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Synthesis and Analysis of Biomass based Green Acoustic Shielding Material

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The accelerating trend of pollution that stands in the world scenario is noise pollution, the data reported by World Health Organization (WHO) in 2018 which invites the challenges for acoustic engineers and architectural designer in kinds of industries. Designing of acoustic shielding material based on biomass has great importance due to its cutting edge scientific mechanism, structure and variety of applications in various fields. *Luffa cyllindrica* waste biomass as indigenously available in the most part of the world posses significant contribution in design of acoustic panel due to its versatile, smart and inbuilt networking structure. The nondestructive ultrasonic pretreatment has been used for surface modification with an alcohol blended tartaric acid. The modification in different functional group of the biomass composition and porous activated structure has been confirmed from FTIR and SEM analysis. The presence of inbuilt networking and perforated structure approaches the ideal value of sound absorption coefficient 0.831 with high insulating heat radiation and zero emission of any green house gas to environment can be potentially used as noise shielding material.

Keywords: Luffa natural fiber, Sound absorption coefficient, Surfactants, Thermal insulation

Introduction

Sound plays a momentous role in the world of human beings within an optimum level. Beyond this level sound is treated as noise which significantly gives rise to sound pollution. With advancement of society noise pollution has become an immerging exigent issue of 21st Century. So the demand of acoustic environment is obligatory for all work sectors and up-to-date digital strategies worldwide. The mechanism of noise control and its principle plays significant role in designing of new variety of eco-friendly acoustic materials for noise free surroundings. This well concept based acoustic materials can only be possible if the intensity of noise is controlled to a required level which is acoustically acceptable by environment. Though there are many varieties of acoustic absorptive materials available, but fibrous, porous and other kind of materials dominates as the effective acoustic materials due to their high efficiency of reduction of noise level.

The intensified studies on acoustic materials fabricated from glass, asbestos, rock wool and foams are found to be associated with drawback such as manufacturing defects like molding, bonding and opening. Further, the acoustic panels fabricated from synthetic material are found to be non-recyclable and enhances environmental pollution by net emission of CO_2 gas when life cycle is considered. Thus the explorated issues can be overcome by alternative potential materials made from organic fibres which are cheaper, renewable, nonabrasive, abundant and bear less health risk.

The fruit of the *Luffa cyllindrica* plant is a Curcubitacea community forest component. It has a somewhat angular, bent and right fruit of cylindrical shape of a somewhat different size. It comprises of fibres spilled over and it has a three-dimensional reticulated structure with the core of inner fibre[1] and an outer core of separate fibrous cords. Microscopic cell architecture of continuous microchanels forming a vascular bundle and yielding a multi modal dynamic porous system[2] characterizes the *Luffa cyllindrica* structure.

This particular structure enables a complex composition depending on the weather conditions of different environmental location in globe. The chemical compositions of luffa fibers comprises of cellulose and hemicelluloses, lignin as well as certain inorganic elements such as glycosides, poly peptides, amino acids, proteins, making it a lingo cellulosic matter. However, the presence of hemicelluloses ranges between 9 to 22%, lignin is between 10% to 22% and the cellulose content ranges between 55% and 90%. Thus it becomes an appropriate for reinforcing polymeric matrix. The abundant of *Luffa*

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cyllindrica[3] and its waste gets difficult to be consumed at its matured stage due to release of purgative chemicals to the environment. Traditionally, dried luffa has been used in bathing and dish cleaning purposes due to its fibrous vascular system and its antifungal property. With increasing advancement in the field of industrialization, biotechnology etc. luffa sponges have been potentially used as engineering material.[4] The presence of fibrous vascular system and unique networking makes it a distinct raw material for synthesis of some advanced novel material related to sound pollution. Due to its heterogeneous and low-added value, lots of luffa products are either incinerated or disposed which is leading to environmental pollution.

