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Thermal and acoustic characterization of musa-coir-epoxy based novel hybrid composites for railway coach interior applications

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Abstract

The high-speed railway coaches are ergonomically designed moving entities that provides thermal and acoustic comfort to passengers. These comforts can be achieved by pasting sheets, foams, layers of the composite at roofs, sides, floor, carrying and supporting the ends of the coaches. The thermal and acoustic properties of composite materials change rapidly and can be controlled easily by mixing natural fibers with a matrix volumetrically. One of the composite materials is Musa-coir-epoxy (MCE) based hybrid composite, which meets the requirement of the railway coach application. In the present study, five different compositions of Musa and coir-based hybrid composites have been synthesized by embedding both the fibers into epoxy resin through the hand layup technique. Epoxy resin is employed as a base matrix for adhesives, whereas solidum hydroxide solution is used as liquid drain cleaners to increase the fiber adhesion. MCE composites are characterized for determining the properties of sound absorption coefficient (SAC) and thermal conductivity. This study helps to identify the most suitable MCE hybrid composite for railway coach interior application. The obtained results demonstrate that 30% coir, 10% Musa and 60% epoxy and 20% coir, 20% Musa and 60% epoxy based MCE composite provides the maximum acoustic and thermal comfort respectively.

Keywords

Biodegradable hybrid composites, Natural fibers, Musa-coir-epoxy, Synthesis and characterization, Thermal and acoustic comfort, Railway coach interior application.

1.Introduction

Composite is a type of smart material, which can be produced by incorporating two or more distinct forms of constituent materials into a single material. The composite materials are lighter in weight, stronger in strength and cheaper in cost as compared to the common traditional materials and also give the requisite physical and chemical properties [1]. The two important components of the composites are fiber and matrix. Fibers can be polymers, ceramics, animal feathers and natural plant-based fibers like jute, coir, silk, banana, bamboo fibers. Matrices are the long-lasting paste, which provide advanced bonding between the fibers [2].

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Further, the composition of two or more distinct forms of fibers with a matrix commonly known as the hybrid composites, provide liberty in modifying the properties of the composite materials.

Chavhan and Wankhade [3] have identified hybrid composite as a reinforcement material mixed with various matrices. They found that better thermal and acoustic properties can be achieved by using hybrid composites. There are many engineering and industrial applications such as automobile, aerospace, packaging, infrastructure etc. where hybrid composites are being utilised commercially [4]. Due to the above-mentioned variety of ranges of properties with low investment cost, the composites can be utilised in railway engineering applications specifically in design of rooftop and coach bodies. It is already evident through previous studied that two-component-based hybrid composites such as Musa (extracted from banana) and coir (extracted from coconut) [5] can be utilized for formation of hybrid composite and availed property benefits of two components. So, in the development of high-speed railway, severe noise, vibration and high heat have become major concerns, which are affecting the passengers.

The interior of high-speed railway coaches is designed in such a way that it should provide comfort to the passenger by considering fire resistance, thermally and acoustically stable environment.

Therefore, the present research is an effort towards finding a suitable hybrid composite that exhibits thermally and acoustically stable environmental properties. As per the various available literature (Detailed discussion in chapter 2), there are very few strong evidences regarding single component-based composites that process these properties [6−7]. In the present study, the synthesis and characterization of Musa-coir-epoxy (MCE) based hybrid composite have been carried out to make the foams, layers and other parts of railway coaches such as sides, roof, floors, supporting ends and carrying ends. To check the thermal and acoustic effects of MCE composite, different volumetric compositions of Musa and coir have been considered in the present study for finding the best suited compositions of MCE composite in the view of high-speed railway coach interior applications [8−9]. In the view of detailed study five composites have been synthesized. Different considered volumetric compositions of Musa, coir and epoxy are tabulated in *Table 1*. The full form of each composite's designation has been also described by the *Table 1*.

Table 1 Different composition of MCE composites

Designation		**Composition (% volume)**		
	Full form of the designation	**Musa fiber**	**Coir fiber**	**Epoxy**
CCCC	Coir-coir-coir-coir	0	40	60
BCCC	Banana-coir-coir-coir	10	30	60
BBCC	Banana-banana-coir-coir	20	20	60
BBBC	Banana-banana-banana-coir	30	10	60
BBBB	Banana-banana-banana-banana	40	0	60

Since, the composite is a combination of two or more contents mixed by volumetrically. Their properties can be evaluated through formula used by [7]. For a MCE composite sample, the simple mixture rule is applied are shown by Equation 1 and Equation 2.

$$P_h = P_1V_1 + P_2V_2 \quad (1)$$

$$V_1 + V_2 = 1 \quad (2)$$

Where, Ph represents the property of the hybridized material, property of the first component (P1) and property of the second component (P2) are the attributes of the individual components, respectively, and volumetric fraction of the first component (V1) and volumetric fraction of the second component (V2) are the volumetric percentage of the 1st and 2nd components, respectively [4]) for determining the properties of hybrid composite. The fibre content is a critical parameter in achieving thermal and acoustic comfort in various composites used in various fields. As the volumetric proportion of fiber reinforcement increases, an increase in the sound absorption coefficient (SAC) as well as the thermal conductivity of the composite is observed [8]. *Table 2* shows the typical properties of Musa and coir fibres [1, 10, 11].

Previous research on MCE hybrid composite materials found that the synthesis and characterization of MCE composites performed well in general applications such as roof tiles, floors, partition boards, automobiles, and so on. However, there is a limited amount of research on the synthesis and characterization of MCE composite for high-speed railway coach interior applications.

As a result, the current study aims to analyze the suitable MCE hybrid composite, which is typically synthesised for high-speed railway coach interior applications. The composition of Musa coir fibres was varied in order to determine the much more thermally and acoustically stable material.

