Journal of Materials Research and Technology 31 (2024) 2402–2413

Contents lists available at ScienceDirect

Journal of Materials Research and Technology

journal homepage: www.elsevier.com/locate/jmrt

Mechanical, vibration damping and acoustics characteristics of hybrid aloe vera /jute/polyester composites

S. Senthilrajan [a,**], N. Venkateshwaran [b], R. Giri [a], Sikiru O. Ismail [c], Rajini Nagarajan [d,*], Kumar Krishnan [e], Faruq Mohammad [f]

[a] Department of Robotics and Automation Engineering, Rajalakshmi Engineering College, 602105, India
[b] Center of Excellence in Digital Manufacturing, Department of Mechanical Engineering, Rajalakshmi Engineering College, Chennai, 602105, India
[c] Department of Engineering, Centre for Engineering Research, School of Physics, Engineering and Computer Science, University of Hertfordshire, Hatfield, AL10 9AB, England, United Kingdom
[d] Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Anand Nagar, Krishnankoil, 626126, Virudhunagar Dt, India
[e] Faculty of Health and Life Sciences, INTI International University, Persiaran Perdana BBN, 71800, Nilai, Negeri Sembilan, Malaysia
[f] Department of Chemistry, College of Science, King Saud University, P.O. Box 2455, Riyadh, 11451, Kingdom of Saudi Arabia

A R T I C L E I N F O

Handling editor, SN Monteiro

Keywords:
Woven
Jute
Aloe vera
Hybrid
Vibration
Acoustic
Transmission loss
Energy efficiency

A B S T R A C T

The development of biodegradable hybrid fibre composites is gaining pace in the automotive and construction industries due to their lightweight structural applications, which offer considerable benefits for the environment. In this present investigation, hybrid bio composites were fabricated using a compression molding machine with plain woven jute and aloe vera mats along with polyester resin as the matrix. Six types of hybrid biocomposite laminates were prepared by varying the stacking arrangement of jute and aloe-vera mats to analyse the impact of stacking arrangements on vibration damping and acoustic behaviour of these hybrid bio composites. From the results, it is concluded that the maximum value of natural frequency is obtained from the JJAJ type of composite. i.e., 157, 326, and 370 Hz for Modes I, II, and III respectively, due to good interlacing of fibres in the weft and warp directions. J/J/A/J (AJ3) hybrid bio composite has highest sound absorption coefficient of 0.47 at 3000 Hz, and a better transmission loss i.e 19.84 dB, according to the results of the acoustic research. The comparison of experimental and theoretical analysis was carried out, and found that experimental and theoretical values are closely related to each other.

1. Introduction

In recent times, noise pollution has grown to be an important worldwide issue. Unfortunately, significant advances in noise reduction are not possible with standard acoustic materials. Acoustic meta-materials, on the other hand, are offering fresh approaches to managing sound waves and, in particular, hold great promise for reducing the spread of noise [1].The concept of circular economics (CE) has been used to lower the use of petroleum-based goods, and the growth of the green economy has highlighted a renewed interest in obtaining the necessary resources to support creative employment policies that encourage recycling and the reuse of existing products over new ones [1].From the 1950s until the early 2000s, the automotive, construction, and aviation sectors were dominated by synthetic fibres like carbon, glass, and kevlar. However, because these fibres are not biodegradable, they have caused substantial harm to the environment [1]. Fiber reinforced polymer (FRP) composites are used in various industrial applications in place of conventional materials. Contrary to conventional isotropic materials such as metals, the mechanical properties of FRP composites, such as load bearing capacity, fracture toughness, and vibration characteristics, can be tailor-made to suit a specific application [1]. This is done by incorporating fibres into proper matrices and orienting them carefully. A larger variety of mechanical characteristics can be obtained by adding two or more fibre types to the same matrix [1]. FRP composites have become a desirable class of construction materials due to their good general mechanical attributes. They are widely used for their light material in a variety of industrial applications, including construction, automotive, aviation, and energy [2]. To obtain enhanced

* Corresponding author.
** Corresponding author.
E-mail addresses: senthilrajan.s@rajalakshmi.edu.in (S. Senthilrajan), rajiniklu@gmail.com (R. Nagarajan).

https://doi.org/10.1016/j.jmrt.2024.06.158
Received 28 December 2023; Received in revised form 11 June 2024; Accepted 20 June 2024
Available online 25 June 2024

hybrid composites designed for specific applications, new materials have recently emerged, which expand new and exciting possibilities in hybrid composites. As polymer composite materials are increasingly expected to fulfil various and potentially even competing performance standards, the necessity for such material systems is growing rapidly [2]. The development and design of environmentally friendly biomaterials using renewable raw materials increased significantly due to environmental concerns and the conservation of natural resources. The use of natural fibre reinforcements, including ramie, banana, hemp, flax, jute, kenaf, sisal, coir, rice husk, and others, has increased significantly in place of synthetic materials [3]. The abrasive nature of synthetic fibres such as glass and Kevlar, as well as the high initial processing costs, are significant drawbacks [4]. For the past few decades' natural fibres have been investigated to strengthen polymer composites for a variety of reasons, including their low cost, better mechanical characteristics, high strength-to-weight ratio, and the fact that they are also recyclable [5]. Also natural fibres have better mechanical, hydrophilic, and biodegradable properties and utilized to create environmentally friendly materials Furthermore, natural fibres also have good vibro-acoustic and damping properties [6]. Natural fibres are also suitable for applications such as automotive door panels, car interiors, seat back support, dash boards, packaging containers, sports goods [7]. The application of natural fibre composites (NFC) for semi-structural components with additional noise and vibration control properties has become a growing requirement in the automobile sector. Vehicles are subjected to engine vibration, road surface irregularity, and noise from the surroundings as well as the engine, all of which are unpleasant because they seriously affect the driver and passengers' safety and comfort [8]. Because woven fibre reinforced composites have superior mechanical properties, such as better shear resistance, improved strength, higher transverse moduli, and greater damage tolerance, they have developed as viable composite materials [9]. This is due to their superior out-of-plane stiffness, strength, and wear resistance, lower fabrication costs, and convenient handling in manufacturing. The woven fabrics are available as either two-dimensional (2D) or three-dimensional (3D) fabrics. Dimensional stability and characteristics in orthogonal directions are enhanced by 2D woven fabrics [9]. Prabu et al. [10] reported on the mechanical, vibration, and wear characteristics of aloe vera/flax/hemp/wire mesh/-$BaSO_4$ laminated composites. The result shows that the natural frequency of the composite was increased with the addition of $BaSO_4$ reinforcement. The addition of filler improves the natural frequencies of the beam due to an improvement in specific stiffness. The mechanical properties of woven aloe vera, sisal, and kenaf fibres, as well as their hybrid composites, were investigated by Kumar and Sekaran [11]. They fabricated different types of woven aloe vera and kenaf, sisal and kenaf, aloe vera, sisal, and kenaf fibre (ASK)hybrid epoxy composites. The results show that the hybrid composite has better flexural properties, and the ASK hybrid composite has the highest impact strength. Rajkumar et al. [12] studied the effect of mechanical and vibration characteristics of natural fibre trapezoidal composite plates. They used jute, ramie fibre, and polyester resin to fabricate the laminate. The natural frequency and mode shapes are obtained for different boundary conditions. Evran [13] investigated the effect of fiber orientation on vibration characteristics of glass fiber composite based on finite element simulation and Taguchi's L9 orthogonal array. The result shows that the increase in fibre orientation angle from 0° to 80° decreases the frequency of the composite beam. Xiaoning et al. [14] investigated the acoustic behaviour of multi-layer non-woven fabric composites. They concluded that the layering sequence had a considerable effect on the sound absorption coefficient. The highest sound absorption coefficient is 0.538 when the polyethylene membrane is placed in the middle position of the multilayer composite structure. Saravanan and Prakash [15] analysed the sound absorption behaviour of chicken feather fibre (CFF) and its hybrid composites. The result reveals that the highest noise reduction coefficient (NRC) is achieved by using 100% CFF fibre. Also, it was concluded that the processing condition, density, temperature, and weight percent of reinforcement have major influences on NRC values. Malawade and Jadhav [16] explored the acoustic behaviour of bagasse fibre composites. The result showed that the thickness of the composite had a major impact on the sound absorption coefficient and flow resistivity. Also, they concluded that increasing the thickness of the composite also increased its sound absorption characteristics. Berardi et al. [17] studied the sound absorption characteristics of broom fibres in different diameters (1.5–4.0 mm) and different thicknesses (60, 80, and 120 mm). The result shows that the increase in thickness of the sample also increases the sound absorption coefficients at lower frequencies. Gokulkumar et al. [18] investigated the mechanical and acoustic properties of Camellia sinensis, Ananascomosus, and glass fibre composites at various weight percentages. The result shows that 25 wt% of camellia sinensis had a significant impact on sound absorption characteristics. Marichelvan et al. [19] reported the mechanical and sound absorption characteristics of bagasse/coconut/coir/polyester resin hybrid composites. From the results, it was concluded that the 20% bagasse/40% coir and 40% polyester resin have a significant influence on sound absorption characteristics. Also, the optimum composite was surface-modified with a 5% NaOH treatment to enhance its mechanical and acoustic characteristics. Sağlam et al. [20] investigated the sound absorption characteristics of black locust, narrow-leafed ash, stone pine, silver lime, sweet chestnut, sessile oak, maritime pine, cedar, and plane trunks. It was concluded that the trunk diameter, bark shape, and the bark's fibrous structure have major influences on sound absorption characteristics. Also, they concluded from the results that the cedar species have better noise reduction coefficients and sound absorption characteristics. Hariprasad et al. [21] discussed the sound absorption characteristics of several natural fibre and polypropylene composites. They investigated the milkweed, kusha grass, sisal, banana, and hay types of natural fibres and their composites. They found from the results that higher thicknesses of the composites did not give better sound absorption characteristics at higher frequencies. Also, they concluded that milkweed fibre and hay have better sound absorption characteristics at 20 mm thickness in the frequency range of 500–2000 Hz. Lee et al. [22] investigated the acoustic properties of flax/epoxy and glass/epoxy composites. Based on the findings, they concluded that flax/epoxy composites have superior properties to glass/epoxy composites. Hassan et al. [23] reported on a review about the influence of the acoustic properties of natural fibre-based materials and composites. In this study, they discussed the effects of content, volume fraction, thickness, effect of fibre size, fibre content, fibre fraction, fibre treatment, perforation, frequency, and back cavity depth. They concluded that when the content, frequency, sample thickness, and fibre inclination of the fibres are increased, the sound absorption coefficient of the composites increases as the fibre diameter decreases. Sound absorption is improved when fibres are alkali-treated. Furthermore, random fibre orientations in composites absorb sound more efficiently than aligned fibres. The incorporation of a plasticizer and a fire retardant into composites raises the sound absorption coefficient (SAC) even more. Thakare et al. [24] investigated the sound transmission loss and flexural strength of an epoxy-reinforced hybrid composite reinforced with jute, flax, sisal, hemp, and kevlar. The experiments were conducted in the frequency ranges of 63–1600 Hz and 1000–6300 Hz. The result reveals that the kevlar/hemp/hemp/hemp/hemp/Kevlar (H-FRP) also had higher sound transmission loss values that were close to the kevlar/sisal/sisal/sisal/sisal/kevlar (S-FRP) with a 2% difference. Furthermore, H-FRP has the highest flexural strength-to-weight ratio of any FRP panel, making it a better choice for structural applications. Bahl et al. [25] investigated the different composites for sound transmission loss tests at aircraft noise. They used glass fibre and polypropylene composites. They used glass fibre in different fibre volume fractions, i.e., 10%, 20%, and 30%. From the results, they concluded that the 10% fibre volume fraction has better sound transmission loss than other types due to the fact that as fibre volume fraction increases, porosity also decreases. Kesharwani et al. [26] measured the sound transmission loss at tonal excitations.

