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# Influences of Various Parameters on Sound Absorption Properties of Vetiver Grass Fiber-based Developed Composite Material

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Recently, the trend of natural fibers based eco-friendly materials utilization in the field of acoustic application has been growing rapidly in place of traditional synthetic materials to counter environmental issues, due to their cheap processing cost and other several advantages. In this work, sound absorption and thermal insulation properties of the vetiver grass (Chrysopogon zizanioides) based material have been investigated. Efforts have been carried out in developing porous vetiver grass fibers based composite material. The developed samples tested for the sound absorption coefficient (alpha) over a wide range of frequencies (100 Hz – 4000 Hz) by the reverberation chamber method as per IS 8225-1987/ISO 354-2003/ASTM 423-909-19 and noise reduction coefficient (NRC) also been calculated. The experimental outcome proved that vetiver grass-based manufactured material has comparable sound absorption to already developed traditional synthetic materials. Further, two different bulk densities, thickness and fibre lengths-based samples were developed and their sound absorption acoustic performances were evaluated to see the influences of these parameters on sound absorption characteristics. Apart from these, some required physical properties as per application requirements were also discussed. However, in this study major focus has been done on acoustical properties.

**Keywords:** Noise reduction coefficient; Reverberation chamber; Sound absorption coefficient; Vetiver grass fibers

## 1 Introduction

Sound is a form of energy which is produced and transmitted by a vibrating matter i.e. sound needs a medium to travel. Sound is a pressure wave which is travel via compression (area of high pressure) and rarefaction (areas of low pressure) produced in the medium as the sound wave travels through matter for example a wave travels through the springs is like a sound wave travels through the air and the places where the springs are close together are like compressions in the air. It travels faster through solids than liquids or gases. Beyond a certain limit sound became unpleasant; termed noise which makes us uncomfortable and we lose concentration on our work. Rapid industrialization makes this noise problem even more serious. Due to this problem, we lost concentration on work and a study suggests that a continuous high-intensity sound can disturb our hearing power which can't be recovered [1-3]. Therefore, this problem is faced almost everywhere in daily life routine and it makes us irritated. Therefore, the prevention of noise pollution is a major task for researchers in the field of acoustic design. There are two techniques of noise control that can be achieved first is active noise control and the second is passive noise control; used by engineers. In passive noise control noise level is reduced by employing a different type of material like sound-absorbing tiles while in active noise control undesired sound is prevented by the application of an additional designed device *e.g.* power source. Passive noise control is becoming more popular in designs and materials while active noise control is used in mobile telephones *etc.* because the former is a less expensive technique.

One of the popular accepted techniques under passive noise control is by employing different kinds of sound-absorbing composite materials in the direction of sound propagation has been used in practice by materials scientists to mitigate undesired sound. When sound waves pass through the porous material, some part of sound wave energy is absorbed by the material, causing a reduction in sound energy due to the friction with the pore walls and thermal exchange. This sound absorption depends on certain factors like materials thickness, bulk density, air cavity, fiber size, airflow resistivity, porosity, temperature etc.

Glass wool, rock wool, foams material (*i.e.*, polystyrene and polyurethane) etc. are traditionally

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used synthetic materials commercially for sound absorption and thermal insulation purpose at various construction sites and in buildings due to their good acoustical performances. Still, these materials are hazardous to human health as well as to the environment due to their toxic nature and $CO_2$ emission during their processing[4]. Studies suggest that there are chances of human health problems due to skin irritation caused by inhaling fibers and particles[5-6]. These shortcomings set the limitation on the uses of traditional synthetic materials. Therefore, researchers interest moved towards finding new alternative eco-friendly, sustainable materials which have comparable acoustic properties. This becomes possible by the discovery of acoustical properties of natural fibers-based materials. Sound absorption properties of natural fiber-based materials *e.g*. bamboo, jute, sisal, banana and kenaf etc. have been investigated by the researchers. Agricultural wastes like wheat straw, rice straw *etc*. also has been studied for noise absorption and it has been reported that these materials can become alternative to the traditional synthetic materials. These materials absorb the incident sound wave energy as the wave travels through the material and this energy is dissipated in the form of heat energy by interacting with the materials fiber and some part trapped in the porous structure i.e. due to frictional and viscous effects, due to interaction between fibers, incident wave, fibers vibration[7]. These natural fibers and agriculture waste materials are eco-friendly in nature, raw material availability, cheap processing cost, safe in handling and comparable acoustic performances make them favourable in place of synthetic materials and remove the shortcomings of synthetic materials[8-9].