Some researchers investigated the leeway of considering luffa fibre in particulate form for reinforcement with polymer like polypropylene[5] and investigated the mechanical, physical, acoustic property. Better results were obtained and observed the compatibility of polymer and lingo cellulose fibre. Luffa fibre treatment with SiO_2 nanoparticle[6] reinforced with epoxy polymer has shown better mechanical properties. Investigation on composites made from reinforcement of epoxy resin with luffa fibre and peanut shell rubble[7] found to have good compressive, tensile, flexural property and impact power. Microstructure analysis has been done with the composite of kaolin and luffa fibre reinforced with polyester resin. The use of analytic techniques on synthesis of luffa composite is bringing new applications in the field of vibration isolation, sound absorption, microwave absorption, etc. After a thorough literature survey on fabrication and production of acoustic material built up from different bio materials, it is observed that few researchers have used *Luffa cylindrica* for synthesis of material which have shown good response for reduction of noise intensities in open environment rather than the general uses like designing of craft material for home decorating, packing materials etc. Though there are many works[8,9] published relating to *Luffa cylindrica* as sound absorbing material considering with its single layer but the same can be modified as more advanced material when considered for different layers. The high mechanical strength, complex networking skeletal internal structure, renewability, cost effectiveness and biodegradability makes as a distinctive raw biomaterial for fabrication of effective graded sound absorbing material compared to other natural fibre.

Experimental Details for Fabrication of *Luffa cyllindrica* Composite

For preparation of optimized compatible blended surfactants the tartaric acid and alcohols of different carbon chains are purchased from CDH chemicals are used without further purification. An appropriate amount of tartaric acid and alcohol such as methanol, ethanol, propanol and butanol with increasing carbon chain were mixed in different concentration and stored in airtight containers for ultrasonic measurement from which optimized compatible blends are to be selected for surface modification of luffa fibres. Compatible parameter called isentropic compressibility was calculated from ultrasonic velocity data in mixture of tartaticacid with varying chain of alcohols for different frequencies from 1 to 5 MHz. The ripened well-matured brown colored luffa cylindrical fruit were collected from local area was dried under the sunlight for 4–6 days. The outer cover of the dried fruits were removed and opened to remove the seeds. The open parts of the luffa sponge were shaped in to mats by cutting them with a scissor. The mat like small sponge pieces of luffa were soaked in an optimized blend of tartaric acid-methanol and subjected under sonication in a sonicator for 30 minutes for well dispersion of surfactants into the luffa fibre for surface modification. As a result luffa fibre becomes hydrophobic by elimination of –OH group present on the luffa sponge and the surface become rough enabling a large no. of pores on the luffa fibre.[10–12] This treatment results in several reaction sites which helps to bind luffa fibre and epoxy polymer for better mechanical strength of the biocomposite.[13–15] The sonicated luffa fibres were placed in hot air oven at 80°C for 24 hours and packed in an air tight container for synthesis of composite material. For synthesis of composites a general hand layout technique was adapted. Mixtures of epoxy polymer with hardener in weight ratio 10:1 are stirred for 20 minutes within a container for well mixing of polymer matrix. The treated luffa mats were placed layer by layer and laminated with the mixture of epoxy and hardener in a rectangular mold. A silicone gel was used on the surface of the mold to make the surface of the mould smooth so that the composite can be removed freely. The composites were layered with single, double and triple sheet of luffa fibre in three distinct weight proportion. The sample was pressed with a weight of 20 kg and allowed to dry for 24 hours. The layered luffa fibre

composite sample was put in hot air oven at 100°C for 2 hours to maintain the post curing process. Samples with necessary dimensions were cut using diamond cutter for their physical characterization and acoustic testing as shown in Fig.1.

Characterization of Luffa Sample and it's Composite

The morphological change takes place at different stages of the processing of luffa fibre was studied using scanning electron microscope operated at 5kV (HITACHI SU 3500). The specimens of the sample were cut into slices and placed over the aluminum stub with the help of a double sided adhesive tape with gold coated sputter under the pressure of 0.1torr and current of 18mA so that sample become conductive. The surface images for different magnifications were recorded in various regions to obtain the clear idea about the surface modification with compositional elements present on the composite by energy dispersive spectra (EDS).Further, a deep insight to the different functional group present on the untreated and treated luffa fibre was well understood by analysis of FTIR spectra recorded by Fourier Transform Infrared Spectroscopy (Bruker Alpha-II USA) operated in the wave number range of 4000-500 cm^{-1} in transmittance mode. Micro hardness testing of the luffa composites was performed with the help of a Vickers hardness test with automated LCD touch panel (Blue star E&E, India).