Table 1
Jute and Aloe-vera fibre significant characteristics [51and52].

S.No	Fibre Characteristics	Jute	Aloe vera
1	**Average fibre cell diameter (microns)**	**10–25**	**8–24**
2	**Warp ends/cm, n_{wp}**	**6.43**	**6.5**
	Weft picks/cm, n_{wf}	**5.1**	**5.5**
4	Fabric thickness (mm)	0.71	1.26
5	Fabric weights g/m^2	264.1	341.1
6	Yarn count/fineness/linear density	226.923	236
	Warp (tex = g/1000 m)	184.375	184.375
	Weft (tex = g/1000 m)		
7	Crimp	2.4	2
	Warp crimp %	4	4.4
	Weft crimp %		
8	Moisture content %	9.68	8.98
9	Air permeability (cm^3/cm^2/s)	245	208
10	Young's modulus of yarn (GPa)	3.72	3.92
11	Cellulose (wt%)	61-71 [51]	64.9 [52]

They used banana fibres, coconut coir fibres, hemp fibres, jute fibres, and kenaf fibres. Fibre diameter and stiffness have played a vital role in sound transmission. Better sound transmission loss (STL) occurs in less stiff fibre and lower diameter shows better sound reduction. Jute fibre and aloe vera fibre as reinforcement in the form of woven mat in this research. This cellulosic fibre-based woven fabric composite has great mechanical and physical characteristics, making it easier to make composites. Additionally, the fabric reinforcement allows for structural qualities based on demand to be tailored, which would be impossible with a random fibre orientation [51]. Because of their impact resistance, ease of handling during manufacture, and balanced properties, woven fabric composites are also of great technological significance in structural applications [59].This study looked at the mechanical, vibrational and acoustic properties of hybrid jute/aloe vera/polyester composites with varying stacking sequences, fibre volume fractions, and thicknesses. Acoustic tests were conducted on hybrid composites to measure the sound absorption coefficient, noise reduction coefficient and sound transmission loss through the impedance tube method. In this investigation, the vibration and acoustic behaviours of the composites were studied. Natural frequencies, damping factors for three modes and sound absorption and transmission loss were found by free vibration test set up and impedance tube the correlation between experimental and theoretical values of vibration and acoustic characteristics was studied, and they are all in good agreement with each other. The interfacial behaviour of the composites were studied by using scaning electron microscope images.

2. Materials and experimental details

2.1. Materials used

Jute fibre and aloe vera fibre as reinforcement in the form of woven mat in this research. Among all other natural fibres, jute is the most affordable and robust option. Each jute fibre has a length of 1–4 mm and a width of 5–30 μm. It is extracted using techniques from retted plants. The process of retting involves breaking down and dissolving materials such as pectin gums, among other compounds, in order to obtain fibre from the plant stem [49]. Aloe vera fibres are strong natural fibres made from the evergreen plant, which may be found in a variety of locations, including homes and tropical jungles. Aloe vera fibres are extracted by peeling and washing the leaves to remove the gel. The fibres are removed and dried. This cellulosic fibre-based woven fabric composite has great mechanical and physical characteristics, making it easier to make composites. Additionally, the fabric reinforcement allows for structural qualities based on demand to be tailored, which would be impossible with a random fibre orientation. In the current study, a 300 × 300 mm woven jute mat was utilized as a reinforcement material. The polyester resin mixture was cured using 1% of a catalyst called methyl ethyl ketone peroxide (MEKP) and an accelerator called cobalt naphthalene. The polyester resin, catalyst, and accelerator were acquired from M/s. Sakthi Glass Fibres located in Chennai, India. M/s. Anakaputhur weaver association in Chennai, Tamilnadu, India, woven the jute and aloe vera woven mats. The composite laminates were made using the compression molding technique at room temperature in six different categories by hybridizing the jute woven mat and aloe vera woven mat. Fabrication of composite as shown in Fig. 2. 1. Polyester Resin (PR), 2. A/A/A/A (A1), 3. A/J/J/J (AJ1), 4. J/A/J/J (AJ2), 5. J/A/J/J (AJ3) and 6. J/J/A/J (J1). After curing, the mold was removed from the compression molding machine and the composite was taken out of the mold and cut into specimens for flexural, free vibration, and sound absorption tests according to the standards. Table 1 discuss about the comparison of woven aloe vera and jute fibre properties. In this study, different types of composites and their nomenclature are tabulated in Table 2. A detailed method of research work and fabrication of composite is shown in Fig. 1 and Fig. 2.

2.2. Fibre dispersion

Four layers of aloe vera and jute woven mat were used in this design. Throughout this research, five different types of composite laminates with different layer arrangements were developed. As a result, four layers of aloe vera (A1) mat and four layers of jute (J1) mat were used. Other composites are an alternating arrangement of these two woven mats. i.e. AJ1, AJ2, and AJ3 respectively which are shown respectively, in Table .2 and Fig. 3. Fig. 4 depicts the arrangement of jute and aloe vera mat with fibre volume fraction.

2.3. Flexural properties

To study the flexural strength (σ_f) and flexural modulus (E_f) of the composites, a three-point bending test was performed using the Zwick/Roell universal testing machine with a flexural set up in accordance with the ASTMD-790-03 standard [71,72] and a test speed of 2 mm/min. Five samples were evaluated for each composite type, and the average value is presented. The following equations (1) and (2) were used to compute the flexural strength and flexural modulus. These modulus values were used to calculate theoretical natural frequencies [27].

$$\sigma_f = \frac{3FL}{2bd^2} \tag{1}$$

Table 2
Thickness and fibre Volume fraction of Hybrid and Non-Hybrid composites (A - Aloe vera and J - Jute).

Symbols	Materials	Layer Arrangement	Avg Thickness mm	Fibre Volume Percentage			Weight Ratio
				Aloe vera (Va)	Jute (Vj)	Va + Vj	
PR	Polyester Resin	Resin	3.4			–	
A1	Non-Hybrid	A/A/A/A	3.6	36	0	36	1:0
AJ1	Hybrid	A/J/J/J	3.4	9	22	31	0.239:0.253
AJ2	Hybrid	J/A/J/J	3.4	9	22	31	0.239:0.253
AJ3	Hybrid	J/J/A/J	3.4	9	22	31	0.239:0.253
J1	Non-Hybrid	J/J/J/J	3.5	0	32	32	0:1

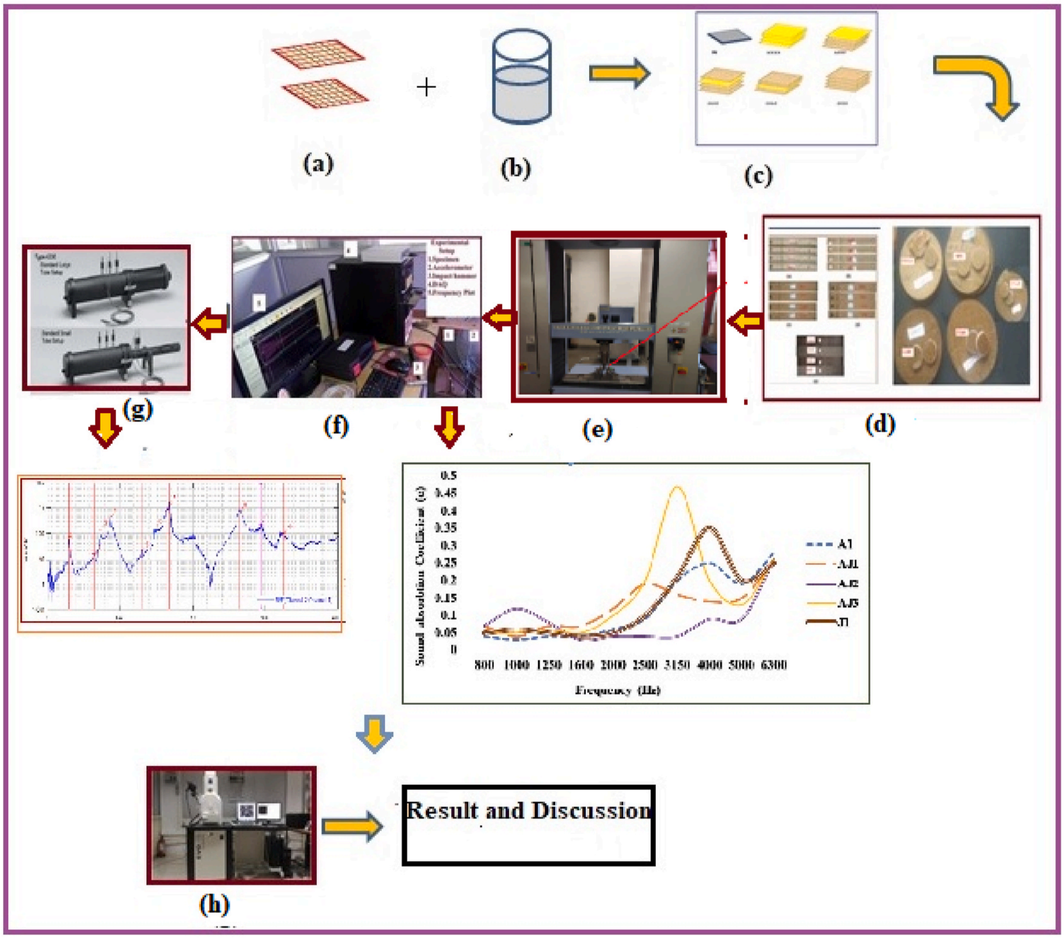

Fig. .1. Method of research work (a) Woven mat (b) Resin (c)Laminate (d) Specimens (e) Flexural Test(f) Vibration Test (g) Acoustic Test (h) Fractrographic image using SEM.

