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Cattail- luffa fibre reinforced and rice stubble ash filled composites for acoustic applications

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The possibility of using fibro-granular acoustic composites for the sound absorption of a wide range of frequencies through an experimental approach has been explored. The fibrous materials (cattail and luffa fibre) and granular materials (rice stubble ash) are used for the manufacturing of acoustic boards. The use of toxic binders, such as phenol-formaldehyde, polyester foams and polyurethane, has been eliminated in this modified method to manufacture acoustic panels through a sustainable development route. The extraordinary free space available in the network of luffa fibres has been utilized to hold the rice stubble ash particles binder and still left free space are used for effective sound absorption. The prepared samples are tested mainly for density, pore size and sound absorption coefficient. The findings show that the developed panels have a density of 80 kg/m^3 and pore size of 110 µm, which are effective in absorbing both low and high-frequency sound waves within the acoustic frequency range 63 −6300 Hz. The sound absorption coefficient of these panels is found more than 0.8, which is comparable with commercially available acoustic boards. These eco-friendly acoustic panels, made of agricultural residues such as cattail fibre, luffa fibre and rice stubble waste, do not require significant capital to make a green utilization of waste materials for product development.

Keywords: Box and Behnken design, Cattail fibre, Fibre reinforced composite, Luffa fibre, Rice stubble ash, Sound absorption

1 Introduction

Demand for cleaner and better environment and more diversified lifestyle has continuously increased over the last two decades, in which a noise-free environment is a basic need in our daily lives. Other sectors, such as transportation, manufacturing, and instrumental engineering, also require more efficient sound absorption materials that are economical and environmentally favourable. Traditionally, rock wool, mineral fibres, synthetic fibres, and foam-based composites are used as sound absorbers. Numerous investigations are attempting to develop novel materials and technologies to solve the issues related to sound pollution[1].

Thin, lightweight and porous materials, which are capable of absorbing a range of sound waves, are urgently needed. Nowadays, the wide use of polymeric materials for sound absorption become preferable due to their best viscoelastic properties, non-exhaustive availability, and the easy manufacturing processes[2]. Composite materials with porous structures prepared by laminating, preheating, and moulding show excellent absorption in the frequency range of 500-2000 Hz[3]. Dualy compressed composites prepared from recycled packaging waste with aluminium foil, expanded polystyrene, and coir stands show sound absorption properties comparable to glass wool[4].The combination of nonwoven fabric with para-aramid paper shows better sound absorption than that of glass wool at frequencies higher than 2000 Hz[5]. The perforated polymeric materials, along with recycled rubber particles, result in considerable sound absorption properties. The particle size of rubber and polymer materials directly influences the sound abruption behaviour of prepared composite. Acoustic panels comprised of polyurethane foam, glass wool along with rubber particles also show significant sound absorption behaviour at a wide range of frequencies. Generally, recycled rubber particles are useful for lower frequency absorption, while polypropylene combined with polystyrene results in higher sound absorption at a wider frequency range[6]. The economical, lightweight, eco-friendly, and sustainable nature of natural fibre gives enough options to satisfy the demands of the present era[7]. In addition, these fibres grow naturally in a cyclic manner and offer environment-friendly acoustic solutions to keep this planet safe for upcoming generations, which is not possible with the

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use of synthetic materials[8]. Acoustic panels made of kenaf and recycled polyester (PET) blanket were tested for sound absorption in a reverberation room, and it was found that they are good sound absorbers at frequencies between 1000Hz and 5000Hz [9]. Insulation boards made of rice straw also have a sound absorption coefficient of 0.5 at a range of 1000-8000 Hz frequency. Composite boards of random-cut rice straws and wood particles were found to demonstrate a higher sound absorption coefficient than particleboard, fibreboard and plywood for the frequency range 500–8000 Hz[10].

Rice stubble composite acoustic panels lightweight in nature exhibited a noise reduction coefficient (NRC) of 0.4 at 63-2000Hz frequency[11]. The sound absorption properties of bamboo fibres-based sound absorption panels were found to be comparable with glass wool and rock wool acoustic panels[12,13]. Durian peel and coir fibre straw particles can also be used for insulation panels as alternative wood-based products in the timber industry[14]. Multi-layered coir fibre-based mattresses with air spacing exhibited good sound absorption properties in a low-frequency range as compared to single-layer coir-based composites; it was concluded that multilayer materials are better than perforated plates with air spacing[15].

Ersoy and Kucuk[16] investigated three different layers of tea-leaf fibre waste materials with and without backing provided by a single layer of woven textile cloth and tested them for their sound absorption properties. However, the studies on the sound absorption properties of composite materials using natural fibres are still limited, and the problem of undesirable and potentially hazardous noise is going to be a threat day by day[17]. The use of synthetic materials for sound absorption is applied extensively in the construction industry. These non-biodegradable/synthetic materials not only cause pollution to the environment but also contribute significantly in increasing CO_2 emissions, causing the effect of global warming. Recently, human hygiene and environmental protection have become prime needs of society, resulting in more environmentally benign, natural materials to be used in daily life applications. Therefore, the researchers are now paying attention for sustainable and eco-friendly solutions to sound pollution that can potentially replace traditionally existing sound absorption materials. The novelty of this study is the application of the use of cattail and luffa fibre in replacing synthetic fibre for making composites for sound absorption. The optimization of luffa fibre pre-treatment (4 – 8%), the effect of filler size (100-200μm) and the extent of spray adhesion for the sound absorption of composite are studied.