In a research study of natural fiber assembly sound absorbers, it was reported that by taking care of density and air cavity behind specimen of pineapple-leaf fibers sound absorption coefficient reached up to 0.9 on average above 1000 Hz frequency[10]. Berardi and Iannace[11] worked on wood fiber material and the results suggest that the 6 cm thickness specimen showed high alpha at 500 Hz and 1650 Hz. Similarly, attempts have been done on Natural Fiber Composite sound-absorbing materials, Samaei *et al*.[12] reported that kenaf fiber and polyvinyl alcohol (PVA) mixed under certain pressure and kenaf fiber treated with NaOH reduces diameter; gives a good appearance and improved sound absorption characteristics as compared to without NaOH treated fiber. It has been also noted that physical and mechanical properties were improved when chemical treated fiber was utilized in manufacturing composite fibre-based materials. Othmani et al.,[13] worked on sugar cane and resign together and founds that sugar cane has good sound absorption at medium to higher frequency ranges. A study has been done on paddy straw and its results suggest that this can be used as an acoustic panel due to its porosity and elasticity[14]. Various studies on natural fibers suggest that the larger the pores, the better the acoustic insulation. In another study, it has been observed that the higher density material of oil palm fiber has good sound absorption[15-16]. Among natural fibers kenaf fiber got more attention because of its excellent acoustic results as well as its good fiber quality especially outer fibers, lower bulk density, mechanical strength, cheap cost, biodegradability and recyclable properties[17]. Therefore, researchers suggest that kenaf can be utilized for the medium density particle boards and sound barriers[18-22].

In the literature survey of natural fibers based on porous structured materials, it was found that these material gives good sound-absorbing results over a wide range of frequency especially at medium to higher frequency but are less effective in absorbing sound at lower frequency range generally below 2000 Hz. This problem can be addressed by creating a certain air cavity behind the sample. Sound absorption is also influenced effected by material's bulk density, thickness etc. In this reported work, vetiver grass-based composite material has been developed, its acoustic and mechanical properties have been investigated experimentally. The selection of this fiber is due to its some unique features as fibers are flat, sustainable in adverse temperature conditions, high tensile strength and fire resistance etc. Its roots have been used for making perfumes and cosmetics widely. In the medical sector, it is used to cool down the body temperature and for skin disease care. It is also grown by the farmers to prevent soil erosion because deep penetration strength of its roots. However, to the best of our knowledge, no research work has been done on vetiver grass-based material for sound absorption. Therefore, the major focus of this study has been done in investigating the sound absorption properties of the vetiver grass fibrous assemblies, the effect of various parameters e.g. density, thickness and fiber length has been studied.

## 2 Materials & methods

#### Materials preparatory process

Vetiver is a climate-friendly crop and can stand in adverse climates. Its fibres were obtained from northern Indian farm fields and Magnesium Oxide (MgO) cement was used as a binding agent for the fibers. Harvesting has been done after planting and fibers were extracted. The vetiver bunchgrass having clumps grows straight high parallel has typically height of 15-200 cm and it can be separated into small pieces. Initially, the obtained fibers were washed in distilled water as shown in Fig. 1(a) to remove impurities and sunlight is given for 1-2 days for drying up. The sundried fibers are shown in Fig. 1(b). Vetiver fibers of an average length of 40-50 mm and width of 3-4 mm have been taken {see Fig. 1(c)}. Alkaline treatment of vetiver grass fibers has been done with 5% Sodium hydroxide (NaOH) solution in distilled water for cleaning the surface of the vetiver fibers for about 40 minutes {see Fig. 1(d)}. The alkaline treated fibers have been shown in Fig. 1(e).