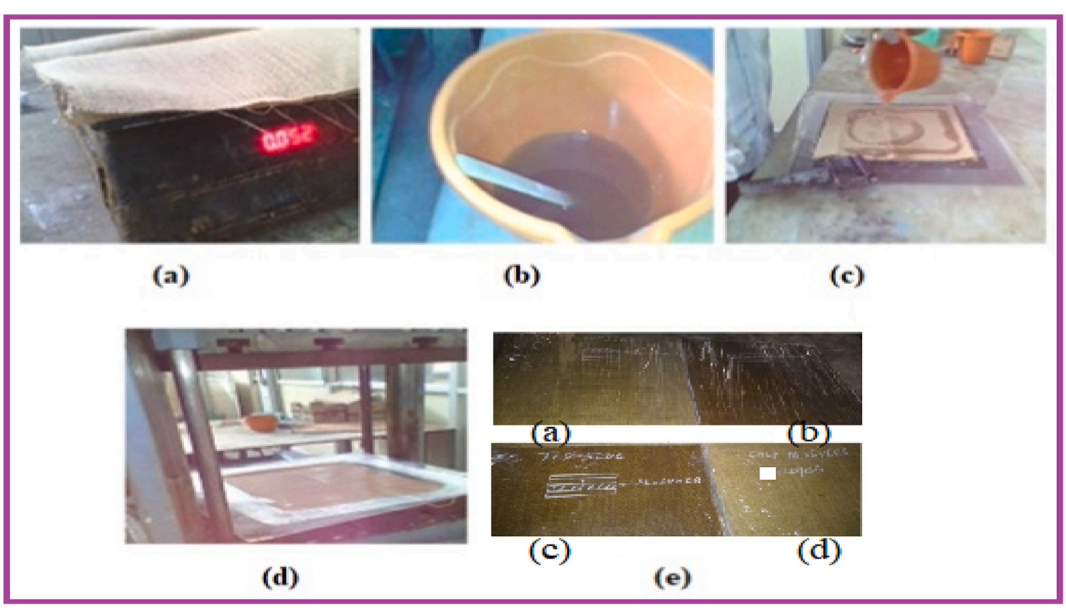

Fig. 2. Fabrication of Composites (a) Weighing of woven mat (b) Resin Preparation (c)Applying the resin to woven mat (d) Compression molding machine (e) all type of composites.

$$\mathbf{E_f} = \frac{\mathbf{L^3 m}}{\mathbf{4bd^3}} \tag{2}$$

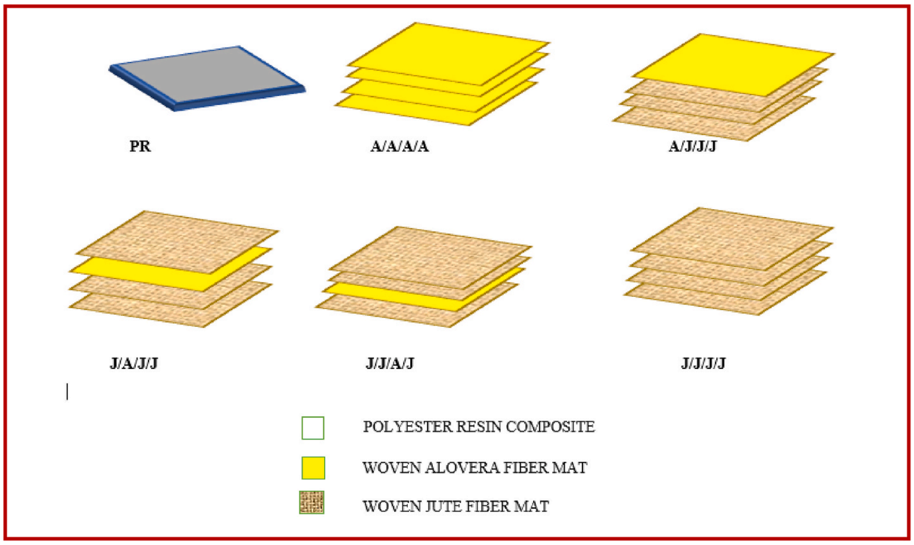

Fig. 3. Stacking arrangement of woven Jute and woven Ale vera plies.

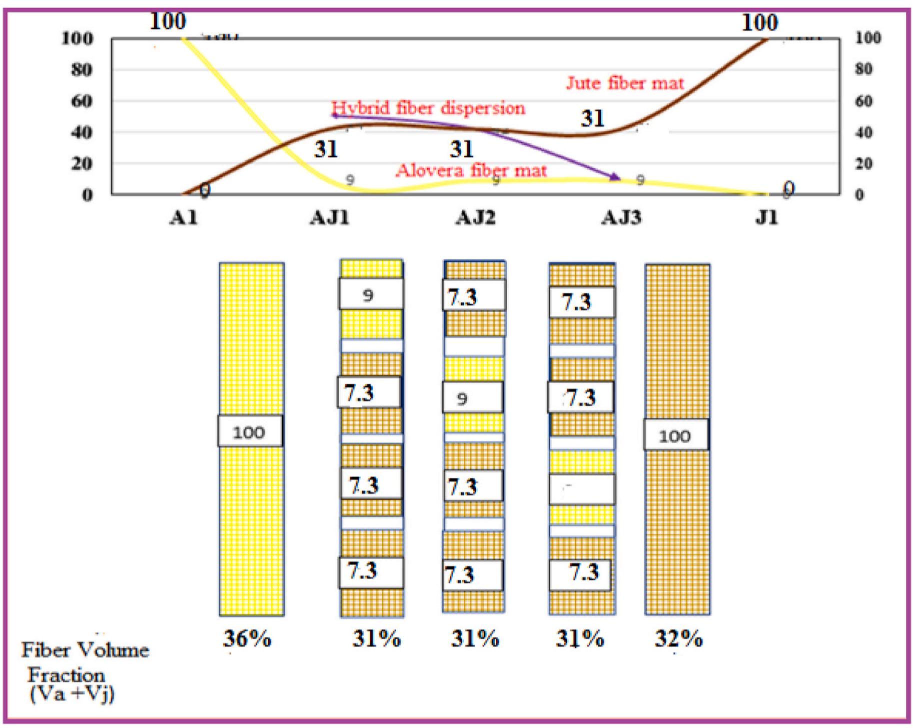

Fig. 4. Arrangement of jute and aloe vera mat with fibre volume fraction [33].

2.4. Free vibration test

It is crucial to know a structure's response in advance and to take the appropriate actions to control structural vibration and its amplitude when designing a structure because almost all structural components are subjected to dynamic loading during their working lives.The free vibration test was carried out in cantilever type with a specimen size of 250 × 25 × 3 mm^3. The accelerometer 8778A500sp was fixed at one point on the cantilever, and impulses were delivered at predetermined points using the impulse hammer (Model 1H-01). The accelerometer and impact hammer output data were saved using the data acquisition software NI-9233. The DewSoft 7.1.1 software was used to convert time signals using the fast Fourier transform. The modal identification function, which shows the peaks of natural frequencies, was generated using curve fitting techniques. The amplitude vs. frequency and acceleration vs. time graphs were used to calculate the natural frequency and damping ratio. The damping ratio (ζ) was calculated using the logarithmic decrement formula, which is shown in the below equation

$$\xi = \frac{1}{2\pi j} \ln \frac{Xi}{Xi + j} \tag{3}$$

where $x_i$was the peak acceleration of the ith peak and $x_{i+j}$was the peak acceleration of the peak j cycles after i^{th}peak. Fig. 5 represents the experimental setup for the free vibration test.

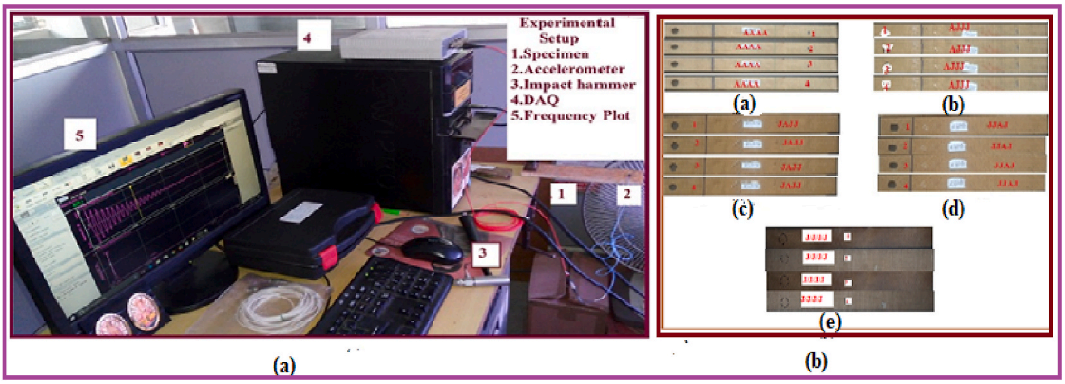

Fig. 5. (a) Free vibration experimental set up (b) Composite specimens for the free vibration test set up.