The significant proportion of the effort went into the synthesis of MCE composites for correct volumetric proportion and composition. Sample preparation took time as well in order to meet the required testing standard. The obtained results were then thoroughly and deeply studied with previously discovered results in comparison to obtain a better and more accurate analysis and conclusion. To meet and propagate a clear and complete view of MCE composite applications, the entire manuscript has been divided into five chapters. The first section was used to briefly explain the motivation and the motive behind current research through introduction, thorough background studies by literature review in the second section. Current research objective fulfilled using material and its characterization has been explained through third section. The fourth section deals with result, and discussion as a part of summary of extensive research done through the current research activity. Finally, it is concluded in section 5.

Table 2 Properties of Musa and coir fibers

Physical properties	**Musa**	**Coir**	**Chemical properties**	**Musa**	**Coir**
Tensile strengths (MPa)	529-914	220	Moisture (wt %)	10-12	8-10
Modulus of elasticity (GPa)	27-32	6	Cellulose (wt %)	63-65	33-36
Fracture strain (in %)	5.9	15-25	Hemicellulose (wt %)	19	13
Density (gm/cm^3)	1.35	1.25	Lignin (wt %)	5	45

2.Literature review

Simple and hybrid composites having various constituents such as fibers, fiber-metals and fiber with nano-filler particles are reviewed by many researchers. Hybrid composite has shown various engineering applications over conventional materials. Some important applications coined by authors [12−18] of simple and hybrid composites for wide engineering applications are as displayed in *Table 3*.

Table 3 Important application of simple and hybrid composites

Engineering area	**Applications**
Electronic devices	Packaging, switches, pipelines, supercapacitors, and so forth.
Industry of aerospace	Rotor blades, helicopter engine components, rotors, tails, and etc.
Civil engineering	Underlayment tiles, floors, doors and window, rafters, and so forth.
Transportation	Gears, train coach interiors, automobiles, and so forth.
Substances and furnishings used in everyday life	Helmets, bags, electric bikes, decorative items, desks, bath facilities, chairs, showers, and other similar items
Tank of storage	Flour silos, biogas canisters, dryers, post-boxes, and so forth.
Tribological procedure	Bearings, gears, cams, piston rings etc.
4D technology and nano compatibilizers	Sports, piping systems, medical, aerospace, multi wall carbon nanotubes etc.
Food processing	Nano emulsions, liposomes, nano encapsulated etc.
Agricultural production	Nano sprays, fertilizers, bio pesticides, veterinary medicine etc.
Leather industries	Infrared-absorbing, antibacterial, self-cleaning leather etc.

According to Fu et al. [19], the compositions of hybrid composite are a reinforced material which is the integration of two or more reinforced and filler material in a single matrix. The process of making a hybrid composite is known as hybridization. Hybridization reduces water absorption capacity and improves mechanical properties due to the presence of nano-filler, affirmed by Jesthi and Nayak [20]. Balaji et al. [21] have identified that hybridization of zea fiber and coir fiber improves impact, flexural and tensile strength and also the thermal stability of the composites. Li et al. [22] have investigated hybridization of jute and glass fibers. They found that adding jute fiber to the glass fiber made the hybrid composite more thermal, mechanical, and water-absorbing. Bledzki and Gassan [23] observed that the thermal ability of hybrid composite made by sugars, palm yarns, reinforced glass fiber with unsaturated polystyrene hybrid composite increases than the conventional materials. Reinforcement of natural fiber polymer composite has many advantages over the reinforcement of synthetic polymer materials. Natural fiber has many properties such as abundance, rash-free skin, nontoxicity, non-irritating towards eyes or respiratory parts of the human body and non-corrosive. The hydrophilic structure of natural fiber affects overall mechanical and other physical inherited properties [24, 25]. Asim et al. [26] have reported that the age, climate and other factors of the natural fibers control the chemical compositions and physical structure of the composite. Kerni et al. [27] have observed that plant-based natural fiber (e.g., vegetables) are classified into many types which are shown in *Table 4.*

Table 4 Classification of vegetable based natural fibers

Type of natural fiber	**Seed**	**Bast**	**Fruit**	**Leaf**	**Stalk**
Examples	Cotton	Flax, jute	Coir	Pineapple	Wheat, banana

Depending on the requirements, several natural fibers are often used to create hybrid composites. Many hybrid composites based on natural fibers operate under different loading condition such as stationary, moving, structural and non-structural, etc. For high-speed railway coach interior applications, many hybrid composites based on natural fibers have been tested. The interior of the high-speed railway coach is a closed chamber meant for occupant with comfort and can be loaded with various luggage's. As it is known that the high-speed railway coaches are built by considering safety and comfort to the passengers, i.e., the coaches should be fire resistant, noise control and thermally isolated environment inside the coaches. These comforts can be achieved by pasting sheets, foam, layers of composite material at roofs, sides, floor, carrying end and supporting end of the coaches. Wide ranges of applications of the composite materials in railway systems have been mentioned in *Table 5* [28, 29].

Table 5 Application of composite materials in railways

Currently employed composites in railways	**Composites in tomorrow's railways**
Cab ends, internal fittings, lightweight panels, etc.	Body shells, bogies, Wheelsets, pantographs, crashworthy vehicles, freight, etc.