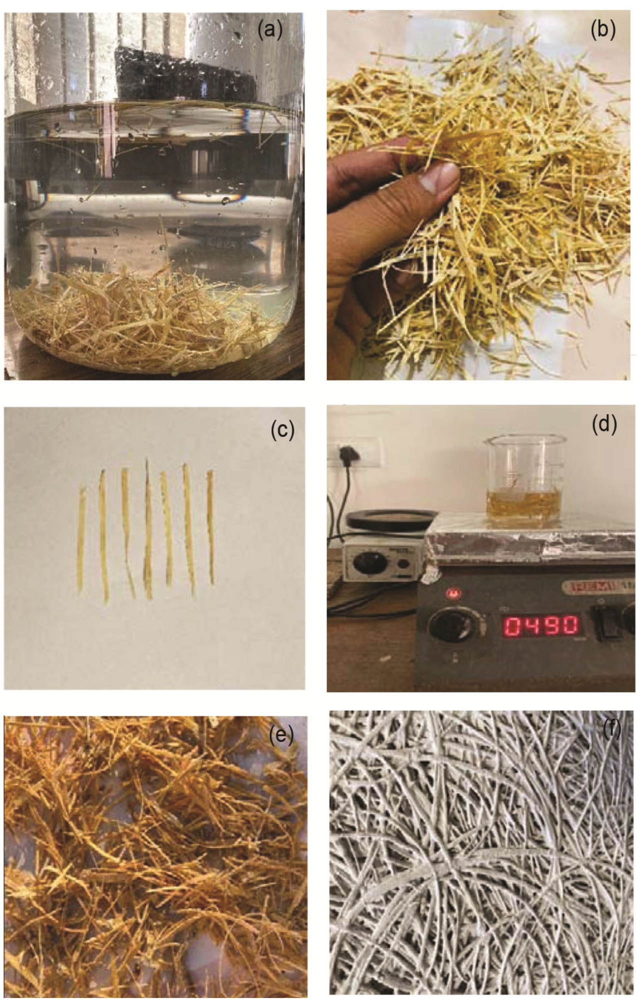


Fig. 1 — (a) Vetiver grass fibers in digital water for purification (b) Fibers in sunlight after washing (c) 30-40 mm length fibers used for material preparation (d) Chemical (NaOH) treatment of fibers (e) Fibers after chemical treatment (f) Final finished composite material.

This treatment also improved the mechanical properties and improve the interaction with the binder. These fibers were then dried in an oven at ± 70 °C temperature for 2-3 hours to reduce the moisture content (MC) by around 3-5 %. Both of these vetiver fibers and MgO with 30% fibre-loaded mixed in a salt solution (Ammonium chloride, NaCl) for providing hardness to the composite material. Further, 1-2% (wt.) of wax is added to prevent material from environmental moisture from the surroundings. The binding agent is used in less quantity to make final material in the porous structure. A simple hand lay-up and compression moulding method are used in forming the composite material. The final finished grass-based composite material has been shown in Fig. 1(f). Before the mechanical and acoustic testing, the samples were kept at a temperature of 20 ± 2 °C and 65 ± 5% RH for 3 days.

## 3 Methodology

The reverberation chamber is the most accurate and standard method for the sound absorption coefficient (alpha) and noise reduction coefficient (NRC) measurement[23]. A reverberation chamber is a large room with very hard exposed surfaces designed to create a diffuse field. Adequate diffusion has been created in the chamber. It is used to calculate the values of alpha, NRC and sound transmission loss (STL) of a material. It is also used for the measurement of the sound power of a source and the calibration of a microphone. The experiments for the sound absorption coefficient (Alpha) have been carried out in a reverberation chamber which is constructed using concrete and solid bricks at CSIR-National Physical Laboratory (NPL), New Delhi as shown in Fig. 2.