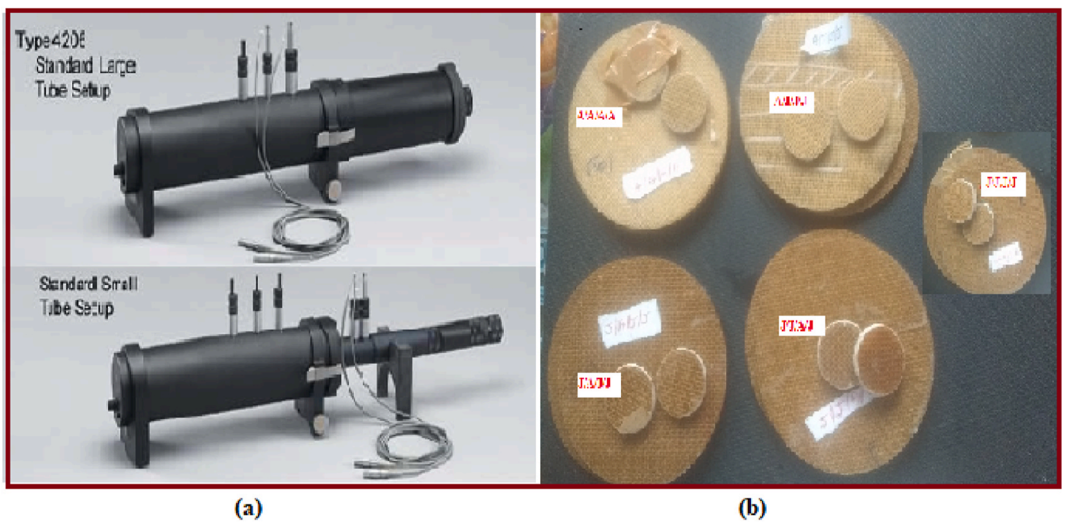

Fig. 6(a). Experimental setup (b) Specimens for Acoustic studies.

2.5. Theoretical modal analysis

The theoretical natural frequency of a cantilever beam was calculated using the Euler-Bernoulli formula, given in equation (4) [28].

$$\omega_1 = (\beta\, L)2\sqrt{\frac{EI}{\rho A L^4}}\,{}^{\mathrm{rad}}/{}^{\mathrm{sec}} \tag{4}$$

where E = Modulus of the beam in MPa,

I = Area Moment of Inertia in mm^{4},

ρ = Density of composites in kg/mm^3,

A = Cross sectional area of the cantilever beam in mm^2 and.

L = Length of the beam in mm.

β = Determined from the boundary conditions. ($\beta = 1.875^2$ &4.694^2).

2.6. Acoustic study by impedance tube method

The measurement was based on a two-microphone transfer-function approach for horizontally mounted samples, according to the ISO 10534-2 [73], ASTM E1050 [74] and ASTM E2611 – 17 standard [75] respectively. The experimental was conducted using Bruel and Kjaer, Denmark, impedance tube setup. The frequency range used to measure sound absorption was 63–6300 Hz. There were four samples made, each having a diameter of 99.5 mm and 29.5 mm respectively. with thickness of 3 mm. The experimental setup and test samples are depicted in Fig. 6 (a) and (b). The experiment was conducted at PSGTECH, COE INDUTECH in Coimbatore, India.

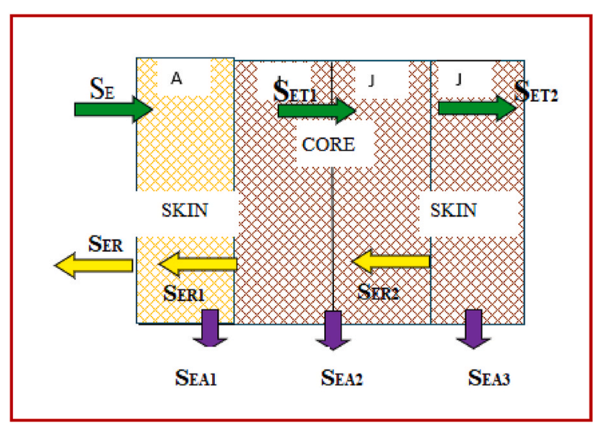

Fig. 7. Mechanisms of sound absorption in two microphone method as per ISO 10534 [72] and, ASTM E1050 [73].

2.7. Mechanism of sound energy (S_E) absorption

Fig. 7 shows the different sound absorption (**S_A**) mechanisms of hybrid composite material. When sound energy impacts on the surface of the composites, some amount of sound energy is reflected (S_{ER}) by the skin surface of the composites and, some amount of sound energy is

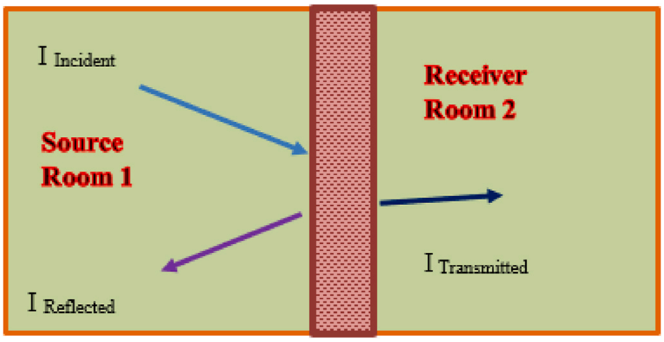

Fig. 8. Mechanism of sound transmissionloss

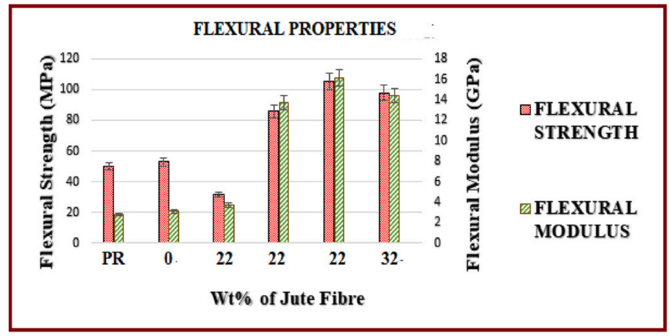

Fig. 9. Flexural properties of Ale vera/Jute polyester composites.

absorbed (S_{EA}) by the surface by thermal exchange, viscous resistance, and damping of micro fibrils and multi-layered cell wall structures in the fibres. Partial amount of sound energy is transmitted ($\mathbf{S_{ET}}$) through skin layer of the composites, remaining part of the energy is reflected by skin-core interface layer. The thermal damping, visco-inertial and multilayer cell wall damping, and air particle movement through micro pores all contribute to the dissipation of sound energy in hybrid and non-hybrid cores. The remaining acoustic energy was absorbed, reflected and transmitted by the skin bottom layer of the composites [29].

2.8. Theoretical predication of sound absorption properties of natural fibres

The theoretical calculated parameters of natural fibres are shown in Table 2, and the Delany-Bazley model [70] and Garai-Pompoli model [70] equations were used to calculate the theoretical sound absorption test, as shown in the following equations.

2.8.1. Delany-Bazley model

$$\boldsymbol{Z}c = \rho_0 C\left[1 + 0.0571\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.754} - j\ 0.087\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.732}\right] \tag{5}$$

$$\boldsymbol{K}c = \frac{\omega}{C}\left[1 + 0.0978\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.7} - j\ 0.189\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.595}\right] \tag{6}$$

2.8.2. Garai-Pompoli model

$$\boldsymbol{Z}c = \rho_0 C\left[1 + 0.078\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.623} - j\ 0.074\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.660}\right] \tag{7}$$

$$\boldsymbol{K}c = \rho_0 C\left[1 + 0.121\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.53} - j\ 0.159\left(\frac{\rho 0\ f}{\sigma}\right)^{-0.571}\right] \tag{8}$$

Where.

Zc - Acoustic Impendence.

Kc - Propagation constant.

ρ_0 and C denotes the density and speed of the air media

σ and f represents the flow resistivity and frequency ($\omega = 2\pi f$).

2.9. Mechanism of sound transmission loss

Sound transmission loss is a measure of a partition's sound insulation value; it is the amount in decibels (dB) by which the magnitude of sound is reduced during transmission through the partition. Fig. 8 depicts the fundamental concept of sound transmission. When sound strikes the partition between two rooms, some of the sound waves are absorbed by the partition, a few are reflected back into the room, and others are transmitted into the adjacent room through the wall [31].

2.10. Fractography study

The ZEISS SUPRA55 scanning electron microscope was used to investigate the morphological behaviour of specimens subjected to vibration and acoustics study. The specimens were made in accordance with the standard, with a uniform surface. The accelerating voltage used in this experiment is 5.00 kV. This research looks at the interfacial bonding of fibre and matrix.

3. Results and discussion

3.1. Flexural properties

The effect of hybridization of aloe vera and jute on the flexural properties of polyester composites was found according to the ASTMD-790 standard [70]. Fig. 9 exhibits the average flexural strength and modulus for various stacking sequences of the reinforcements in the polyester composite. These modulus values are used to find the natural frequency of the woven composite. As shown in Fig. 8, the addition of aloe vera/jute mat to the resin had a significant effect on the strength and modulus of aloe vera/Jute woven mat type composites. The woven reinforcement increases the modulus and makes the woven jute mat stack more resistant to loading [37]. It also evenly distributes stress throughout the composite. The crimp angle and fibre yarn arrangement are responsible for the woven composite's strength and stiffness [39]. The maximum flexural strength was observed for the J/J/A/J (AJ3) type, and the corresponding value was 105 MPa, which was 52% greater than polyester resin. The highest flexural modulus of the hybrid woven composite J/J/A/J (AJ3) is 16.13 GPa. It was discovered to be 83 % higher than neat polyester resin.The fibre count, fibre orientation, fibre strength, and fibre–matrix interfacial bonding all affect the woven composite's flexural strength [53,56]. Beyond from this, a composite material's weave type significantly affects its improved qualities. The conclusion drawn from the data is that, under flexural loading, no specimen entirely fractures at the maximum force. These results from the way that continuous long fibre strands and weave type affect the flexural properties of sandwich composites. also from this finding suggests that the extreme outer layer strength, which establishes the composite material's flexural values, affects the sandwich composite material's flexural strength [58].The most important factor impacting the tensile, flexural, and impact strength models is the fibre volume fraction in the fibre direction, which is crucial in enhancing the mechanical properties of the composites [69].In addition, the long continuous fibres in the woven fibre mat have superior load-bearing capabilities than the short discontinuous fibres in the chopped strand mat. The location of the resin-rich area and the fibre orientation have a significant impact on the flexural strength values. However, the weave architecture of the woven fabric reinforced hybrid composite, which affects the in plane properties of the fabric mat, is primarily responsible for the minimal increase in flexural strength [70].