Laboratory Designed set up for Measurement of Different Properties

Measurement of sound propagation through the material was conducted through laboratory designed experimental setup comprising 50cm long tube whose one end is designed to hold the sample and other end is connected with sound level detector. The sound level detector was connected with the compatible system which runs with EXTECH software for sensitization of the sound through material. A system generated sound whose frequency varies from audible range to ultrasonic range was allowed to pass through the material for 10 minutes and the data recorded was observed through the irregular variation of different peaks observed in the screen. The laboratory designed entire experimental arrangement for sound absorption test is shown in Fig. 2. The experiment was conducted with and without use of material and the average intensity of sound was recorded. The incident sound energy may get reflected, transmitted or absorbed to the extent depending on the surface texture of the material[16] as shown in Fig. 3. The extent of absorption of sound or sound absorption coefficient (α) depends on the surface condition which was recorded for difference in amplitude of sound through the material and without material from which the drop of intensity of sound (d) can be calculated using the Eq .1[(17)] given by:

$$\alpha = 1 - 10^{\frac{d}{20}} \quad ...(1)$$

The thermal conductivity of the luffa composite was measured with the help of a thermal analyzer KD2 PRO with sensor TR-3 designed for composite material. For measurement of thermal conductivity of the prepared composite a small hole was made with drilling machine to configure the sensor and thermal conductivity was recorded for different wt% of the composite at room temperature.

Fig. 1 — Layered luffa composite

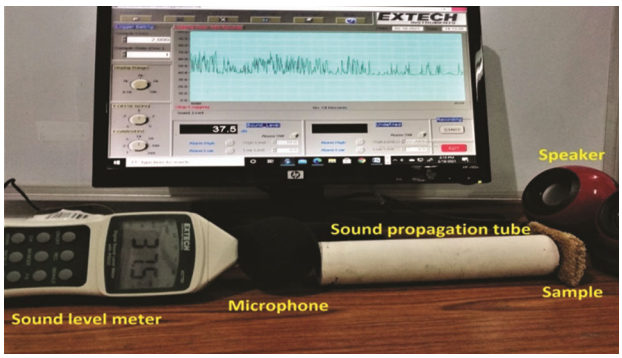

Fig. 2 — Experimental setup for measurement of sound absorption

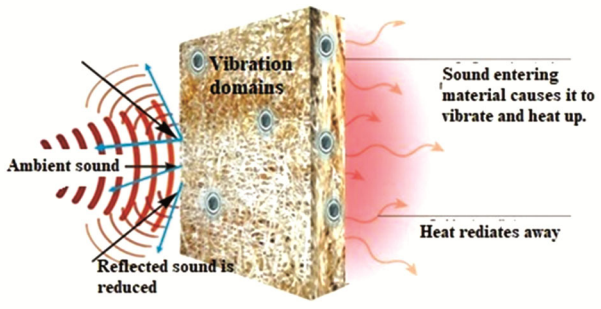

Fig. 3 — Mechanism of sound absorption within the composites

Results and Discussion

For surface treatment of raw luffa fibres, the optimized compatible blends of tartaric acid with different alcohol chains were prepared. The compatibility of the selected solvent mixture was analyzed from isentropic compressibility value computed with ultrasonic velocity data. The suitability of tartaric acid with of different chains of alcohol was selected for surface treatment due to fact that alcohols are easily evaporated from the surface with formation of active sites for interlocking between the fibres and polymer matrix due to demoisturization of the fiber surface. The highly compatibility concentration and optimum blends i.e 0.4 mole fraction of ethanol with tartaric acid signifies its best suitability compared to other alcohols for surface modification of the raw luffa fibre. The scanning electron microscopic images of untreated, treated and composite of luffa fibre are shown in Fig. 4 (a)–(c) where there was a major transformation in exterior surfaces is quite important to understand the interlocking between the fibres for synthesis of composite. From the Fig. 4(a) it is confirm that the raw luffa fibre has highly smooth and regular surface with large amount of foreign materials. While treated luffa fibre are highly uneven and formless outside as shown in Fig. 4(b). This confirms that, by exterminating the lingo cellulosic matrix, alcohol treatment separates several fibres. Though the ultrasonic wave is unable to dissociate into raw luffa fibres but increases the available exposed area on the surface of the luffa fibre by creating a large no. of active sites.[18] The presence of large no. of active site due to available of more no. of activated carbon and interaction of ultrasonic wave with the surfactants to remove the foreign material as well as moisture creates a large no. of pores on the surface of the composites as observed in Fig. 4(c). The availability of large no. of pores on the surface of the composite and complex elastic skeletal structure enhances the absorption of sound energy incident on the surface of the composite material.

