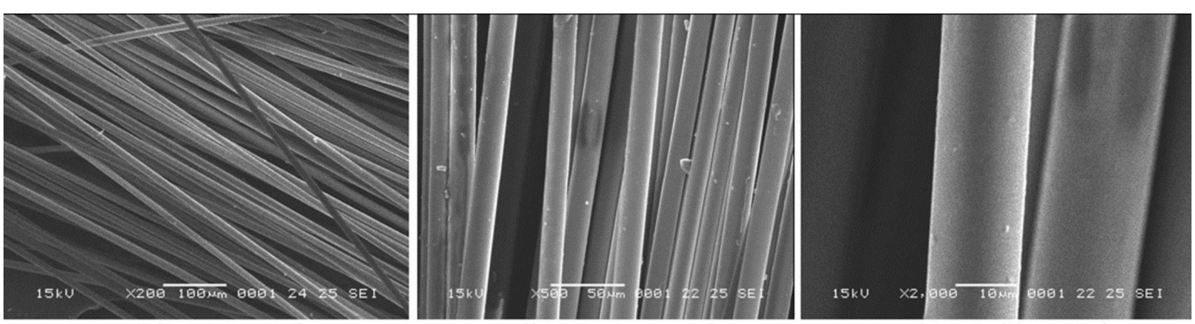
Dynamic mechanical properties are highest useful in the studying of the viscoelastic behavior of polymer composites. The storage modulus comparison between the untreated, base treated and acid treated basalt fiber composites as a function of temperature is shown in Fig. 4. The storage modulus curve exhibits the two regions, at lower temperature glassy region from the brittle state into a molten or rubber like state and a sudden drop of modulus which exhibits the relaxation in the matrix after which no major rise or fall was observed[10,30,31]. No major change was observed in the composites after 40°C to 90°C. A constant value of storage modulus was observed in all kinds of composites following this, it was the indication of the melting of the composites[32]. A highest storage modulus was obtained from the untreated basalt fiber composites than surface modified composites. This could probably be due to findings indicating of significant disruption in the interfacial bonding strength of the specimens due to surface treatment. Figure 3 shows the presence of a fiber damage during the NaOH treatment of fiber.

The loss modulus (*E*'') is a measure of the ability of a material to dissipate heat per cycle under deformation. Figure 5 shows the variation in loss modulus with the temperature of the untreated, base treated and acid treated basalt fiber composites. The figure clearly shows the peak for the untreated basalt fiber composites. The transition region for all the composites is shown at around 70°C only. But there was no significant changes in the peak as well as the transition temperature in the case of untreated and acid treated composites[31]. The loss modulus decreses with a futher increase in temperature, indicating uniform dissipation of heat[32].

Mechanical damping is nothing but loss modulus to storage modulus and relates to the molecular mobility in a polymer material[31]. Damping relates to the impact resistance of the material and movement of molecules within the polymer structure. The higher the value of damping, the greater would be the molecular mobility[26]. Due to weak interfacial bonding, mobility of molecules would be high, surface modified

Table 1 — Natural frequency and damping for the basalt fiber and glass fiber

Treatment	Modes	Glass fiber		Basalt fiber	
		Frequency	Damping	Frequency	Damping
Untreated	Mode 1	9.7	0.102	29.2	0.118
	Mode 2	92.3	0.09965	180.68	0.118
	Mode 3	201.62	0.010867	471.76	0.021
Acid treated	Mode 1	14.65	0.1	29.3	0.075
	Mode 2	180.65	0.022319	171.64	0.076
	Mode 3	301.12	0.0218	449.53	0.021
Base treated	Mode 1	14.648	0.07	19.5	0.01
	Mode 2	122.89	0.07752	147.68	0.045
	Mode 3	315.19	0.037372	374	0.0198



(a) Untreated (b) Base treated (c) Acid treated

Fig. 3 — SEM micrograph of surface modified basalt fibers

composite showing a lower value of damping. This is an indication of the higher degree of mobility, i.e, better damping properties[32]. The damping of basket fiber composite is shown in Fig 6.