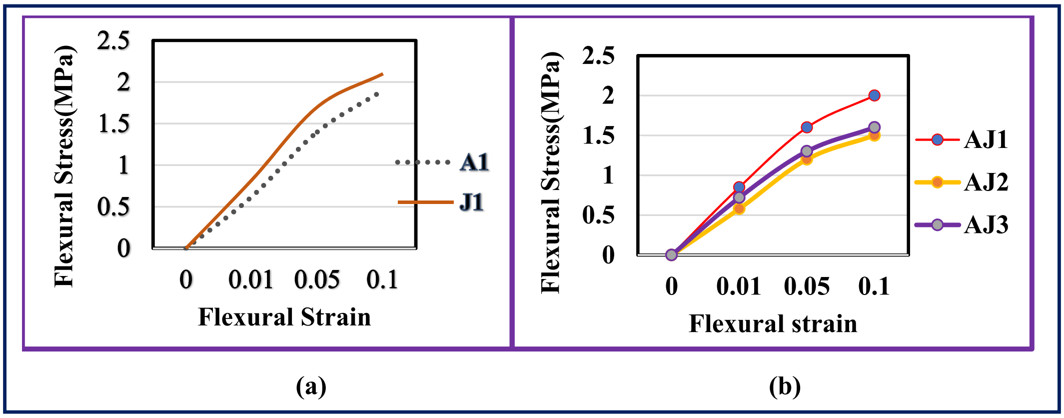

Fig. 10. Stress strain characteristics of (a)Non hybrid Ale vera - Polyester and Jute - Polyester composites (b)Hybrid of Jute -Ale vera - Polyester composites.

3.2. Strength and stiffness improvement

Flexural test experiments were conducted for non-hybrid Jute-Polyester, Aloe vera-Polyester, and hybrid jute-Aloe vera-Polyester composite laminates, The layer arrangement are shown in Table 2.The ratio of hybrid laminate's flexural strength (T) and flexural modulus (E) with respect to non-hybrid Aloe vera/polyester strength (T_A) and flexural modulus (E_A) respectively, is also shown. The average flexural strength of plain aloe vera/polyester resin (A1) laminates was 53 MPa. When 42% jute fibres by volume is added to AJ1, the strength increases by 39%–50%. But the 42% introduction of jute fibre in the layering arrangement of AJ1 type strength is reduced to 40%, which is 31.54 MPa. In other words, changing the plie arrangement (AJ2, AJ3) increases the composite's flexural strength by 1.62 and 2 folds, respectively. A similar trend is obtained for flexural modulus, where around 16%–81% increased by the addition of 42% of the volume fraction of jute fibre. It was observed from the experiments that the flexural strength and modulus of the composite specimen AJ1 are less than those of the specimens AJ2 and AJ3. The flexural values significantly differ for the same fibre fraction but with different fibre stacking layouts. AJ3 hybrid laminate is stronger than AJ2 and AJ1 hybrid laminates. This discussion clearly shows that the hybrid composite strength is affected by interlayer fibres having dissimilar failure strains [33,50]. The microfibrillar angle is the angle formed by the cellulose fibrils and the axis of the fibre's cell in the secondary wall (S2) Lower microfibrillar angle increases tensile and flexural strength and provides higher stiffness along the fibre path [48,57].

3.3. Constitutive behaviour

The constitutive behaviour of composites is used to describe the material's responses to various mechanical and thermal loading conditions, as well as the stress-strain relationships that are used to formulate the governing equations [14]. The addition of aloe vera fibres to the composite changed the overall constitutive relationships. Aloe vera - polyester, unlike jute - polyester, has significant non-linear stress-strain characteristics (Fig. 10a). This nonlinearity is caused by the natural fibre constituents' nonlinear flexural behaviour, which is caused by defects or dislocations in the fibres [46and47]. The addition of aloe vera as reinforcement, changes the linear stress-strain behaviour of jute fibre composite as evident from Fig. 10b.

3.4. Free vibration test (FVT)

The free vibration test (FVT) was used to determine the experimental natural frequency for all the types of hybrid woven composites in the cantilever mode. The experimental natural frequency was determined using the free vibration test (FVT), which was performed under cantilever mode on all three types of hybrid woven composites and two types of non-hybrid woven composites.The frequency response function is the frequency domain representation of the measured time domain data. This displays the number of peaks that exist at the systems' resonance frequencies. These peaks occur at frequencies where the time response is observed to give the greatest reaction in relation to the input excitation's oscillation rate [69]. Fig. 11 depicts a sample plot of frequency vs. time for the J/J/A/J (AJ3) composite. The peaks in the frequency vs. time plot show the mode I, mode II and mode III natural frequencies, respectively. Table 3 shows the comparative natural frequencies of different types of composites under mode I, II and III based on experimental and analytical findings. Further, from the results, it is evident that the maximum value of natural frequency is obtained from the JJAJ (AJ3) of composite, i.e. 157 Hz, 326.Hz and 370 Hz under Mode I, II and III respectively. This is due to good interlacing of fibres in weft and warp directions [37,38]. The natural frequency of JJAJ is 84% higher than AAAA, 82.16% higher than AJJJ and 88.53% higher than JAJJ at Mode I, and 55.82 %, 43.86 and 62.57 respectively, at Mode II. Similarly, 2.63 %, 24.64 % lesser frequency & 10% higher frequency at Mode III respectively. The experimentally determined values are compared with

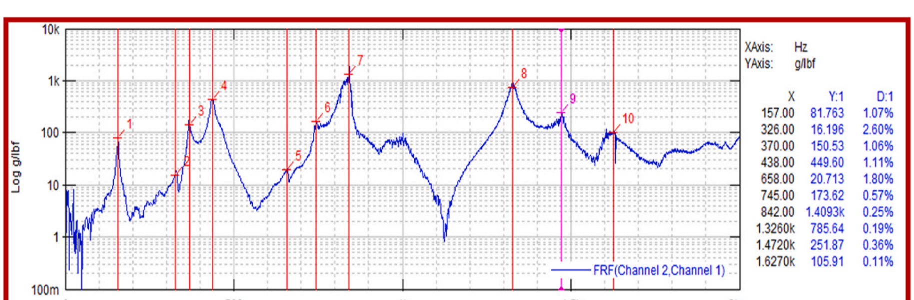

Fig. 11. Frequency Vs Time Plot of JJAJ (AJ3) Type Hybrid woven Composite.

Table 3
Experimental and Theoretical Natural Frequency and Damping factor of the Composites.

Type of Specimens	Natural Frequencies (Hz) Experimental			Natural Frequencies(Hz) Theoretical			Damping Factor (ξ)		
	Mode I	Mode II	Mode III	ModeI	Mode II	Mode III	Mode I	Mode II	Mode III
PR	13.43	119.6	390.6	20.75	121.5	221.3	0.0161	0.0269	0.0160
A1	25	144	380	20.07	125.79	352.26	0.0829	0.0278	0.0154
AJ1	20	162	361	21.99	137.80	385.88	0.0364	0.0284	0.0154
AJ2	18	122	333	22.80	142.91	400.19	0.0107	0.0260	0.0106
AJ3	157	326	370	128.62	279.39	502.36	0.0161	0.0269	0.0160
J1	32.96	231.9	659.2	28.15	176.46	494.2	0.0333	0.0273	0.0315

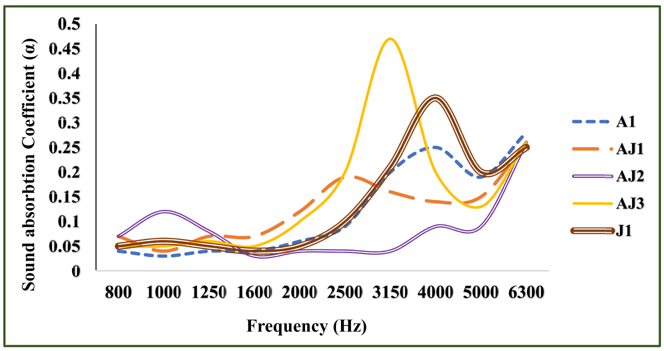

Fig. 12. Sound absorption characteristics of composites.

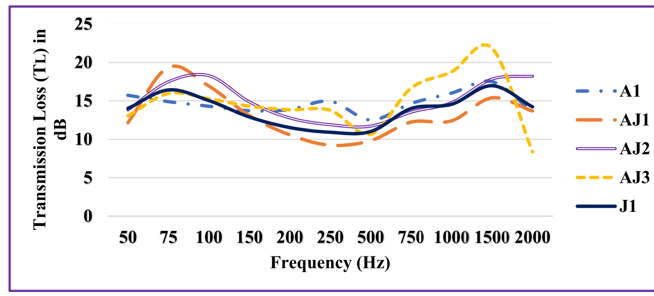

Fig. 13. Sound transmission loss of composites.

the theoretical values; both values are closely correlated to each other. JJAJ have higher natural frequency because of the higher void percentage. These voids influence the stiffness and mass of the composite, as well as the interlacements and tows of the woven fibres, which influence the natural frequency of the composites [42, 59]. The addition of jute mat and aloe vera mat in hybrid type has a considerable effect on the natural frequency of the composite.There was a constant difference between the experimental and theoretical findings. It could be because there are not any voids. Additionally, voids lower mass, which causes natural frequencies to migrate upward. To ascertain the net change of natural frequencies, it is therefore necessary to understand the net effect of changes in stiffness and mass based on the void percentage [60]. For the hybrid composites of the AJ3 type, the greatest frequency was observed. In fact, the natural frequency of the composites is affected by an increase in stiffness. However, the natural frequency of the composites is greatly impacted by the change in the type of fibre [69].