One of the well-known hybrid composite materials is MCE based hybrid composite, which meets the requirement of the railway coach application. MCE hybrid composites can be operated in stationary conditions as noise control, thermal insulating, structural material and filling gap between two surfaces of roofs, sides, floor, carrying end and supporting end of the high-speed railway coaches. *Figure 1* demonstrates a typical high-speed railway bodyshell [30] with a major portion where MCE composite can be used. Musa fiber extracted from the banana tree bark, coir fiber taken from coconut and epoxy is used as a binder. Therefore, this hybrid composite is named as MCE. Chand and Fahim [31] have identified that the Musa fiber is produced from the stems of banana trees and is highly long-lasting. They also found that the fibre is made up of thick wall cell tissues kept together by natural gums. Carlile et al. [32] found that the coir is a fibrous material made up of the thick middle layer (meso carp) of the coconut fruit (Cocos nucifera). Mir et al. [33] studied the abundance, structural and mechanically stable properties of coir and discovered that it can be stretched above the elastic limit without failure due to the presence of helical microfibers.

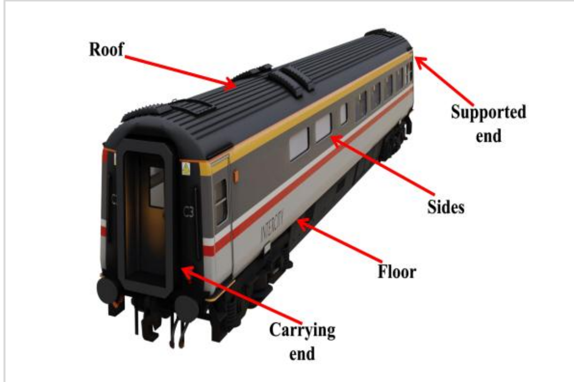


Figure 1 Typical bodyshell of high-speed railway

Chemical properties of natural fibres influence their overall thermal, acoustic, mechanical and other properties. Kumar et al. [34] have investigated hybrid composite by considering natural fibers such as Musa and coir fibers. They identified that the layering pattern of banana-coconut and alkali treatment have positive effects on energy absorption, i.e., damping indication and mechanical efficiency. They observed that natural fibers consist of majorly four components such as cellulose, hemi-cellulose, lignin and moisture. It has also been observed that the cellulose, through its hydrogen bond and various other linkages, gives stiffness and strength to the fibers. Essabir et al. [35] have remarked that the presence of hemicellulose makes the fiber biodegradable, thermal degradable and gives moisture absorption ability. They also identified that lignin has a unique ability, which made the fiber thermally stable at the expense of ultraviolet degradation. Hariprasad et al. [36] investigated the effect of sodium hydroxide (NaOH) chemical treatment (alkali treatment). They observed that the characteristics of a coir banana epoxy hybrid composite, treated with NaOH alkali have higher impact and tensile strength than coir banana epoxy composite that has not been treated. Shalwan and Yousif [37] have investigated the effect of volume fraction, type of treatment and type of natural fibers on composite performance. They found that the mechanical and tribological behaviours are significantly affected by the volume fraction, type of treatment and types of natural fiber. They also found that the chemical treatment by using NaOH was a more effective treatment than other methods for adhering natural fibers to the matrix. Micro level study on chemical bonding of natural fibers have been studied by Bar et al. [38]. They observed that the application of alkali chemical treatment made the outer surface of fiber rough because of the elimination of lignin, hemi-cellulose, wax and oils from the natural fibers, which allows proper fiber packaging.

For railway passenger, the insulation of extreme noise and temperature can be achieved by using natural fibers with adhesives. The noise from the railway exterior sources is primarily transferred into the interior via structural excitation, with no contribution from air excitation [39, 40]. Investigation on high-speed train by Hardy [41] reveals that noise and vibration in confined spaces such as carriage affect the health of passengers. Several research has been conducted to study the impact of interior noise, vibrations, coupled dynamics and mechanism of high-speed railway system [42–46]. According to Li and Ren [47], the efficacy of noise control materials can be determined by noise labels using SAC. They reported that for typical heat insulating material, the thermal conductivity should be less than 0.29 W/mK, compression strength should be higher than 0.3 MPa and nominal density should be higher than 1000 kg/m3. In order to produce symmetrical sound, the contribution of floor, roof, left and right side walls have been investigated by Li et al. [48]. They observed that the generation of sound is more from floor at low speed, while it is more from roof at higher speed (greater than 300 km/h). For various speeds of railway, Zhao et al. [49] have identified that when a low-cost shock proofing or damping measurement devices are employed, the porous sound-absorbing concrete reduces railcar noise. Horikawa et al. [50] reported that around 90% of the noise is generated by interior and exterior sources and around 10% of the noise propagates through a closed section. Wennberg and Stichel [51] have conducted tests on high-speed train for multifunctional and multi-level design strategy composite materials. They used the composite to make glass inner wall, fibrous insulation layer and the load-bearing board of the train. They found that the use of composite fully satisfies the design constraints, such as mechanical properties, stiffness and the structure of the train. They also reported that there is much scope for acoustic and thermal insulating materials in the high-speed railway.

According to a review of the literature on MCE hybrid composite materials, the synthesis and characterization of MCE composite have performed for general applications such as roof tiles, floors, partition boards, automobiles, and so on. However, there is a limited amount of research on the characterization and synthesis of MCE composite for high-speed railway coach interior applications. As a result, the current research aims to determine the best-suited MCE hybrid composite, which is typically synthesised for high-speed railway coach interior applications. The composition of Musa coir fibres was varied in order to determine the most thermally and sonically stable material.

3.Methods

Various techniques can be used to produce hybrid composites and evaluate their performance. The fabrication process of a novel hybrid composite was performed in this current study using two natural fibres and a fixed portion of epoxy by a hand layup technique known as synthesis of MCE composites. The generation of data for conclusive decision-making has begun using the open-source software ilastik. Then, to determine the precise behaviours of these novel hybrid composites, experimental research was carried out. *Figure 2* depicts the various processes of the methods used, from sample preparation to data collection.