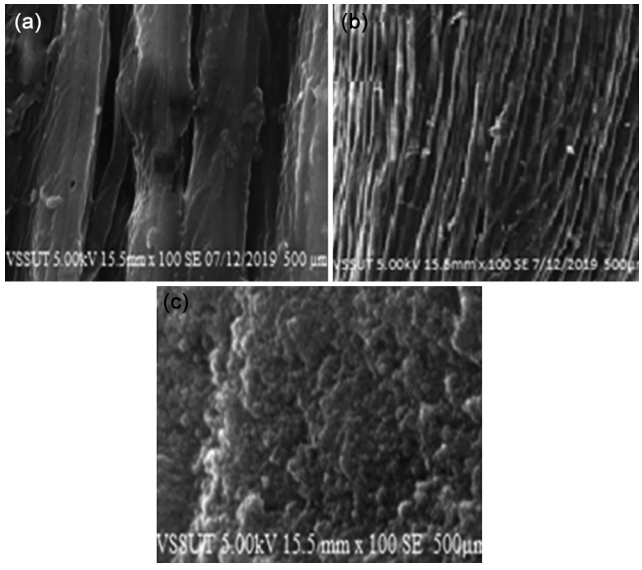

Fig. 4 — SEM of (a) untreated luffa (b) treated luffa (c) luffa composite

Energy dispersive spectra (EDS) have been used to analyze the presence of elemental compositions in the luffa fibre composite as shown in Fig. 5. EDS of the luffa composite indicates the presence of various percentages of different elements by weight.

The components such as carbon, oxygen and silicon are expressed well in the layered luffa fibre-epoxy composite below 20 Kev by their highest and wide peak observed. The presence of silicon with epoxy polymer enhances the mechanical strength and hardness value of the luffa composite. In addition to this, as the silica absorbs the moisture with elimination of other foreign material making the composite become more porous for which the other functional group converts the carbon into active carbon. The presence of carbon and oxygen in high percentage helps the composite to absorb the incident energy on the material and the presence of void space filled with oxygen makes the material become light weight. The identification of the functional group in presence and absence of the surface modifier is of great importance for analysis of the luffa fibre and its suitability to fabricate the composite. The sonicated treatment of luffa fibre with ethanol blended tartaric acid changes the interaction between the different functional group of the luffa fibre which are well studied with FTIR spectra of the untreated and treated luffa fibre as shown in Fig. 6. The wide absorption

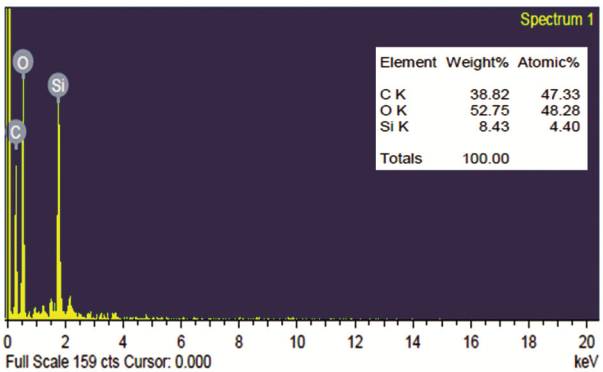

Fig. 5 — Energy dispersive spectra of luffa composite

band of 3650 to 3250 cm^{-1} represents the starching of hydrogen bond between –OH group of epoxy polymer and that of –OH group of cellulose, hemicelluloses and lignin as shown in Fig. 6(a). It is also observed that the wideness of peaks goes on shifting towards right in treated luffa fibre as compared to that of untreated luffa fibre as shown in Fig. 6(b) which indicates that – OH group of ethanol and polymeric group present in the surface of the luffa fibre polymerizes forming a polyfurfuryl coating on the surface of the fibre. Further, there is no significant peak except 2900 cm^{-1} was occur which signifies stretching vibration in C-H polymer present in lignocelluloses compound of the fibre surface. The presence of different small peaks at 1738 cm^{-1}, 1608 cm^{-1}, 1373 cm^{-1}, 1420, 1318, and 1246 cm^{-1}, 1204 cm^{-1}, 1157 cm^{-1} and 1104 cm^{-1} in untreated luffa fibres indicates the various stretching, bending and rotational vibration between -CO_3, -OH, -CO, and - C-O-C which forms elastic skeletal structure between the fibre component.[19–21] In treated luffa fibre the peaks are observed at 1373 cm^{-1}, 1738 cm^{-1} and 1608 cm^{-1} indicates the O-H bending, −CO_3 stretching and removal of hemicelluloses absorption of water molecules due to treatment of alcohol blended tartaric acid.[22,23]