The damping ratio (ξ) of the hybrid woven composite was calculated using equation (2). The average damping ratio of all samples is given in Table .3. It was found that the JJAJ (AJ3) had the lowest damping factor. This result shows that the addition of a hybrid woven mat decreases the damping factor due to the absorption of energy that was dissipated during the vibration. The J/J/A/J (AJ3) has a lower damping factor in all three bending modes due to interaction between the fibre and matrix, which occurs due to the resistance of free molecular mobilisation [32]. Hence, the addition of jute mat increases the damping property of composites. Due to the high probability of slippage at the interfaces, the large availability of fibre/matrix interfaces in composites can lead to increased energy dissipation. As a result, the J/J/A/J (AJ3) composite produces the lowest damping value. Furthermore, damping can be affected by changing the layering pattern when using two different fibres [40].

3.5. Influence of addition of hybrid of aloe vera/jute/woven mat/polyester composite

In this investigation, large and small impendence tubes were used to determine the sound absorption properties of the composites. For obtaining the sound absorption coefficient, the larger and smaller tube measurements were combined in the frequency range of 63–6300 Hz. The mechanism by which natural fibres absorb sound has three parts. First, when the sound wave strikes the fibres, the viscous effect between the fibres and air cavities will weaken a portion of the sound energy and convert it into heat. Next, heat transfer between various fibres will occur with constant heat addition, and this process will further dissipate sound energy [30and41] Third, the vibration of air in the bulk materials causes vibration in fibres, which propagate the sound through the air spaces and inside the lumen of natural fibres. The amount of sound absorbed by the specimen is collimated using the absorption coefficient. The plot of sound absorption coefficient vs. frequency for various composites is shown in Fig. 12. Among these composite specimens, J/J/A/J (AJ3) composites have the highest sound absorption value, 0.47 Hz, around 3000 Hz. Which occurs due to The frictional components in composite that offer resistance to the motion of sound waves are the fibres interlocking [61].Excellent results for the absorption of high-frequency sound waves were achieved by the composite porous in nature [62]. The composite J/A/J/J (AJ2) has the lowest sound absorption coefficient of all the materials at all frequencies.The successful localization of the incoming sound wave within the structure is attained by the distributions of sound pressure and intensity within the composite [54,55]. Fig. 11 shows that, at low frequencies, all samples have very low and identical coefficients. This is because lower frequencies see a decrease in sound energy dissipation. In contrast to those at 800–2000 Hz, the rise in the sound absorption coefficient was more pronounced between 2500 and 6300 Hz [64]. Higher fibre volume percentages in composites allow for improved absorption. Furthermore, AJ3 composite has a better sound absorption rate than other composites. It is also likely that as the fibre content increases, composite materials become more compressed, and sound waves travel a greater distance along the thickness [65].The higher flow resistance of the woven mat is one of the reasons for the AJ3 Composite's higher sound absorption coefficient [66].

3.6. Transmission loss (TL)

The coefficient of absorbency (α) indicates the ability to absorb acoustic energy, whereas sound transmission loss refers to the ability to reflect or block sound [64]. Fig. 13 shows the variation of transmission

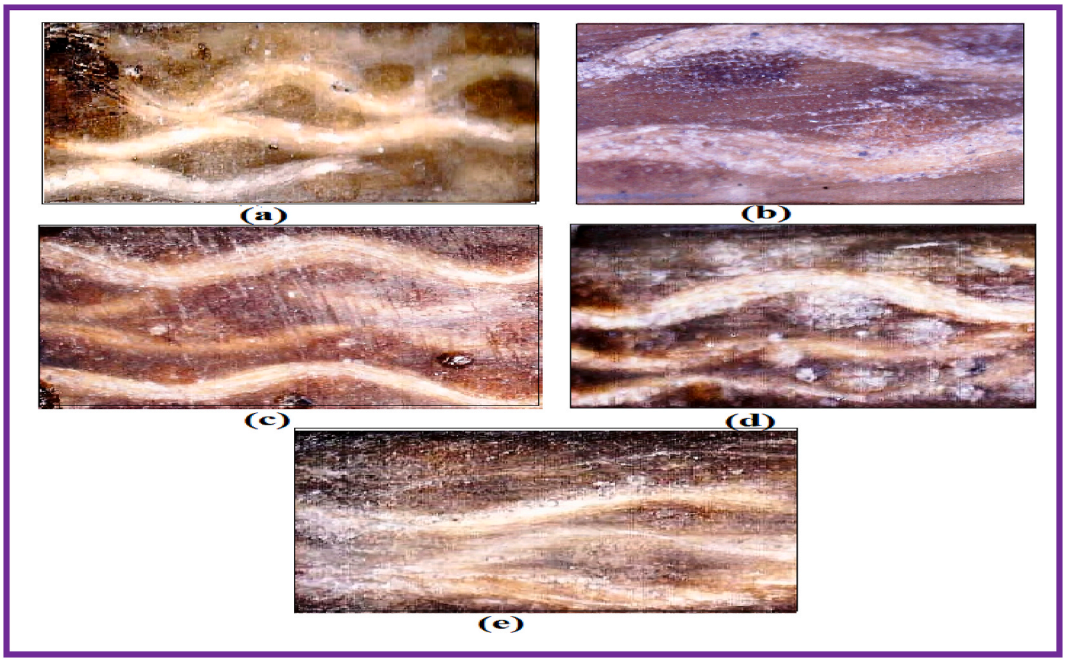

Fig. 14. Micrograph of Jute and Ale vera hybrid composites.

loss with respect to frequency in the 100-mm-diameter impedance tube of 3-mm-thick samples. The result shows three peaks in the curve for all composites that have a maximum transmission loss. The first peak values obtained for neat PR and A/A/A/A, A/J/J/J, J/A/J/J, J/J/A/J, and J/J/J/J composites are 14.02, 15.72, 22.15, 23.05, 16.8, and 18.02 dB, respectively. The second peak values obtained are as follows: 13.52, 19.49, 15.39, 16.83, 18.85, and 16.97 dB. The frequency range is 50–75 Hz for the first peak and 1500 Hz for the second peak. The Transmission loss of A/A/A/A, A/J/J/J, J/A/J/J, J/J/A/J, and J/J/J/J composites is higher than the PR of 31%, 12%, 20%, 28%, and 20%, respectively. This indicates that the addition of woven mats had a positive effect. From Fig. 13, the point in the curve is seen at 400–500 Hz with a transmission loss of 9–11 dB. This point shows the minimum possible transmission loss throughout the frequency range, where the noise level is at its maximum. The improvement in transmission loss is due to the addition of woven mat, which further increases the transmission loss to 19.84 dB for J/J/A/J due to the increased density of the composites. This also indicates that the sound waves travelled a longer duration in the thicker sample [43and44]. Fatima and Mohanty [45] found similar results for transmission loss in their investigation of jute/felt reinforced with latex type composites. Maximum sound transmission loss occurs at higher frequencies. It has been shown that natural fibres have less of an impact on sound absorption at low frequencies. The wavelength of the sound waves is shorter at high frequencies than the thickness of the substance that absorbs sound. Therefore, the material has the ability to lessen the incident sound wave's energy. However, the wavelength of the sound wave is much larger than the material's thickness at low frequencies [63]. The Sound transmission loss of samples shows a growing tendency with frequency increase for greater transmission loss at full frequencies. It is likely that the superior sound-blocking performance of woven Jute mat outer layers contributes to the enhanced transmission behavior of laminates when compared to alternative options.Their natural porous structure due to lumens, volume fraction, and lower resistance might contribute more transmission loss at higher frequencies [64].This value is consistent with some commercial materials, although a soundproof phone station can drop between 15 and 25 dB [67]. They are also compatible with noise barriers, which can block 12 dB at a frequency of 25 Hz [68].

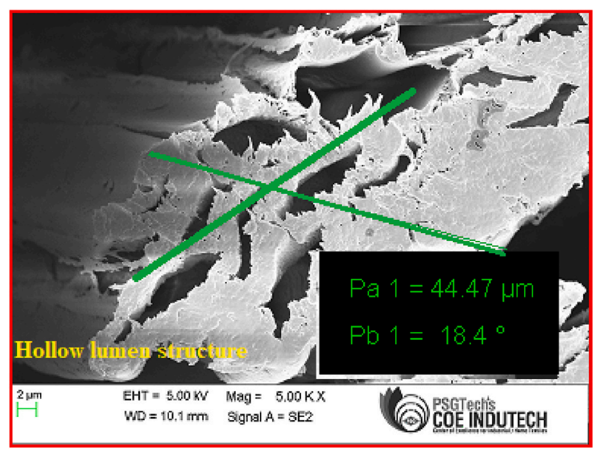

Fig. 15. SEM image of single jute fibre with Hollow lumen structure.

3.7. Fractography study

Jute fibres in the composite have an effect on overall constitutive relationships. Aloe vera/polyester, unlike jute/polyester, has significant non-linear stress-strain properties. This nonlinearity is caused by the nonlinear flexural behaviour of natural fibre constituents, which is caused by fibre faults or dislocations [33]. The amount by which hybridization with jute fibres has a significant effect on the overall non-linearity of the resultant composites. When single jute polyester plies are interspersed or distributed amongst Aloe vera plies in AJ2, there is a greater departure from linear behaviour for the same jute fibre volume fraction as when jute plies are blocked in hybrid laminates (AJ1-AJ3).Fig. 14 depicts the micrograph of jute and aloe vera fibre composites.