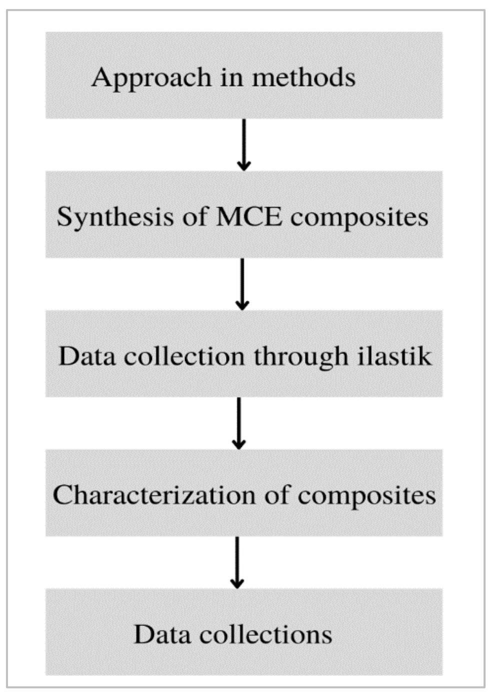


Figure 2 Step by step process used in methods

3.1Synthesis of MCE composite

Before beginning the synthesis process of any composite, it is beneficial to select such materials which fulfil the requirements of the railway coaches. High coefficient of acoustic absorption, lower thermal conductivity, high thermal resistance, high impact strength, high flexural strength and high damping capability are some basic properties required for the synthesis of the composite. These properties can be achieved by using Musa and coir fibers. In the view of railway coach interior application, five MCE composite samples having different compositions of Musa and coir fibers are synthesized by embedding within epoxy resins.

Figure 3 enlightens the step-by-step synthesis process of Musa-coir based reinforced composite. The hand layup technique has been applied to synthesize the composite samples.

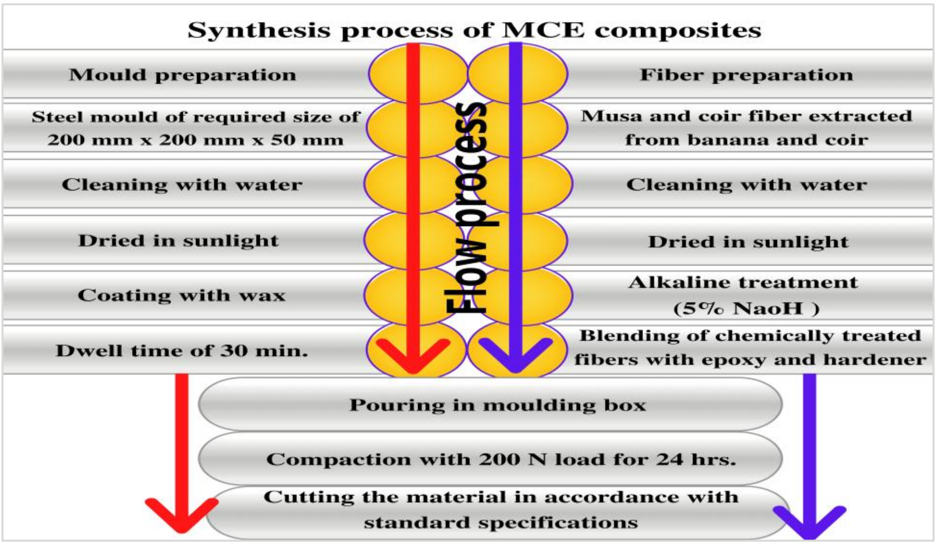
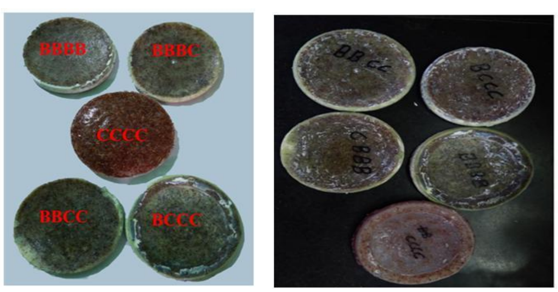