The sound absorption coefficient has calculated from the variation of sound intensity in between the frequency range 50–7000 Hz. The sound intensity has been recorded in EXTECH software for different frequencies and time when the sound propagates through air and material medium which is shown in Fig. 2. From the analysis of recorded data, it is highly impressive that the luffa fibre composite significantly reduces the sound intensity. With increase in frequency the sound absorption coefficient also increases which is shown in Fig. 7. At low frequencies the absorption is comparably less than higher frequencies. After 500 Hz, the maximal value for sound absorption coefficient is observed. The four layered Luffa biocomposite shows the highest value of sound absorption coefficient. The analysis of sound absorption value for luffa may account for different factors. Inside the composite luffa fibres are randomly arranged within the epoxy creating many void places with considerable pores structure through which sound can absorb.[24] Since the luffa fibres are treated with alcohol solution, due to removal of lower molecular weight material the reflection of sound becomes lower which leads to more sound absorption. But there is some fluctuation in absorption value which is controlled by the specific characteristics such as density and porosity present in luffa fibres. The porosity may cause inter-reflected sound where as density creates sound energy absorption. With the increase of layers of luffa fibres are more compact and become more closure to each other within the epoxy matrix.[25] As a result this compactness decreases the size of the pores and void spaces having low volume of air within the composites. This causes narrow path for the sound propagation with a long path. Further the sound absorption depends on size, number of pores and type of pores in the material.[26–28] When the porous surface of the material was exposed to the high intensity of sound frequency then the air molecules within these pores are free to vibrate. These vibrations are the causes loss of energy in the form of heat. As a result within the material the sound energy dissipated in to thermal energy. This conversion is very less at lower frequencies and the changes are isothermal in lower frequencies and adiabatic at higher frequencies. The optimum value of sound

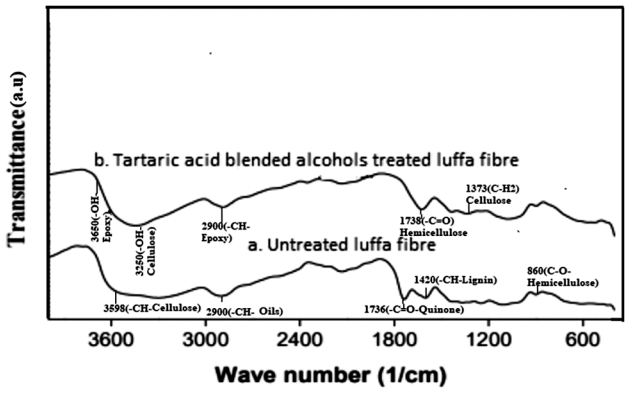

Fig. 6 — FTIR spectra of (a) untreated luffa fibre (b) treated luffa fibre

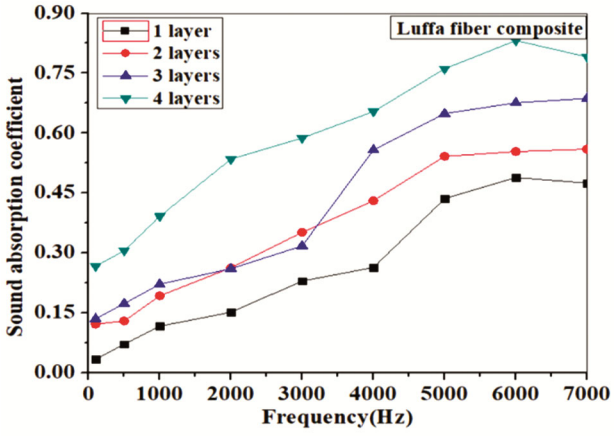

Fig. 7 — Sound absorption coefficient of luffa fibre composite

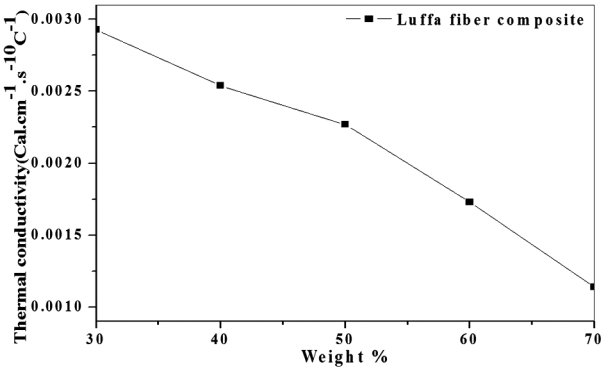

Fig. 8 — Thermal conductivity of luffa fibre biocomposite

absorption coefficient is 0.831 at 6000 Hz frequency for fourth layer of luffa composite which is to be Class-B type sound absorber as per the standard SR EN ISO 11654, 2002.