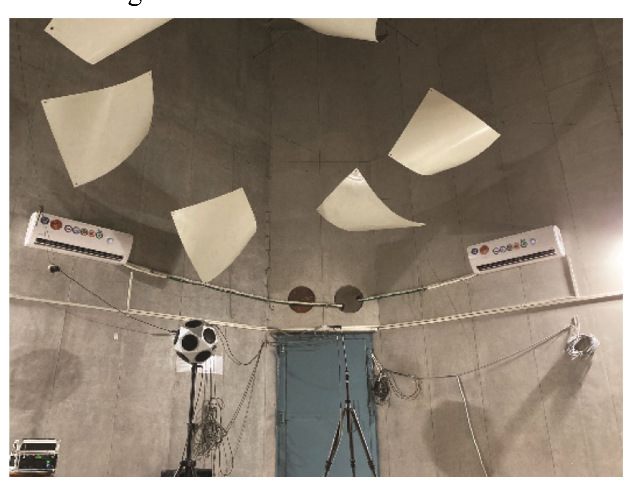

Fig. 2 — Reverberation chamber facility at CSIR-National Physical Laboratory, New Delhi.

The various equipment used in the testing process is traceable to the primary standards maintained at CSIR-NPL, a National Metrology Institute (NMI) of India. The accuracy of these primary standards is verified periodically by participation in key–comparison exercises with leading NMIs in the world. The microphones used in the testing were calibrated by absolute method on the Reciprocity Calibration System (B&K Type 9699) in the frequency range 31.5 Hz to 25.0 kHz using plane-wave couplers. Vetiver grass fibers based composite material panels were tested for their sound absorption coefficient by reverberation method as per IS: 8225 – 1987(R2005) under existing environmental conditions in a reverberation chamber of volume 257 $m^3$, surface area 240 $m^2$. The designed chamber has dimensions of 6 m (L) x 6.5 (W) m x 7 m (H), yielding a total volume of 257 $m^3$ and having a cut off frequency of 80 Hz. The frequency range for testing was taken from 100 Hz to 4000 Hz. The chamber was of irregular shape, and adequate diffusion was obtained by using suspended stationary diffusers. A loudspeaker with uniform spherical radiation was used as the source of sound suspended at the height of 2.5 m above the floor in one corner while the microphone was kept in different locations near the other corners of the room and at least 1 m away from any surface.

Measurements were made by using 1/3-octave bands of the random noise signal, the signal was amplified by using a preamplifier {see Fig. 3(b)} and several decay rates were determined for each of the loudspeaker and microphone positions using Bruel and Kjaer type 2270 sound level meter. The used sound source, preamplifier, sound level meter, and the microphone has been shown in Fig. 3(a-d). The sound absorption coefficient by Reverberation Chamber Method is measured as per IS 8225-1987/ISO 354-2003/ASTM 423-909-19, and the correction for boundary absorption was applied. The evaluated uncertainty in measurement is ± 5% which is at a coverage factor k = 2 and corresponds to a coverage probability of approximately 95% for normal distribution. For each measurement, temperature and the relative humidity of the chamber were recorded by the temperature-humidity sensor as shown in Fig. 3 (e).

The sound absorption coefficient (α) is defined as the ratio between the energy of a sound wave which is absorbed by the surface of the material to the incident sound wave energy[24].