Figure 3 Step by step synthesis process

This technique has been divided into two parts, i.e., mould preparation and fiber preparation. In mould preparation, a mild steel-based moulding box with 200 mm × 200 mm × 50 mm dimension has been selected to fulfil the standard requirements. The moulding box acts as a cover for the fibers, which compresses them and prevents from leakages during compaction. Moulding box has been cleaned with water and has been dried in the sunlight. When the moulding box is completely dry, a layer of wax coat is applied inside the box for easy removal of the compacted composite samples. The dwell time of approximately 30 minutes has been provided to settle the wax coat. In fiber preparation, Musa is extracted from banana tree bark and coir is obtained from the coconut fruit. Musa and coir fiber of 10 mm length are cleaned with water and dried in sunlight to extract the moisture. To increase interfacial adhesion of Musa and coir fibers an alkali chemical treatment is required. For this treatment, coir and Musa fibers have been soaked for 8 hours in 5% NaOH solution. Then these chemically treated fibers are blended with epoxy resin and hardener. An eco-friendly carbon black clear casting epoxy resin has been selected, which provides higher binding strength, excellent chemical and insulating properties. To achieve the desired thickness of composite an N (3-dimethylaminopropyl)-1, 3 propylene diamine hardeners has been utilised as curing agent. To get maximum binding strength the epoxy resin (adhesive) and hardener are blended in a 3:1 ratio. Properties of carbon black clear casting epoxy resin and a typical hardener are shown in *Table 6*. After blending, the achieved material has been poured in moulding box. Then the moulding box has kept under continuous 200 Newtons load condition for 24 hours. After compaction, the composite sample has been taken out from the moulding box and cut it in accordance with standards specifications. All considered compositions of MCE composite are synthesized and the top and bottom view of the samples are shown in *Figure 4(a)* and *(b)* respectively. After synthesis process, the cell (pixel) level classifications of Musa and coir in MCE composite samples are determined by using different methods and are presented in *Figure 5*. A two-dimensional (2D) pixel classifier has been employed using “ilastik”, an open-source software [52]. The different classes of pixels are discriminated by using the pixel features (such as colour, intensity, edge and texture) and their scales (scale factor (σ) value ranges from 0.3 to 10). In this pixel classification process, whole workflow has been assigned by two labels (one for Musa and another for coir fiber) based on pixel features and user annotations considering $\sigma = 0.7$. To get the sharp edges of the imported 2D images of the samples, the Laplacian of Gaussian method is selected and has been illustrated in *Figure 5(a).* Textures of the samples in 2D form are obtained by selecting Hessian of Gaussian eigen value method and reported in *Figure 5(b).* Structure tensor eigen value method as presented in *Figure 5(c)* is selected to get different colours of 2D texture for better view. Gaussian smoothing method is used to get the sharp colour and intensity of the samples, which is illustrated in *Figure 5(d).* To get clear segmentation of Musa and coir fiber in the composite samples, the finite method probabilistic feature view approach has been utilized and is shown in *Figure 5(e).* It has been clear that MCE composite sample CCCC has highest red spot due to coir fibers whereas BBBB has highest green spot due to Musa fibers. Further, the characterizations of these standard composite samples are used to determine the thermal conductivity and SAC.

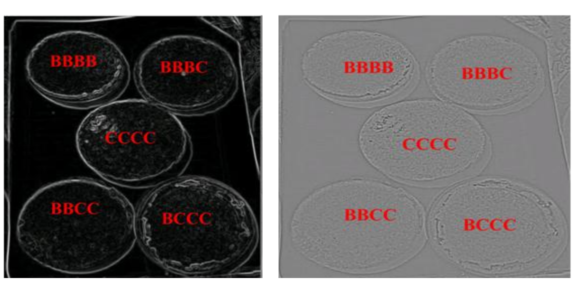
Table 6 Properties of epoxy resin and typical hardener used in this study

Properties of epoxy resin		**Properties of typical hardener**	
Glass transition temperature (°C)	102	Chemical name	N(3-dimethylaminopropyl)-1,3 propylenediamine
Compressive strength (MPa)	83	Colour	Light yellow
Thermal conductivity (W/mk)	0.52	pH	12 (at 20 °C)
Density (gm/cc)	1.07	Boiling point	> 200 °C
Coefficient of thermal expansion (ppm/ °C)	62.53	Density	0.95 g/cubic cm at 25 °C
Tensile strength (MPa)	56	Thermal decomposition	> 200 °C
		Vapour pressure	4 Pascal at 20 °C

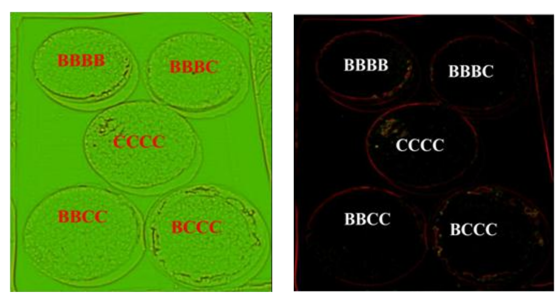


(a) (b)

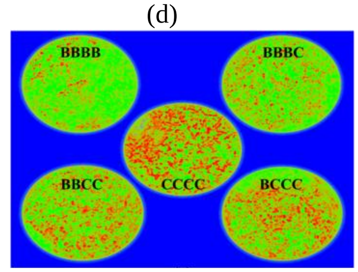
Figure 4 Sample of MCE composite (a) top view (b) bottom view



(a) (b)



(c) (d)



(e)

Figure 5 Different pixel level classifications of MCE composite sample by using (a) Laplacian of Gaussian method (b) Hessian of Gaussian eigen value method (c) structure tensor eigen value method (d) Gaussian smoothing method (e) finite method probabilistic feature approach

3.2Characterization of MCE composite

The characterization of MCE composite is divided into two parts, i.e., measurement of thermal and sound absorption properties.

3.2.1Measurement of thermal properties

To ascertain the thermal properties of MCE composite specimens, the heat flow meter apparatus is used and the schematic diagram is shown in *Figure 6*. The test procedure and essential calibration are done by considering the guidelines given by the American Society for Testing and Materials (ASTM) C 518-76 standards [53, 54]. The measuring procedure of the test apparatus for thermal conductivity is as follows:

- The synthesized sample is kept in the heat flow meter between the hot and cold plates. The edges are properly insulated to minimize the heat loss from the heat flow meter's edges.
- During the test procedure, control the temperature of cold and hot plates, so that the temperature does not vary more than 0.5 % of the temperature difference between the both plates.
- The test procedure should be repeated until the apparatus reaches thermal equilibrium.
- Then, mean temperature and the electromotive force output of the heat flow meter and temperature drop across the samples are noted.
- To obtain a thermal conductivity measurement that is within 1% error, five consecutive observations are required.