The non-uniform dispersion and complex inbuilt networking pattern of luffa fibers within the matrix result in changing the heat conductivity of composite material. Thermal conductivity decreases from 0.0010 $Cal.cm^{-1}.s^{-1}.\ {}^{0}C^{-1}$ to 0.0030 $Cal.cm^{-1}.s^{-1}.\ {}^{0}C^{-1}$ as the weight percentage of the material goes on increasing with increase of layers of luffa fibers s shown in Fig. 8. It may depend on several parameters, including the nature of the constituents, the interface of the fibre/matrix, the construction and composite geometry[29]. The presence of open and isolated closed void spaces which behaves as elastic skeletal within the composite decrease of thermal conductivity values due to decrease of amplitude of vibration of the particles. In composites, when luffa fibres are mixed with epoxy polymer dispersed randomly increases the compactness with increase of fibre wt%. The presence of large numbers of pores filled with air makes the material become insulating and the heat exchange takes place slowly as the air is a poor heat conductor.[30–32] As a consequence, the heat energy produced by the vibration of air molecules inside skeletal structure decreases due to loss of kinetic energy of the particles accommodated within the elastic skeletal wall.

The composite material to be an ideal if it is has good absorption, low weight and mechanically strong. The micro hardness property of the fabricated material was measure by Vickers Hardness test. As seen in Fig. 9, the hardness values of the luffa fibre composite increase with load increase.

This is due to the strong intermolecular bond between the fibre molecules with epoxy polymers.

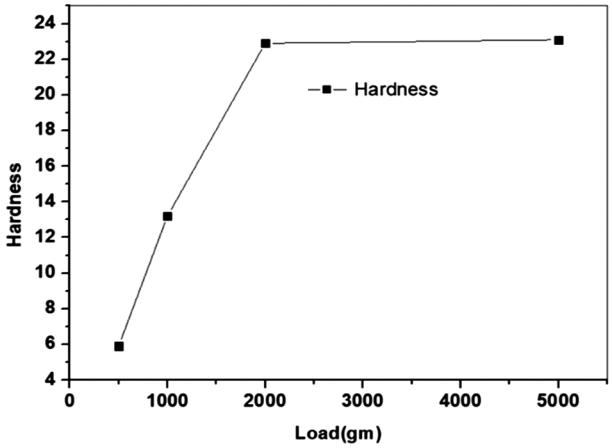

Fig. 9 — Micro hardness of luffa biocomposite

Carbon is the key element in the hardness of any material whose density increases with the rise of fibre reinforcement.[33] Again, the size of the fibre is an important element in the hardness of a bio-composite material. The micro hardness is improved by the small fibre size which helps in interlocking between the base material and the interface of the fibre network.[34]

Conclusions

The luffa composite materials were prepared by suitable reinforcement of luffa fibre in epoxy resin with treatment of alcohol blended tartaric acid. The surface morphology of the composite is well signified by the presence of large number of elastic skeletal structures within which the ambient noise propagates due to multiple collisions leading to decrease in sound intensity. The interlocked network structure and porous layers are well ventilated and isolated making variety of pore with different dimension between the wall boundaries of luffa fiber layers. The optimum value of sound absorption coefficient is 0. 831 at 6000 Hz frequency for fourth layer which is clearly signifies that thickness of the material plays significant role in reduction of sound intensity. Form thermal properties it is concluded that the material has ability to absorb heat due to randomization distribution of the luffa fibres and compactness of the material. Thus during the propagation of sound wave inside the multi layered structure it dissipated in to heat and this heat is absorbed by the material. Vickers hardness property increases with increase of weight percentage indicates the mechanically stiffness of the materials. As the disposal of the composite material to open environment not produces any harmful effect it is regarded as green material which find its application

basically as acoustic building material for design of the many technological devices where it needs.

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NOMENCLATURE

α	Sound absorption coefficient
EDS	Energy dispersive spectra
d	Drop of intensity of sound
FTIR	Fourier Transform Infrared Spectroscopy

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