For Alpha measurement, the material is mounted at a rigid surface inside the chamber of volume 257 $m^3$ to get an exposed specimen area of 12 $m^2$. A loudspeaker, which emits uniform spherical radiation in all directions, has been used as a sound source, the sound is induced by a signal generator from 100 Hz to 4000 Hz frequencies, fixed at one of the corners of the chamber at a certain height. A standard working microphone (associated uncertainty ± 0.2 dB, as per national standards) has been placed at different corner positions inside the chamber with a minimum of 1 m away from any surface. The microphone was calibrated with an acoustic calibrator (Bruel & Kjaer 4231) before placing for the experiment. After placing the specimen, for the alpha and NRC, a measurement of the reverberation time has been done in the empty chamber (which is defined as the time taken by the sound to decay by 60 dB after the sound source ceased in closed space)[25] and again with the sample placed in the chamber. This difference in the reverberation times gives the alpha of the material using the below formula.

$$\alpha = \frac{55.3\,V}{S(331+0.6\,t)}\left[\frac{1}{T_w} - \frac{1}{T_s}\right] \#(2)$$

Where, $T_w$ and $T_s$ are reverberation time of chamber without a sample (s) and with sample (s) placed inside the reverberation chamber respectively, $V$ = volume


(a) Omni-Directional Sound Source

(b) Pre-Amplifier (B & K Type ZC-0032);

(c) B&K Sound Level Meter (Type-2270);

(d) Microphone;

(e) Sensor for Temperature & Humidity measurement

Fig. 3 — (a-e) Used equipment for the measurement of Alpha and NRC.

of the chamber ($m^3$), $S$ *and* $t$ are temperature (°$C$) of the chamber and sample area ($m^2$) respectively. The formula in equation 2 is derived empirically by Sabine[27]. The NRC is calculated by taking the mean value of alpha at four different frequencies: 250 Hz, 500 Hz, 1000 Hz and 2000 Hz and it is widely used commercially for rating the materials[26].

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \#(3)$$

Where $\alpha_n$ is the sound absorption coefficient at different frequencies. The measurement has been taken using 1/3-octave bands of random noise, and the evaluated uncertainty in the measurement is ± 5%. This experiment has been carried out in the reverberation chamber by placing the material under existing environmental conditions, and the temperature and humidity of the chamber were measured by the sensor placed inside the reverberation chamber. Several measurements were done by placing a microphone at the different locations inside the chamber for each test, and the average value of the measurements was taken for the accurate result. This whole methodology is summarised in the flowchart given in Fig 4.

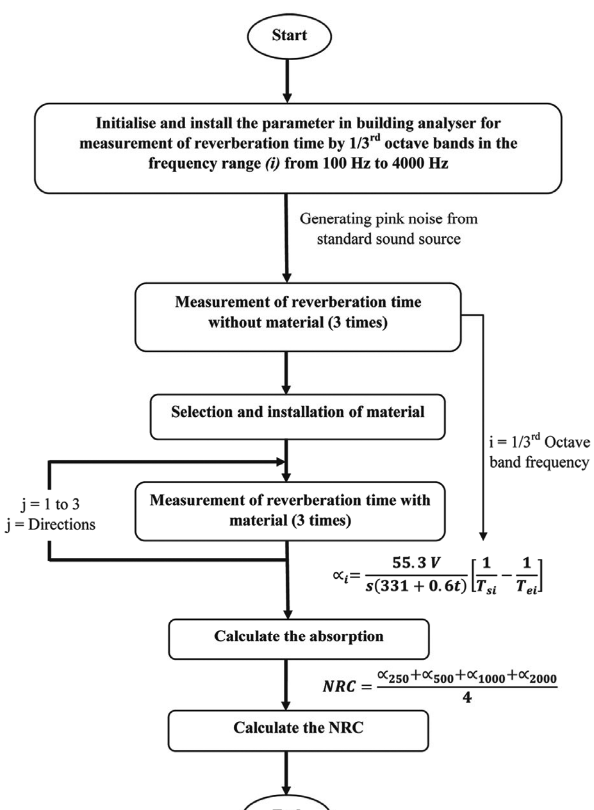


Fig. 4 — Flow chart of the measurement of Alpha and NRC.