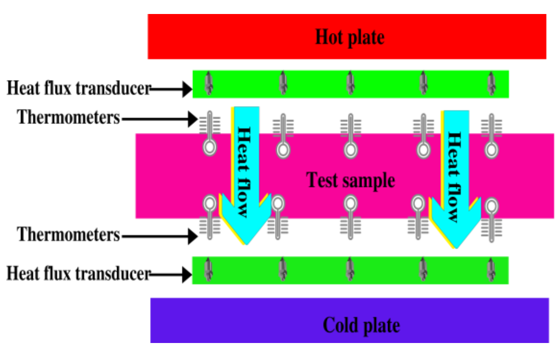


Figure 6 Schematic diagram of heat flow meter apparatus

The thermal conductivity of the MCE composite samples has been calculated by Equation 3.

$$k = S \times e \times \left(\frac{D}{\Delta T}\right) \tag{3}$$

Where k is the thermal conductivity of the sample (W/mK), S is the sensitivity of the heat flow meter (W/m2V), e is heat flow meter output (V), D is the thickness of the sample (m) and ΔT is the temperature difference across the sample (K). As per the standard, the diameter and thickness of the sample are kept as 50 mm and 15 mm respectively. The range of temperature between hot and cold plate is maintained between 225 K and 825 K for successful and reliable results.

3.2.2Measurement of sound absorption properties

To determine the acoustic properties of MCE composite samples, the impedance tube approach has been utilized and the schematic diagram of impedance tube apparatus is shown in *Figure 7*. The test procedure and calibration of the apparatus are conducted in accordance with ASTM E 1050-12 (38) standards [55, 56]. The measuring procedures of the test apparatus for SAC are as follows:

- The sonic tube is used to carry out the test with two microphones, which are fixed over the tube wall. Two microphones have an important role in the SAC calculation. These measure the sound pressure and give sound propagation function.
- In the test procedure, the source generates a specific amount of normal sound wave, which travels through the sonic tube and reaches to the test sample.
- Then, the sound wave approaches to the microphones and data related to sound are recorded in the acoustic analyser. Based on output received from acoustic analyser, calculations for SAC have been carried out. This method has been used because it is convenient and advanced.

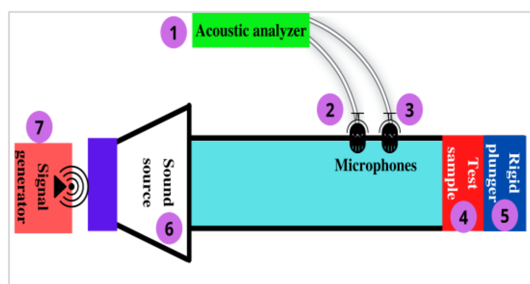


Figure 7 Schematic diagram of impedance tube apparatus

The SAC (α) is the ratio of absorbed acoustic energy ($I_{absorbed} = I_{incident} - I_{reflected}$) by the sample to the acoustic energy incident ($I_{incident}$) on the surface of the sample. The value of SAC lies between 0 and 1. The overall SAC is calculated by averaging SAC values obtained at different frequencies i.e., f = 500, 1000, 1500, 2000, 2500, 3000, 3500 and 4000 Hz. Various labels of SAC as shown in *Table 7* are defined for noise control materials having different ranges of SAC values [56]. The SAC values obtained from the samples are compared with the labels and ranges of SAC.

Table 7 Labels of SAC of noise control material

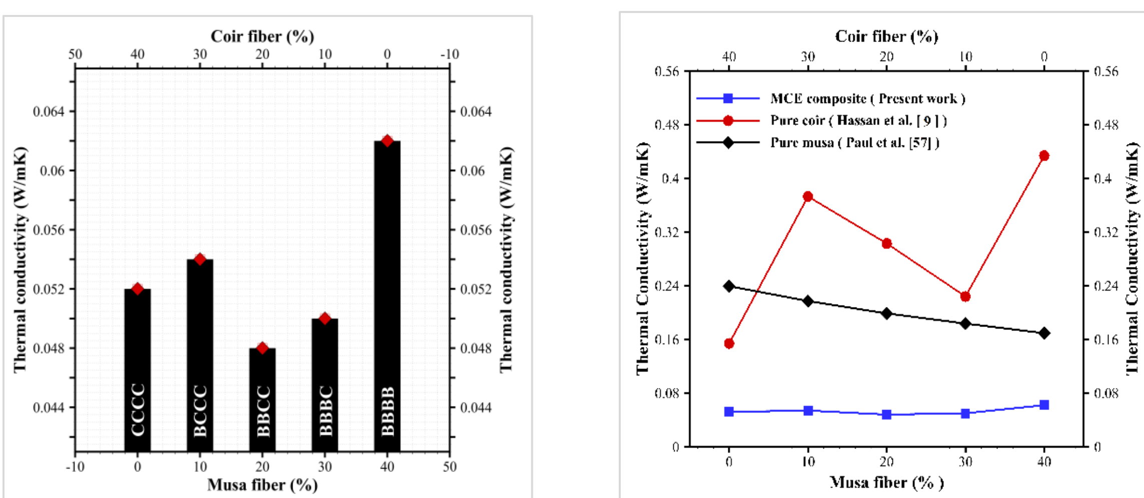
Labels	A	B	C	D	E	F
Range of SAC	0.90 - 1.00	0.80 - 0.85	0.60 - 0.75	0.30 - 0.55	0.15 - 0.25	0.00 - 0.10

4. Results and discussion

After the synthesis of different MCE composite samples, the characterization has been performed to determine the thermal conductivity and sound absorption coefficient. The obtained results of various samples are discussed in two parts i.e., measurement of thermal and acoustic characteristics.

