Acoustic Behaviour of Natural Fiber Reinforced Epoxy and Epoxy-Pine Composites

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Abstract

In this work, the Grewia Optiva fibers (GOFs) have been used as reinforcement in epoxy resin and hybrid (epoxy-pine) resin, and the acoustic properties of GOFs, resins, and their composites have been examined. Recently, green or natural materials have been gradually explored for use in absorption of sound for greater environmental sustainability and bio-waste management. This paper characterizes the acoustic behaviour of natural fiber reinforced composite in terms of the sound absorption at octave frequency signals (32 Hz-16 kHz). The composites are fabricated in different weight percentages of 5%, 10%, and 15%. The acoustic test for this study is conducted in a 3.5 mm thick glass box without and with samples by point method of sound power measurement. The results are also compared with pure resin (PE). Moreover, the results revealed that the sound pressure level is decreased at different points with an increased percentage of GOF in the composite and hence increases the sound absorption coefficient (SAC). Additionally, the results indicate that these composites can significantly absorb the sound in the mid-frequency range. The GOF reinforced epoxy-pine composites have higher values of SAC as compared to other counterparts. Also, the findings have revealed the possibility of natural resin as a substitute for synthetic resins for better economic and environmental sustainability. Usually, the SAC bigger than 0.2 for any material qualifies it as a sound absorbing material.Normally, SAC greater than 0.6 for any material is known as best sound absorbers. Therefore, the development of such kind of composites can be an environment friendly approach to the sound community.

Keywords : Grewia Optiva fiber, Hybrid resin, Pine, Point method, Sound absorption coefficient.

1. Introduction

Noise pollution is the annoying or unnecessary noise that may damage the activity or balance of any living bodies. Now-a-days, the level of sound in our nearby environment is rising steadily leading to noise pollution. This can be seeming in private as well as in working environments. The fast growth and urbanization have enhanced the noise pollution and it became the third-largest pollution that harmfully disturb the human health, economy, and environment [1]. Road traffic, train, aircraft, construction, household appliances, industrial, etc. are the common major source of noise [2]. Common adverse effects of noise are headaches, dizziness, hearing impairment, etc., which can lead to depression, hypertension, cardiovascular diseases, sleep disturbance, etc. [3–5]. Therefore, annoying, and uncontrolled noise should be reduced by

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using noise absorbing system. Noise can be decreased by sound insulation and sound absorbers such as fibrous, cellular, and granular [6].

Despite of several advantages of the conventional sound absorbers such as good sound insulation properties, extensive range of flexibility and stiffness, low-density, resistance to chemicals, etc., these absorbers cannot deliver acceptable thermal and mechanical performance in harsh conditions [7]. Furthermore, these commercial sound absorbers (carbon fiber, glass fiber, glass wool, etc.) not only the reason of environmental pollution but also the source of CO_2 emission. To eradicate these difficulties, novel, and innovative materials (eco-friendly, lightness, sustainability, cost-effectiveness, etc.) are required to substitute these commercial absorbers. Plant fibers have acknowledged greater attention because of porosity, non-hazardous nature, lightweight, biodegradability, easy processing, corrosion resistance, and eco-friendly [6,8]. Natural fiber composites are frequently used as a passive absorber due to its inherent sound dampening qualities as a porous material.

Natural fibers such as hemp [6,9], jute [10,11], kenaf [4,6,12], coir [13,14], sisal [15], flax [1], yucca gloriosa [5], ramie [1], sugarcane [15], pineapple leaf [16], etc. have been used in composites and has displayed good sound absorption properties. Therefore, the plants by-product is one such substitute to develop green sound absorbers. The consumption of these fibers in sound absorbers may resolve the disposal problem of unused waste byproducts and maintain a green environment. The sound absorption occurs in the natural fiber is due to the viscous effects of internal friction of sound with fiber walls and the heat transfer between different fibers [1]. The sound absorption mechanism has three parts that unite and work collectively on the acoustic waves for acoustic energy transfer. Firstly, the air inside the fiber pores vibrates and rubs against the cell wall, produces viscous resistance, and dissipates acoustic energy into thermal energy. Next is heating and cooling the air inside the pores, and the last is the vibration of fibers that causes sound energy dissipation [4].

The investigation of Grewia Optiva Fiber reinforced composites (GOFRCs) as a sound absorber has not been done before in literature to the best of our knowledge. Therefore, in this work, GOFs-epoxy resin composite (GOFREC), and GOFs-epoxy-pine resin composite (GOFREPC) have been prepared with 5, 10, and 15 wt.% of fiber reinforcement. The objective of this paper is to find the influence of the percentage of GOFs on the acoustic behaviour of the composites.