## 4 Results and discussions

**Physical and mechanical properties of the material**

The prepared specimen was placed in constant temperature (25 °C) and humidity (64% relative humidity) conditions for about 15 days before testing its properties. It is necessary to check some required mechanical and thermal properties before developing any composite material as per applications. Physical and mechanical properties like density, thickness, fire class, climate conditions, and thermal conductivity are desired as per building requirement applications. Therefore, these parameters of the developed vetiver grass material have been evaluated in this reported work. C. zizanioides - based composite material has a bulk density of 400 kg/$m^3$ and thickness of 20 mm. It has been checked for fire resistance and It was found that this material is of fire Class 1 rated (lowest flame spread) which is the highest rating. Generally, Class 1 fire rated materials are applied for building constructions. It can adopt Climate conditions of temperature up to 50 °C ± 2 and relative humidity (RH) 95 ± 2%. Thermal conductivity of a material tells the rate at which heat is transferred by conduction via a unit cross-sectional area i.e. it tells about the material's ability to conduct heat. Higher the thermal conductivity higher the flow of heat occurs and vice versa. The measured thermal conductivity value of developed vetiver grass-based composite material was 0.07 W/m k which is measured by LFA (Laser flash analysis) technique. 0.07 W/m k is a low value which means vetiver grass-based material provides good thermal insulation.

**Acoustical result of the composite material at rigid backing**

Vetiver grass fibers based composite material were tested for alpha and NRC by reverberation chamber method. The prepared composite panels of 400 kg/$m^3$ density and 20 mm thickness was installed inside the reverberation chamber as shown in Fig. 5. Experiments have been done at the existing environmental condition of a temperature of 21°$C$ and relative humidity of 54 %. Results are shown in Fig. 6, it can be noted that alpha kept increasing its value in the lower frequency ranges from 100 Hz to 2000 Hz and after that it reached the optimum maximum alpha of 0.72 at 2 kHz frequency and become nearly constant in the frequency range of 2000 Hz to 3000 Hz and later alpha slightly decreased and in the range of 3000 Hz – 4000 Hz[27]. This follows the basic trend of porous natural fibers based materials. Thus, this material

Fig. 5 — Vetiver grass panel of density 400 kg/m$^3$ and thickness 20 mm installed in a reverberation chamber at rigid surface backing at CSIR-National Physical Laboratory, New Delhi.

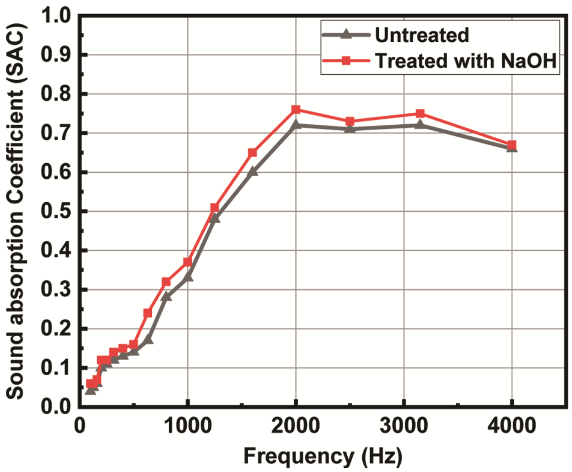


Fig. 6 — Frequency Vs Alpha graph of Vetiver fibre-based composite sample of Density 400 kg/m$^3$ & Thickness 20 mm.

absorbs a good amount of sound effectively at a medium to a higher frequency range. The NRC value calculated at four frequencies is 0.33 is comparable to some already commercially used developed materials[28].

It is evident from Fig. 6 that alkaline treated fibers based composite material show enhanced absorption properties at almost all frequencies. The Maximum absorption peak of untreated fibers based composite was observed at 0.72 at a frequency of 2 kHz while for treated fibers based peak was observed at a higher 0.76 at the same frequency. This might be due to the removal of impurities from the surface of the fibers which increases the roughness of the fibers and this increases the adhesion with the binder[16]. From previous studies, it was also established that chemical treatment of fiber reduces the diameter of fiber and this causes more fibers to be reinforced in the composite of the same volume[17]. Therefore, more number of fiber means the sound wave interacts with more fibers and it travels through a more tortuous path hence more sound get dissipated in form of heat via viscous and frictional losses.