The contrast between jute and Aloe vera fibre in hybrid is studied by Optical micrograph which has 10x magnification which is shown in Fig. 13and fracture surfaces are examined by SEM images. SEM images are used to analyse the interfacial adhesion of composites. Fig. 16a and16b show the matrix crack and better fibre matrix adhesion. Fig. 16c reveals the warp and weft directions of the fibre weaving. The natural

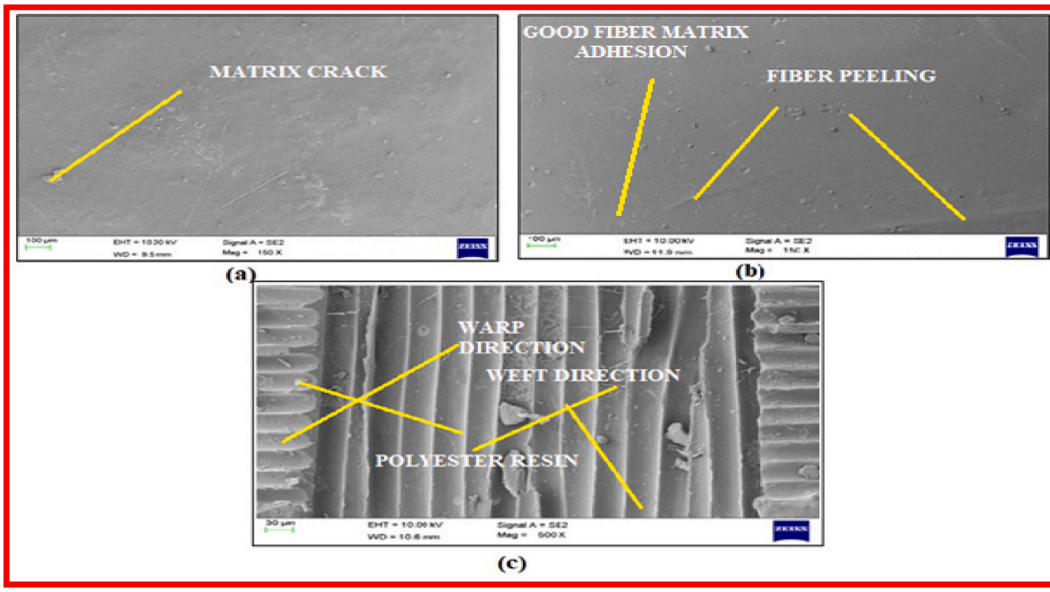

Fig. 16. SEM image of JJAJ (AJ3) type of composites.

fibre's surface irregularity, viscosity of resin, and porous nature create a mechanical interlocking mechanism that increases the fibre-matrix interfacial shear strength [33].Fig. 15 shows the single jute fibre with hollow lumen structure.

4. Conclusions

In the current study, hybrid jute-aloe vera woven mat composites that have a tendency to strengthen natural fibre reinforced composites are compared to nonhybrid jute-ale vera woven mat composites. Flexural characteristics of different stacking patterns of jute-aloe vera hybrid arrangements were observed, as were notable increases in strength and stiffness. The strength and stiffness of the composite are impacted by the different failure strains of the interlayer fibres. Compared to the hybrid composites AJ2 and AJ1, the AJ3 (J/J/A/J) has a higher strength.

The JJAJ (AJ3) type of stacking configuration in the fabric reinforcement is found to provide better flexural and vibration characteristics, i.e., higher natural frequencies and the lowest damping factors in all modes. According to the findings of the acoustic study, the JJAJ (AJ3) type has a higher sound absorption coefficient. Further, the addition of woven mat increases the density of the composites, resulting in a 19.84 dB increase in transmission loss for J/J/A/J (AJ3).The results of the SEM study clearly demonstrate the ply-blocking of numerous hybrid jute and aloe vera fibre interfaces and analyse the interfacial adhesion of the composites.

Declaration of conflict of interests

The authors declare that they have no known competing financialinterestsor personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors acknowledge the funding from Researchers Supporting Project number (RSP2024R355), King Saud University, Riyadh, Saudi Arabia.

References

[1] NehaUppal AsokanPappu, Kumar SornaGowri Vijaya, Thakur Vijay Kumar. Cellulosic fibres-based epoxy composites: from bioresources to a circular economy. Ind Crops Prod 2022;182:114895.

[2] Sargianis JJ, Kim HI. Andres E, Suhr J. Sound and vibration damping characteristics in natural material based sandwich composites. Compos Struct 2013;96:538e44. https://doi.org/10.1016/j.compstruct.2012.09.006.

[3] Van Truong T, Kureemun U, Tan VBC, Lee HP. Study on the structural optimization of a flapping wing micro air vehicle. Struct Multidiscip Optim 2017:1e12.

[4] Koenig Muller D, Thoben K. Acoustical parameters of automotive interiors using hybrid fleeces basing on natural fibres. J Acoust Soc Am 2008;123:3675.

[5] Mittal V, Saini R, Sinha S. Natural fibre-mediated epoxy composites e a review. Composites Part B 2016;99:425e35. 1j.composites.2016.06.051.

[6] Sargianis JJ, Kim H-I, Andres E, Suhr J. Sound and vibration damping characteristics in natural material based sandwich composites. Compos Struct 2013;2013(96):538e44.

[7] Rwawiire S, Tomkova B, Militky J, Jabbar A, Kale BM. Development of a biocomposite based on green epoxy polymer and natural cellulose fabric (bark cloth) for automotive instrument panel applications. Composites Part B 2015;81: 149e57. https://doi.org/10.1016/j.compositesb.2015.06.021.

[8] Qatu Mohamad S, Abdelhamid Mohamed Khalid, Pang Jian, Sheng Gang. Overview of automotive noise and vibration. Int J Vehicle Noise and Vibration 2009;5(1/2): 1. https://doi.org/10.1504/IJVNV.2009.029187.

[9] Huang Z ming. The mechanical properties of composites reinforced with woven and braided fabrics. Composites Sci Technol 2000;60(4):479–98. https://doi.org/10.1016/s0266-3538(99)00148-7.

[10] Halpin J, Jerine K, Whitney J. The laminate analogy for 2 and 3 dimensional composite materials. J Compos Mater 1971;5(1):36–49.

[11] Prabu K, Rajamurugan G, Aravindraj S, Edwin Sudhagar P. Vibration and wear characteristics of ale vera/Flax/Hemp woven fibre epoxy composite reinforced with wire mesh and BaSO4. J of NatFib 2020;2020:1–17.

[12] Kumar KP, Sekaran ASJ. Some natural fibres used in polymer composites and their extraction processes: A review. JReinfPlast Comp. 2014;33(20):1879–92. https://doi.org/10.1177/0731684414548612.

[13] Rajkumar DR, Santhy K, Padmanaban KP. Influence of mechanical properties on modal analysis of natural fibre reinforced laminated composite trapezoidal plates. J NatFib 2020:1–17. https://doi.org/10.1080/15440478.2020.172423.

[14] Evaran S. Investigation of effects of fibre orientation angles on deflection behavior of cantilever laminated composite square plates. J Polytech 2020;23(3):633–9.

[15] XiaoningTang,XianshengZhang, XingminZhuang,HuipingZhang, XiongYan,Sound absorption properties of nonwoven fabric based multi-layer composites 201840, 5 2012-2018 https://doi.org/10.1002/pc.24981.

[16] Prakash Saravanan K& C. Study of acoustic properties of chicken feather fibre (CFF) and its hybrid composites. J NatFib 2019;2019. https://doi.org/10.1080/15440478.2019.1629560.

[17] Jadhav Malawade MG. Investigation of the acoustic performance of bagasse. J mat res tech 2020;9(1):882–9. https://doi.org/10.1016/j.jmrt.2019.11.028.

[18] Berardi Umberto, Iannace Gino, Gabriele Maria Di. The acoustic characterization of broom fibres. J NatFib 2017;14(6):858–63.

[19] Gokulkumar S, Thyla P, Prabhu L, Sathish S. Characterization and comparative analysis on mechanical and acoustical properties of camellia sinensis/ AnanasComosus/glass fibre hybrid polymer composites. J NatFib 2019;18(7): 978–94. https://doi.org/10.1080/15440478.2019.167521.