4.1 Measurement of thermal characteristics

The thermal characteristics of experimentally tested MCE composite samples are measured for thermal conductivity. *Figure 8(a)* illustrates the effect of fibre loading on thermal conductivity of MCE composite samples. The fiber loading of MCE composite samples depends on the percentage volumetric composition of Musa, coir and epoxy. The volumetric composition of epoxy has been kept fixed as 60% for all the cases and the volumetric composition of Musa and coir are varied from 0 to 40%. A specific designation has been given to each combination of Musa, coir and epoxy, as reported in *Table 4*. From *Figure 8(a)*, it can be seen that the value of thermal conductivity is minimum for banana-banana-coir-coir (BBCC) (20% Musa and 20% coir) and is maximum for banana-banana-banana-banana (BBBB) (40% Musa and 0% coir). The mixing of Musa and coir fiber in equal proportion yields the lowest thermal conductivity due to lower packing density and disorganized material structure. Hence, the sample BBCC has lowest thermal conductivity, equal to 0.048 W/mK. The sample BBBB has the maximum thermal conductivity as 0.062 W/mK, due to its organized material structure, highest packing density and the lowest possible moisture content after the chemical treatment. Furthermore, the thermal conductivity of all other samples lies between the thermal conductivity of these two samples. To understand the influence of thermal conductivity values of different MCE composite samples, these values have been compared with the thermal conductivity values of pure coir (coir + epoxy) and pure Musa (Musa + epoxy) obtained from Hassan et al. [9] and Paul et al. [57]. *Figure 8(b)* shows the effect of fiber loading on thermal conductivity of pure coir, pure Musa and MCE composite samples. For the 60% volumetric composition of epoxy, it has been found that pure Musa has higher thermal conductivity followed by pure coir and MCE composites. Overall, the pure Musa and pure coir have a higher order of magnitudes of thermal conductivity than all MCE composite samples. As is known that, for better thermal comfort inside the railway coaches the temperature should be minimum. To achieve the minimum temperature inside the coach, the heat transfer from outside to inside should be minimum, for less heat transfer the thermal conductivity of materials of railway bodyshell has to be minimum, since the MCE composite samples possess the lower thermal conductivity, it can be recommended for railway coach interior applications.

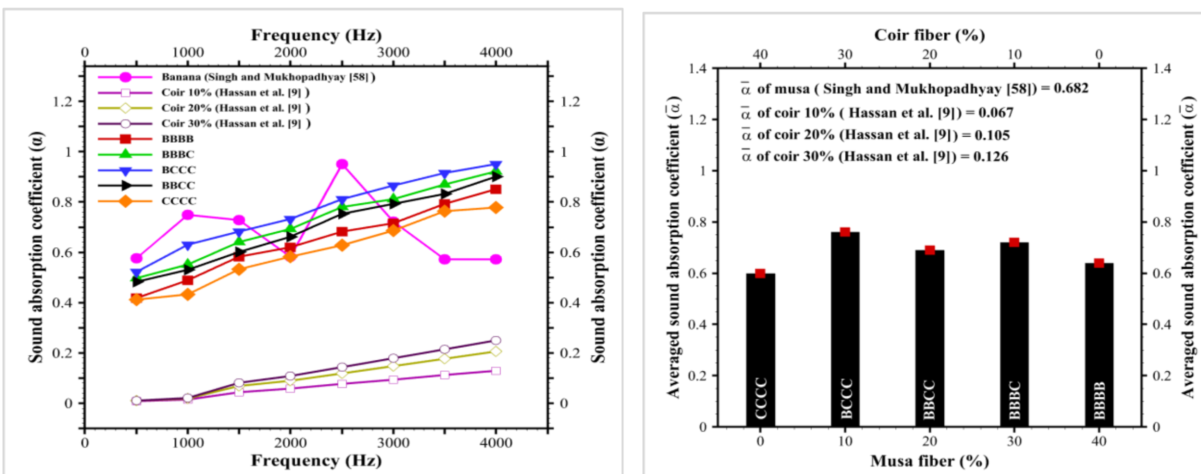


(a) (b)

Figure 8 Effect of fiber loading on thermal conductivity of (a) various MCE composite samples (b) pure coir, pure Musa and MCE composite samples

4.2Measurement of sound absorption characteristics

The sound absorption characteristics of MCE composite samples are measured by SAC. *Figure 9(a)* shows the effect of variation of SAC with change in frequency for pure coir (coir + epoxy) [4], pure Musa (Musa + epoxy) [58] and present MCE composite samples. With increase in frequency, it is observed that the value of SAC increases in the case of pure coir (10%, 20%, 30%) and all MCE composite samples, except for pure Musa. The trend for pure Musa is not uniform with increase in frequency. The magnitudes of SAC are found to be very less for pure coir as compared to pure Musa and all MCE composite samples. *Figure 9(b)* depicts the effect of fiber loading on average SAC of all MCE composite samples. It is observed that the value of averaged SAC is maximum for banana-coir-coir-coir (BCCC) (10% Musa and 30% coir) and the minimum for coir-coir-coir-coir (CCCC) (0% Musa and 40% coir). The higher value of averaged SAC is due to highly disorganized and zig-zag structure of Musa and coir in MCE composite samples. Whereas, the lower value of averaged SAC is because of uniformity in the internal structure of Musa and coir in the samples. It is also found that the averaged SAC values are higher for almost all MCE composite samples than pure Musa and pure coir. As is known that, to get acoustic comfort inside the railway coaches, the higher averaged SAC values are desirable. Hence, to achieve the higher averaged SAC value, the composite should have highly disorganized and zig-zag internal structure. This can be obtained in MCE composite samples. Since, MCE composite samples possess higher averaged SAC value as compared to pure Musa and pure coir, it can be recommended for the railway coach interior applications.