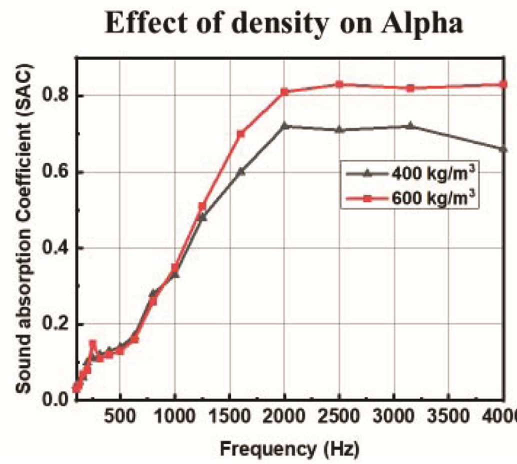


Fig. 7 — Frequency Vs Alpha at two different densities 400 kg/m$^3$ and 600 kg/m$^3$; and a constant Thickness of 20 mm.

**Influence of density on Alpha**

The bulk density of the material affects sound absorption properties largely because it has a relation with the porosity of the material. Therefore, it is the most important parameter which influences the sound absorption coefficient of the material. The porosity, σ, of vetiver grass fibrous assembly is calculated by using the formula[29]:

$$\sigma = (1 - \frac{\rho 1}{\rho 2})\ x\ 100\#(3)$$

Where, $\rho_1$ = bulk density of vetiver grasses fibrous assembly (kg/m$^3$) and $\rho_2$ = is the density of vetiver fiber (kg/m$^3$). Wool fiber material was investigated by ballagh et. al. and it was observed that higher density material absorbs a larger amount of sound at high and medium frequency ranges (maximum absorption occurred above 500 Hz) as compared to lower density material.

To observe the effect of bulk density on sound absorption properties; two different bulk density of 400 kg/m$^3$ and 600 kg/m$^3$ vetiver grass fiber assemblies-based panel has been tested in a reverberation chamber for sound absorption coefficient starting from 100 Hz to 4 kHz at one third octave band frequencies.

The results shown in Fig. 7, Show that the average Alpha increased from 0.33 to 0.39 when the bulk density increased from 400 kg/m$^3$ to 600 kg/m$^3$ while thickness has fixed at a value of 20 mm. Alpha initially increased with an increase in density but only up to a certain limit after a further increase in density leads to a decrease in alpha; this can be understood because a very dense arrangement of fiber assemblies results in the decrease of porosity and sound wave reflects more instead of absorption also each fiber acoustic material has an optimal range for better absorption results, also increased density material have more fiber per unit area which increase surface friction and more sound energy get dissipated in form of heat[30]. Therefore, results of both densities have proved that the 600 kg/m$^3$ density panel is more efficient at a higher frequency range in absorbing sound. Thus, vetiver grass fibrous assemblies are more efficient acoustical damping materials with an optimal bulk density of 600 kg/m$^3$.

**Influence of thickness on Alpha**

Materials thickness is an important parameter which affects sound absorption significantly. Coates *et. al*. observed that when the thickness of the material is one-quarter of the incident sound wave then effective sound absorption occurs and peak absorption occurs. Taban et al. worked on the palm-fruit-fibre-based composites material and observed that sound absorption of a higher thickness material has good sound absorption. A previous study suggests that at lower frequency ranges the alpha and NRC increase with an increase in thickness i.e. thicker the material better the sound absorption at lower frequencies[31]. For the constant bulk density of 400 kg/m$^3$, the experiment has been performed at two different thicknesses of 15 mm and 20 mm of the vetiver grass panels in the reverberation chamber. From Fig. 8; it can be concluded that alpha improved significantly at lower frequencies below 2000 Hz and not much effect was observed at higher frequency ranges. This behaviour can be understood; as the sound waves in the lower frequency ranges travel mostly through thicker materials and are absorbed along the air path and through the materials[32].