2. Material and Methods

2.1 Materials

The GOFs were collected from the forest of a village Pancheshwar, District: Pithoragarh, Uttarakhand, India for this work. Araldite (AW 106) and Hardener (HV 953 IN) were used for this work. The reaction ratio between Araldite and Hardener by weight was 10:8. Both were purchased from local vendor, Prayagraj, U.P., India. The pine gum was collected from the field of Pancheshwar, District: Pithoragarh, Uttarakhand, India. The demonstration glass box has been made of float glass with a dimension of 200 mm cube and 3.5 mm thickness. The empty glass cube boxes with different thicknesses, i.e., 3.5 mm, 5 mm, and 8 mm has been used for repeatability of the measurement. In the glass box method, GOFRCs for acoustic characterization have been fabricated with 5, 10, and 15 wt.% of GOF as a reinforcement and two different types of polymers, i.e., Epoxy Resin (Araldite and Hardener), and hybrid (Pine and Epoxy Resin) as a matrix. The compositions and designations of each composite sample are mentioned in Table 1.

2.2 Methods

Generally, the sound power measurement was accepted as per ISO 9614 standard. It has two parts, viz., ISO 9614-1 for the point method, and ISO 9614-2 for the scanning/sweep method. In this paper, the point method has been used to measure the sound pressure level (SPL) because this method gives stable and precise results [17]. This method does not need expensive facilities such as impedance tubes and anechoic or reverberation chambers. Also, in this technique, the steady background noise level can be tolerated during the measurements. The sound power level (L_w) is calculated with the help of SPL, as given in Eq. (1) [18].

$$L_w = L_p - 10\log_{10}\left(\frac{Q}{4\pi r^2}\right) \qquad (1)$$

where, L_p is SPL, $Q = 2$ is the directivity factor, and r is the distance of the source.

In this method, the SPL is calculated in four planes (PL1, PL2, PL3, and PL4) and at 18 points (P11 to P14, P21 to P24, P31 to P35, and P41 to P45), as shown in Fig. 1. Furthermore, the planes are defined at different distances, 0, 100, 200, and 300 mm from the sound source to study the effect of the distance on SPL determination. The sound pressure is measured at r = 150, 170, 210, 290 mm at PL1, PL2, PL3, and PL4 planes, respectively, from the sound source. A portable Bluetooth speaker (Sony SRS-XB12) is used as the sound source for this setup. The audio signal is generated through a Scilab software, and the SPL (dB) is measured by the sound level meter (indi6182). The SAC(α) is defined as the ratio of the absorbed sound to the incident sound and is calculated by Eq. (2).

$$SAC\ (\alpha) = \frac{(L_w)_{absorbed}}{(L_w)_{incident}} \qquad (2)$$

Table 1 — The compositions and designations of samples for glass box method

S. No.	Wt.% GOF	Wt.% Epoxy resin	Wt.% pine gum	Designation
1.	0	100	0	PE
2.	5	95	0	5GOFREC
3.	10	90	0	10GOFREC
4.	15	85	0	15GOFREC
5.	5	75	20	5GOFREPC
6.	10	70	20	10GOFREPC
7.	15	65	20	15GOFREPC

Fig.1 — Sound intensity measurement setup with (a) empty glass box and (b) composite samples.

3. Results and Discussion

The acoustic behaviour of 5, 10, and 15% of GOF-reinforced epoxy, and hybrid composites have been evaluated in a 3.5 mm, 5 mm, and 8 mm thick glass box by point method. The SPL of empty glass box has also been measured and taken as a reference for other materials to evaluate acoustic behaviour. The SPL and the SAC have been estimated at each corner of the 3.5 mm glass box in all four planes. The plane-wise variation of SPL for each material is given in Tables 2-4.

Table 2 — Maximum value of SAC of materials at different planes in 3.5 mm thick glass box

Frequency	Plane	SAC (Maximum)						
		PE	5GOF REC	10GOF REC	15GOF REC	5GOF REPC	10GOF REPC	15GOF REPC
32.5-500 Hz	PL1	0.18	0.20	0.18	0.18	0.21	0.20	0.19
	PL2	0.17	0.18	0.17	0.17	0.20	0.18	0.17
	PL3	0.15	0.17	0.16	0.15	0.18	0.16	0.16
	PL4	0.15	0.17	0.16	0.17	0.18	0.17	0.16
1-4 kHz	PL1	0.22	0.27	0.24	0.23	0.50	0.26	0.24
	PL2	0.20	0.26	0.22	0.21	0.49	0.23	0.22
	PL3	0.19	0.24	0.21	0.20	0.46	0.23	0.20
	PL4	0.20	0.24	0.22	0.20	0.46	0.23	0.21
8-16 kHz	PL1	0.13	0.16	0.14	0.14	0.28	0.15	0.15
	PL2	0.12	0.15	0.14	0.14	0.28	0.15	0.14
	PL3	0.13	0.16	0.16	0.15	0.29	0.17	0.16
	PL4	0.13	0.16	0.16	0.15	0.28	0.16	0.15

Table 3 — Maximum value of SAC of materials at different planes in 5 mm thick glass box