[20] Marichelvam MK, Kandakodeeswaran K, Geetha M. Mechanical and acoustic properties of bagasse – coconut coir based hybrid reinforced composites. J Nat Fibers 2020:1–10. https://doi.org/10.1080/15440478.2020.185414.
[21] Sağlam S, Güzelçimen F, Bingöl D, Özkan UY, Ekici B. An evaluation on acoustic behavior of untreated tree trunks depending on bark physical properties and fibre cell structure. J Nat Fibers 2020:1–15. https://doi.org/10.1080/15440478.2020.1779901.
[22] Hariprasad K, Ravichandran K, Jayaseelan V. T. Muthuramalingam Acoustic and mechanical characterisation of polypropylene composites reinforced by natural fibres for automotive applications. J Mater Res Technol 2020;9(6):14029–35. https://doi.org/10.1016/j.jmrt.2020.09.112. ISSN 2238-7854.
[23] Lee HeowPueh, Ng Benson Mun Pun, Tran AbhishekVishwanathRammohan& Le Quan Ngoc. An investigation of the sound absorption properties of flax/epoxy composites compared with glass/epoxy composites. J of NatFib 2017;2017 14(1): 71–7. https://doi.org/10.1080/15440478.2016.1146643.
[24] Hassan T, Jamshaid H, Mishra R, Khan MQ, Petru M, Tichy M, Muller M. Factors affecting acoustic properties of natural-fibre-based materials and composites. A Review. Text. 2021;1(1):55–85. https://doi.org/10.3390/textiles1010005.
[25] Thakare PA, Kumar N, Ugale VB. Sound transmission loss and flexural strength assessment of hybrid composite reinforced with natural fibres and kevlar. Mater Today Proc 2019. https://doi.org/10.1016/j.matpr.2019.07.754.
[26] Bahl S, Bagha AK, Sehgal S. Experimental investigations into sound transmission loss by different materials at aircraft noise. Mater Today Proc 2021;44:2048–53. https://doi.org/10.1016/j.matpr.2020.12.153.
[27] Kesharwani A, Bedi R, Kumar Bagha A, Bahl S. Experimental study to measure the sound transmission loss of natural fibres at tonal excitations. Mater Today Proc 2020. https://doi.org/10.1016/j.matpr.2020.04.839. 2020 S2214785320334933.
[28] Senthilrajan S, Venkateshwaran N, Naresh K. Parametric study of different fibre parameters and their influence on acoustics and vibration behavior of jute fibre/polyester resin composites. J Nat Fibers 2022. https://doi.org/10.1080/15440478.2022.2085225.
[29] Chandradass J, Kumar MR, Velmurugan R. Effect of nanoclay addition on vibration properties of glass fibre reinforced vinyl ester composites. Mater Lett 2007;61(22): 4385–8. https://doi.org/10.1016/j.matlet.2007.02.009. 2007.
[30] Zhang J, Shen Y, Jiang B, Li Yan. Sound absorption characterization of natural materials and sandwich structure composites. Aerospace 2018;5(3):75–88. https://doi.org/10.3390/aerospace503007.
[31] Senthilrajan S, Venkateshwaran N, Lenin Babu MC, Alavudeen A. Impact of fibre length and surface modification on the acoustic behaviour of jute fibre. ApplAcoust 2021;173:107677. https://doi.org/10.1016/j.apacoust.2020.107677.
[32] Wei-Hong Tan, Lim EA, Chuah HG, Cheng EM, Lam CK. Sound transmission loss of natural fibre panel. Int J Mech Mechatron Eng 2016;16(6):33–42.
[33] Rajesh M, Hameed Sultan M, Uthayakumar M, Jayakrishna K, Md Shah A. Dynamic behaviour of woven bio fibre composite. Bioresources 2018;13(1):1951–60.
[37] Zhong Y, Tran LQN, Kureemun U, Lee HP. Prediction of the mechanical behavior of flax polypropylene composites based on multi-scale finite element analysis. J Mater Sci 2017:1–11. https://doi.org/10.1007/s10853-016-0733-7.
[38] Venkateshwaran N, ElayaPerumal A, ArwinRaj RH. Mechanical and dynamic mechanical analysis of woven banana/epoxy composite. J Polym Environ 2012;20 (2):565–72.
[39] KhizarRouf Nancy L, Denton RichardM. French., Effect of fabric weaves on the dynamic response of two-dimensional woven fabric composites. J Mater Sci 2017; 52(17):10581–91. https://doi.org/10.1007/s10853-017-1183-6.
[40] Rajesh M, Pitchaimani J. Dynamic mechanical and free vibration behavior of natural fibre braided fabric composite: comparison with conventional and knitted fabric composites. Polym Compos 2018;39:2479–89.
[41] Senthil Kumar k, Siva I, Rajini N, WinowlinJappes JT, Amico SC. Layering pattern effects on vibrational behavior of coconut sheath/banana fibre hybrid composite. Mater Des 2016;90:795–803.
[42] Sagartzazu X, Hervella-Nieto Luis, Pagalday JM. Review in sound absorbing materials. Arch Comput Methods Eng 2007;2007(15):311–42. https://doi.org/10.1007/s11831-008-9022-1.
[43] Senthilrajan S, Venkateshwaran. Impact of stacking sequence on vibration damping and viscoelastic behaviour of woven jute sustainable compositesMaterial today proceedings. https://doi.org/10.1016/j.matpr.2023.04.1.69; 2021.
[44] Yashwant SM, Ravindra BI, Siva I. Vibration damping and acoustic characteristics of sisal fibre–reinforced polypropylene composite. Noise.Vib 2018:1–9. https://doi.org/10.1177/0957456518812784.
[45] Naghmouchi I, Espinach FX, Del Rey R. Comparison of the soundproofing characteristics of olive stone filled polypropylene, gypsum boards and wood fibre reinforced polypropylene. CellulChemTechnol 2016;50:411–5.
[46] Fatima S, Mohanty AR. Acoustical and fire-retardant properties of jute composite materials. ApplAcoust 2011;72:108–14.
[47] Hughes M. Defects in natural fibres: their origin, characteristics and impli- cations for natural fibre-reinforced composites. J Mater Sci 2012;47:599e609. https://doi.org/10.1007/s10853-011-6025-3. 2012.
[48] Zhong Y, Tran LQN, Kureemun U, Lee HP. Prediction of the mechanical behavior of flax polypropylene composites based on multi-scale finite element analysis. J Mater Sci 2017;2017:1e11. https://doi.org/10.1007/s10853-016-0733-7.
[49] Alfredo R, SenaNeto Marco AMA, Raiza MPB, Alessandra SF, Tonoli Gustavo HD, Souza Fernanda VD, Mattoso Luiz HC, Marconcini Jose M. Comparative study of 12 pineapple leaf fibre varieties for use as mechanical reinforcement in polymer composites. Ind Crops Prod 2015;64:68–78.
[50] Kretsis G. A review of the tensile, compressive, flexural and shear properties of hybrid fibre-reinforced plastics. Composites 1987;18:13e23. https://doi.org/10.1016/0010-4361(87)90003-6.
[51] Mahmud Sakil, Konlan John, Deicaza Jenny, Li Guoqiang. Coir/glass hybrid fibre reinforced thermoset polymer composite laminates with room-temperature self-healing and shape memory functions. Ind Crops Prod 2023;201:116895.
[52] VimalanandSuthenthiraveerappa&VenkatachalamGopalan. Elastic constants of tapered laminated woven jute/epoxy and woven aloe/epoxy composites under the influence of porosity. J Reinforc Plast Compos 2017;36(19):1453–69.
[53] Balaji AN, Nagarajan KJ. Characterization of alkali treated and untreated new cellulosic fibre from Saharan ale vera cactus leaves. Carbohydr Polym 2017;174: 200–8. https://doi.org/10.1016/j.carbpol.2017.06.065.
[54] NanshaGao Jing Liu, Deng Jie, Chen Dongyang, Huang Qiaogao, Pan Guang. Design and performance of ultra-broadband composite meta-absorber in the 200Hz-20kHz range. J Sound Vib 2024;574. https://doi.org/10.1016/j.jsv.2023.118229.
[55] NanshaGao Hu Yu, Liu Jing, Deng Jie, Huang Qiaogao, Chen Dongyang, Pan Guang. Experimental investigation of composite metamaterial for underwater sound absorption. Appl Acoust 2023;211. https://doi.org/10.1016/j.apacoust.2023.109466.
[56] NanshaGao Zhicheng Zhang, Deng Jie. XinyuGuo , hong HouAcoustic metamaterials for noise reduction. A Review 2022. https://doi.org/10.1002/admt.202100698.
[57] Kumar Gurjar Ashish, Kulkarni Satyabodh M, SharnappaJoladarashi SaleemsabDoddamani. Investigation of mechanical properties of luffa fibre reinforced natural rubber composites: implications of process parameters. J Mater Res Technol 2024;29:4232–44. https://doi.org/10.1016/j.jmrt.2024.02.133.
[58] Suppanucroa N, Nimpaiboon A, Boonchuay K. A. KhamkeawGreen composite sponge of natural rubber reinforced with cellulose filler using alginate as a dispersing agent. J Mater Res Technol 2023;27(August):3119–30. https://doi.org/10.1016/j.jmrt.2023.10.139.
[59] Rajesh M, Singh SP, Pitchaimani J. Mechanical behavior of woven natural fibre fabric composites: effect of weaving architecture, intra-ply hybridization and stacking sequence of fabrics. J Ind Textil 2018;47(5):938–59. https://doi.org/10.1177/1528083716679157.
[60] KhizarRouf Nancy L Denton, Richard M. French Effect of fabric weaves on the dynamic response of two-dimensional woven fabric composites". J Mater Sci 2017; 52:10581–91. https://doi.org/10.1007/s10853-017-1183-6.
[61] Huang H, Talreja R. Effects of void geometry on elastic properties of unidirectional fibre reinforced composites. Compos Sci Technol 2005;65(13):1964–81.
[62] Sakthivel S, Senthil Kumar S, Solomon E, et al. Sound absorbing and insulating properties of natural fibre hybrid composites using sugarcane bagasse and bamboo charcoal. J Eng Fibres and Fabrics 2021;16. https://doi.org/10.1177/15589250211044818.
[63] Shoshani Y. Studies of textile assemblies used for acoustic control. Tech Text Int 1993;3:32–4.
[64] Kesharwani Ankush, Bedi Raman, Kumar Bagha Ashok, Bahl Shashi. Experimental study to measure the sound transmission loss of natural fibres at tonal excitations. Mater Today Proc 2020. https://doi.org/10.1016/j.matpr.2020.04.839. S2214785320334933.
[65] ErdemSELVER. Acoustic properties of hybrid glass/flax and glass/jute composites consisting of different stacking sequences. TekstilveMühendis 2019;26(113): 42–51. 2019.
[66] Jayamani E, Hamdan S, Bakri MKB, Heng SK, Rahman MR, Kakar A. Analysis of natural fibre polymer composites: effects of alkaline treatment on sound absorption. J ReinfPlast Compos 2016;35(9):703–11.
[67] Soltani P, Zerrebini M. The analysis of acoustical characteristics and sound absorption coefficient of woven fabrics. Textil Res J 2021;82(9):875–82.
[68] NetWell. Available from: https://www.controlnoise.com/product/acoustibooth/,.
[69] NetWell. dB-Bloc. Available from: https://www.controlnoise.com/wp-content/uploads/2017/04/dB-BlocSpec2.jpg.
[70] Sathishkumar T, Naveen J, Navaneethakrishnan P, Satheeshkumar S, Rajini N. Characterization of sisal/cotton fibre woven mat reinforced polymer hybrid composites. J Ind Textiles 2016;47(4):429–52. https://doi.org/10.1177/1528083716648764.
[71] Jawaid M, Abdul Khalil HPS, Abu Bakar A. Woven hybrid composites: Tensile and flexural properties of oil palm-woven jute fibres based epoxy composites. Mater Sci Eng: A 2011;528(15):5190–5. https://doi.org/10.1016/j.msea.2011.03.047.
[72] ASTM D790-03 - Standard Test Methods for Flexural properties of unreinforced and reinforced plastics and electrical insulating materials.
[73] ISO 10534-2 1998 Acoustics - determination of sound absorption coefficient and impedance in impedance tubes - Part 2: transfer-function method.
[74] ASTM E1050 1998 Standard test method for impedance and absorption of acoustical material using a tube, two microphones and a digital frequency analysis system.
[75] ASTM E2611 – 17. Standard test method for impedance and transmission loss of acoustical material using a tube, four microphone method.

Further reading

[34] Kureemun U, Ravandi M, Tran LQN, Teo WS, Tay TE, Lee HP. Effects of hybridization and hybrid fibre dispersion on the mechanical properties of woven flax-carbon epoxy at low carbon fibre volume fractions. Compos B Eng 2018;134: 28–38. https://doi.org/10.1016/j.compositesb.2017.09.