(a) (b)

Figure 9 Variation of (a) sound absorption coefficient with change in frequency for pure coir [40], pure Musa [50] and MCE composite samples (b) fiber loading on averaged sound absorption coefficient of various MCE composite samples

4.3Limitations of present work

The current work is concerned with three-dimensional (3D) hybrid composites, specifically Musa, coir, and epoxy-based composites, where controlled properties can be achieved by using a volumetric fraction of Musa, coir, and epoxy. For effective component binding, 60 percent epoxy is used, which can be increased or decreased, and other component fractions can be investigated at the same time. Due to a lack of funds, hand layup techniques were used in this analysis; however, researchers could use other automated methods of synthesis that have significant effects on material packing as well as SAC and thermal conductivity.

There are numerous other tests such as microscopy (electron/optical), thermal gravimetric analysis, and tensile test data, as well as dynamic mechanical analysis, that can be used to determine the composite's applicability in other applications. The manuscript places a strong emphasis on composite railway coach interior applications. The proposed application is intriguing, so model parts can also be used to evaluate the indicated properties.

A complete list of abbreviations is shown in *Appendix I.*

5. Conclusion and future work

Natural fiber reinforcement hybrid composite with different volumetric fractions of Musa and coir with epoxy has been synthesized and characterized, preferably for the railway coach interior applications. *Table 8* presents a qualitative analysis for various MCE hybrid composite samples. The following conclusions are drawn from the results, in the context of the railway coach interior applications.

In general, the thermal conductivity of any substance indicates how fast heat will flow in a given material. Whereas, SAC of any material shows the ability of the material to absorb the incident energy i.e., sound waves. Good thermal insulating materials must have lower thermal conductivity and good acoustic insulating materials must have higher SAC. Railway bodyshell materials with low thermal conductivity and high SAC are required for the thermal and acoustic comfort inside the railway coaches.

The thermal conductivity of MCE hybrid composite samples ranges from 0.048 to 0.062 W/m-K with a difference of 0.04 between the lowest and highest values. The lowest value of thermal conductivity is obtained for BBCC due to an equal volumetric fraction of natural fibers, i.e., 20% coir and 20% Musa fiber. In comparison to all MCE samples, the thermal conductivity value varies as BBCC < BBBC < CCCC < BCCC < BBBB.

All the samples show good acoustic absorption characteristics. Still, BCCC has reached the category label "B", whereas others lie in the label "C". However, their capacity to absorb sound pressure differs from different SAC values at different frequencies and materials compositions. The averaged SAC of MCE hybrid composite samples ranges from 0.60 to 0.76 and BCCC sample has the highest averaged SAC. In comparison to all MCE composite samples, the overall averaged SAC value varies as BCCC > BBBC > BBCC > BBBB > CCCC. In the view of thermal and acoustic comfort inside the railway coaches BCCC, BBCC and BBBC of MCE composite samples are recommended for railway coach interior applications, as they exhibit the desired lower value of thermal conductivity and a higher value of SAC.

Table 8 Concluding remarks

Designation	**CCCC**	**BCCC**	**BBCC**	**BBBC**	**BBBB**
Full form of designation	**Coir-coir-coir-coir**	**Banana-coir-coir-coir**	**Banana-banana-coir-coir**	**Banana-banana-banana-coir**	**Banana-banana-banana-banana**
MCE hybrid composite (coir + Musa + epoxy)	40% + 0% + 60%	30% + 10% + 60%	20% + 20% + 60%	10% + 30% + 60%	0% + 40% + 60%
Thermal conductivity (k)	0.052	0.054	0.048	0.050	0.062
Recommendation	✓	✓	✓✓	✓	×
Averaged sound absorption coefficient ($\overline{\alpha}$)	0.60	0.76	0.69	0.72	0.64
SAC labels	C	B	C	C	C
Recommendation	×	✓✓	✓	✓	✓

The final remarks on MCE composite can be used to meet similar comfort requirements in the railway, automobile, and space industries. This research can be expanded with various other fillers or constituents so that they can be used in other applications.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Dilbag Singh Mondloe: Conceptualization, investigation, data curation, writing – original draft, writing – review and editing, analysis and interpretation of results. **Aman Khare:** Data collection, conceptualization, draft manuscript preparation. **Harish Kumar Ghritlahre:** Study conception, writing – review and editing, draft manuscript preparation, Guidance. **Gajendra Kumar Agrawal:** Conceptualization, draft manuscript preparation, Guidance. **Hemant Naik:** Conceptualization, draft manuscript preparation, writing – original draft, writing – review and editing, analysis and interpretation of results, guidance.

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Appendix I

S. No.	Abbreviations	Description
1	2D	Two Dimensional
2	4D	Four Dimensional
3	ASTM	American Society for Testing and Materials
4	BBBB	Banana-Banana-Banana-Banana
5	BBBC	Banana-Banana-Banana-Coir
6	BBCC	Banana-Banana-Coir-Coir
7	BCCC	Banana-Coir-Coir-Coir
8	BIS	Bureau of Indian Standards
9	CCCC	Coir-Coir-Coir-Coir
10	D	Thickness of the Sample
11	e	Heat Flow Meter Output
12	f	Frequency
13	$I_{absorbed}$	Energy Absorbed by Surface
14	$I_{incident}$	Energy Incident on Surface
15	$I_{reflected}$	Energy Reflected by Surface
16	k	Thermal Conductivity
17	MCE	Musa-Coir-Epoxy Composite
18	NaOH	Sodium Hydroxide
19	P_h	Property of Hybrid Material
20	P_1	Property of the First Component
21	P_2	Property of the Second Component
22	S	Sensitivity of the Heat Flow Meter
23	SAC	Sound Absorption Coefficient
24	V_1	Volumetric Fraction of the First Component
25	V_2	Volumetric Fraction of the Second Component
26	σ	Scale Factor
27	ΔT	Temperature Difference Across the Sample