Frequency	Plane	SAC (Maximum)						
		PE	5GOFR EC	10GOF REC	15GOFRE C	5GOF REPC	10GOF REPC	15GOF REPC
32.5-500 Hz	PL1	0.12	0.16	0.14	0.13	0.16	0.16	0.15
	PL2	0.14	0.17	0.16	0.15	0.18	0.17	0.16
	PL3	0.14	0.16	0.15	0.14	0.17	0.16	0.16
	PL4	0.15	0.17	0.15	0.14	0.17	0.16	0.16
1-4 kHz	PL1	0.21	0.24	0.23	0.22	0.52	0.25	0.23
	PL2	0.21	0.24	0.23	0.22	0.52	0.26	0.23
	PL3	0.20	0.23	0.23	0.21	0.49	0.25	0.22
	PL4	0.20	0.23	0.22	0.21	0.50	0.25	0.22
8-16 kHz	PL1	0.13	0.17	0.15	0.14	0.30	0.15	0.14
	PL2	0.12	0.17	0.16	0.14	0.30	0.15	0.14
	PL3	0.12	0.16	0.15	0.13	0.27	0.14	0.13
	PL4	0.11	0.15	0.14	0.12	0.27	0.14	0.12

Table 4 — Maximum value of SAC of materials at different planes in 8 mm thick glass box

Frequency	Plane	SAC (Maximum)						
		PE	5GOFREC	10GOFREC	15GOFREC	5GOFREPC	10GOFREPC	15GOFREPC
32.5-500 Hz	PL1	0.06	0.10	0.07	0.07	0.12	0.09	0.08
	PL2	0.06	0.11	0.08	0.07	0.14	0.10	0.13
	PL3	0.09	0.09	0.07	0.08	0.19	0.17	0.15
	PL4	0.05	0.10	0.08	0.06	0.12	0.09	0.08
1-4 kHz	PL1	0.23	0.29	0.27	0.24	0.52	0.28	0.26
	PL2	0.24	0.30	0.28	0.25	0.52	0.29	0.26
	PL3	0.22	0.28	0.26	0.23	0.49	0.27	0.25
	PL4	0.23	0.29	0.26	0.24	0.50	0.27	0.25
8-16 kHz	PL1	0.12	0.17	0.16	0.15	0.34	0.19	0.16
	PL2	0.12	0.17	0.16	0.14	0.34	0.18	0.16
	PL3	0.11	0.16	0.15	0.13	0.32	0.17	0.15
	PL4	0.11	0.16	0.15	0.14	0.32	0.18	0.15

Due to the non-linear behaviour of the sound absorbing materials, the values of SAC are different in all frequency regions. The sound is reflected and refracted as it enters the composite samples and due to the low energy elastic collision, small amount of sound energy is converted into heat. Therefore, the composite samples have low SAC during low frequency range. The waves have high wavelength near low frequencies and hence low energy. The sound waves reflect and refract and lose energy after the collision with the material. There is less collision and less loss of sound energy in the low frequency region. If the material has small pores or inclusions, there may be difficulty for sound waves to enter into the material, which results in low absorption.

Furthermore, at low frequency region, the thickness and denser structure of the material plays an important role and has a direct relationship with frequency. Because of the above reasons, all types of samples display decreasing trend in SPL in the 500-1000 Hz frequency range. Alternatively, in medium and high frequency region, there is more energy loss in the form of heat due to the inelastic collisions. Moreover, at high frequencies, due to coincidence dip phenomenon and in-phase relation between the incidence and reflected wave, which causes the decrease in SAC by slight amount. Also, the comparison has been made with the maximum SAC frequency range of different reinforced materials and it has been concluded that the SAC is maximum within the frequency range 1-4 kHz, which is consistent with the data given in Table 5.

Table 5 —Maximum value of SAC of materials at different planes in 3.5 mm thick glass box

S. No.	Type of concrete composite	Frequency Range	Maximum SAC	Ref.
1.	Concrete with cenosphere	1000 Hz	0.23	[19]
2.	Hemp concrete	500-2000 Hz	0.44-0.49	[20,21]
3.	Concrete with bottom ash	1000 Hz	0.28	[22]
4.	Glass-based concrete	250-3150 Hz	0.2-0.37	[23]
5.	Normal concrete	3000-5500 Hz	0.05-0.1	[23]
6.	Coconut fiber concrete	1250-3200 Hz	0.42-0.80	[23]
7.	GOF reinforced hybrid polymer composite	1000-4000 Hz	0.19-0.52	Current work

4. Conclusions

Based on the findings from glass box test method, one can conclude that the substitution of GOFs in polymer increases the sound absorption properties. The results indicate that the SAC of GOF-reinforced hybrid (epoxy-pine) resins composites are superior than GOF-reinforced pure epoxy composites. Similar results have been obtained in all three (3.5 mm, 5mm, and 8 mm) glass box to determine fairly accurate SPL, sufficient point density, and repeatability of the measurement. The composite samples have SAC, i.e., (0.17-0.20) during low frequency range due to the non-linear behaviour of the sound absorbing materials. All types of samples display decreasing trend in SPL in the 500-1000 Hz frequency range. In medium frequency region, there is more energy loss in the form of heat due to the inelastic collisions and hence high SAC has been found, i.e., 0.19-0.52. Moreover, at high frequencies, due to coincidence dip phenomenon and the in-phase relation between the incidence and reflected wave, which causes the decrease in SAC by slight amount, i.e.,0.11-0.34.

Acknowledgement

First author thanks the Ministry of Human Resource and Development, Ministry of Education (MOE), Government of India for giving Ph.D. fellowship.

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