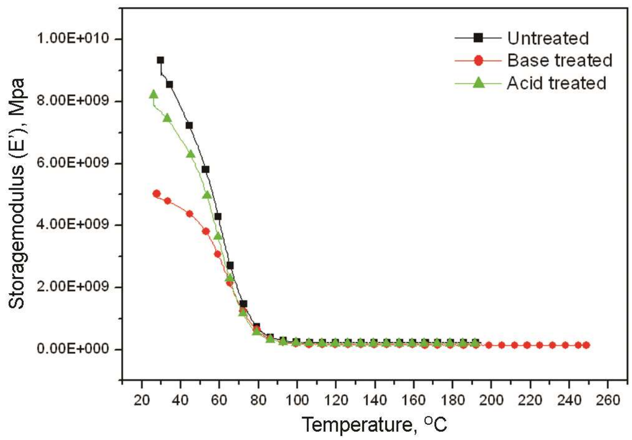


Fig. 4 — Storage modulus of basalt fiber composite

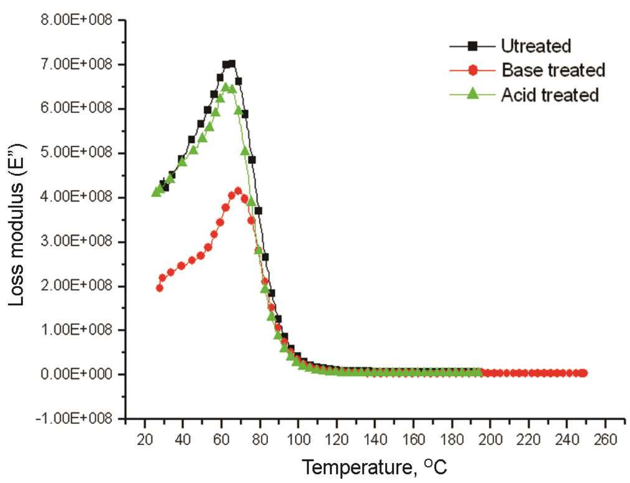


Fig. 5 — Loss modulus of basalt fiber composite

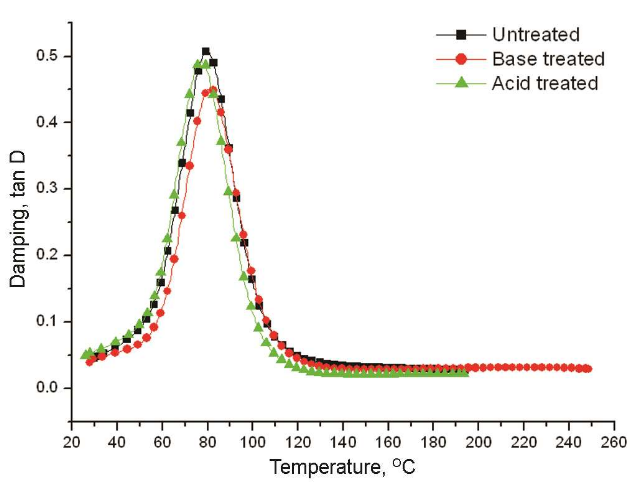


Fig. 6 — Damping factor of basalt fiber composite

Conclusions

In this study surface modified basalt fiber reinforced polyester composites were prepared using hand lay up techniques and evaluation of natural frequency and dynamic mechanical analysis was done. The following conclusions are drawn:

(i) A comparison of the natural frequency and damping factor of the basalt fiber and glass fiber composites was made. Untreated basalt fiber composites showed improved natural frequency and damping behavior compared to other types of composites prepared.

(ii) Dynamic mechanical analysis also showed untreated basalt fiber composites getting enhanced properties in storage modulus, loss modulus and damping factor.

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