**Influence of fiber length on Alpha**

Vetiver grass fibers which are obtained are cut into two different lengths of 30-40 mm and 60-70 mm to study and analyze the effect of fiber length on sound absorption properties. The used grass fibers of two different lengths have been shown in Fig. 10 (a-c).

Fig. 9, shows the alpha of both fiber length assemblies' panel and it can be seen that both fiber length has similar absorption at all frequencies except

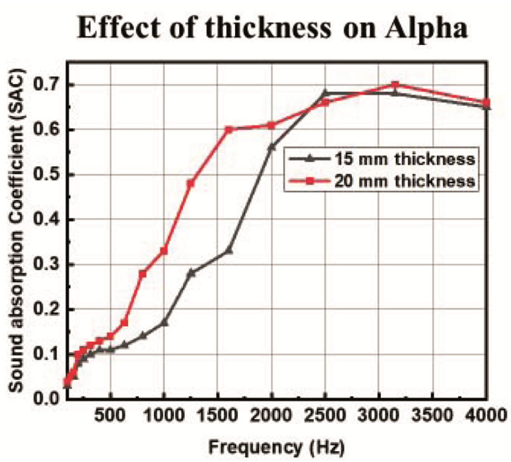


Fig. 8 — Frequency Vs Alpha at two different thicknesses 15 mm and 20 mm; and a constant density of 400 kg/m$^3$.

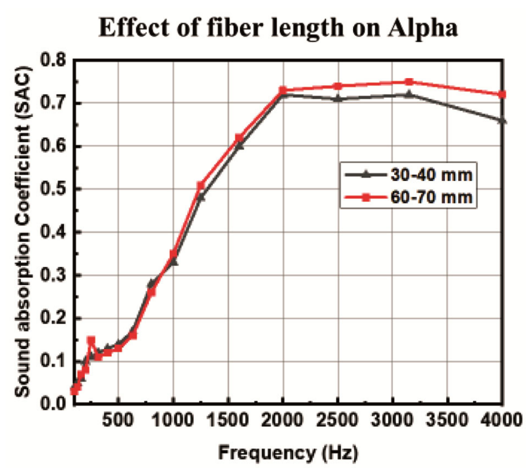


Fig. 9 — Frequency Vs Alpha at two different fiber lengths with long 60-70 mm and short 30-40mm fibers; with a constant thickness of 20 mm and Bulk density of 400 Kg/m$^3$.


Fig. 10 — (a) Vetiver grass fiber of length 30-40 mm (b) Vetiver grass fiber of length 60-70 mm (c) Vetiver grass fiber of length 30-40 mm and 60-70 mm.

at a very high frequency above 3000 Hz. This increased absorption at high frequencies is might be due to the more tortuous path sound travels when long fibers are used[30]. This demonstrates that vetiver grass panel alpha has little dependence at high frequencies[33].

## 5 Conclusions

Vetiver grass fibers based on developed composite material can be utilized in buildings, interiors and other construction sites as a ceiling, walls, rooftops etc. as it has comparable sound absorption values to already developed materials. This also gives excellent heat insulation. Its eco-friendly nature, non-toxic behaviour, and relatively cheap processing cost made it more favourable than other traditionally used synthetic materials like Rockwool, glass wool, foams etc. Alkaline treatment has been given to the fibers because this improved the mechanical and thermal properties of the fibers. Starting from 100 Hz alpha increases with frequency at lower frequency ranges, it reached to the value of 0.72 at 2.0 kHz and after that, it became nearly constant between 2.0 kHz to 3.5 kHz frequencies. Further, Results suggest that sound absorption is largely influenced by density at higher frequencies and thickness at lower frequency side while sound absorption is less dependent on fiber length except at much higher frequencies. Therefore, these results suggest that before developing any acoustic material for sound absorption particular combination of density and thickness is much more important than fiber length. Therefore, these types of composite materials bring the concept of sustainability, eco-friendly, and recyclability and will encourage researchers to develop this kind of new materials with improved properties to the existing materials.

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