2 Materials and Methods

Cattail fibre was used as reinforcing material. In first phase, chemical extraction of cattail fibre takes place, in which cattail leave are separated out and then beaten with mallet followed by treatment with sodium hydroxide solution for 6 h at 80°C. The extracted fibres are opened through an opener and then fed to a laboratory card for web formation. The cattail single fibre average diameter, fineness and length were 90 μm, 9.6 tex and 12.5 cm respectively. Tensile strength was 32.58 gf/tex.

Luffa fibre was selected as the backing of the composite. Luffa fibre was first cut in the form of sheets and flattened by applying external pressure, then subjected to alkali treatment for smoothening, removing impurities and increasing cohesiveness to other constituent materials.

Rice stubble ash was used as filler. Firstly, control burning of rice stubble is carried out, followed by crushing through the grinder and sieving through three types of meshes, namely 100,150 and 200 microns. It can be seen that rice stubble ash has about 82% silica content[18].

Spray adhesive was used as a binder consisting of dichloromethane as a crosslinking material that solidified and strengthened quickly after spray bonding took place.

2.1 Composite Manufacturing

Composites were prepared using a spray impregnation method. In the first step, the luffa fibrous sheet was fitted into a mould size of $20 \times 20\ cm$. Then, spray bonding was carried out from a 25 cm distance, followed by the distribution of the ash particles on the surface of the sprayed fibre. In the next step, the cattail fibrous web was layered, and spray bonding took place. After that, this fibrous sheet filled with rice stubble ash is compressed at 100 °C and 5 MPa pressure for 10 min by using a hydraulic hot plate press for the composites of about 5 mm thickness as shown in Fig. 1. The weight of each fibreboard was recorded before and after impregnation to control the fibre content of 80 wt

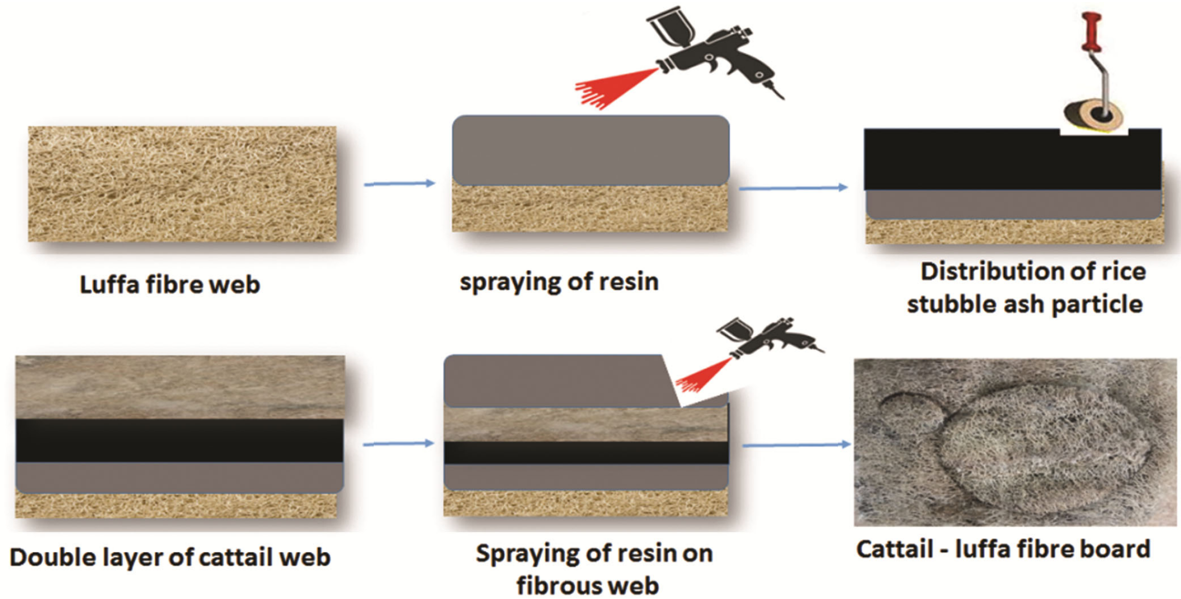

Fig. 1 — Flow diagram of composite manufacturing

Table 1 — Box and Behnken design for optimization

Sample code	Filler size (coded factor)	NaOH, % (coded factor)	Pressure level (Coded factor)	Filler size, µm (actual factor)	NaOH, % (actual factor)	Pressure level, psi (actual factor)
S1	1	1	0	200	8	45
S2	-1	0	-1	100	6	30
S3	0	-1	-1	150	4	30
S4	-1	0	1	100	6	60
S5	-1	-1	0	100	4	45
S6	-1	1	0	100	8	45
S7	1	0	1	200	6	60
S8	0	0	0	150	6	45
S9	0	1	1	150	8	60
S10	1	0	-1	200	6	30
S11	0	0	0	150	6	45
S12	0	0	0	150	6	45
S13	1	-1	0	200	4	45
S14	0	1	-1	150	8	30
S15	0	0	0	150	6	45
S16	0	-1	1	150	4	60
S17	0	0	0	150	6	45

%.With luffa fibre pre-treatment with NaOH 4-8%, rice stubble ash particle size 100-200 µm and the applied pressure level of spray adhesive 30-60 psi were optimized by using Box and Behnken experiment design (Table 1). The resultant fibreboard was trimmed to avoid edge effects and then cut into specimen size as per the characterization method.

2.1.1 Sound Absorption Test

A sound absorption test was conducted using an impedance tube (Beijing Shengwang Acoustoelectric Technology). The impedance tube showed two tubes, viz a tube of 100 mm diameter for low sound frequencies (63-1600 Hz), and a tube of 30 mm diameter for high frequencies (1000 - 6300 Hz). This approach uses the corrected acoustic transfer function (H_{12}) to determine a test sample's complex sound-reflection coefficient (R). The complex sound reflection coefficient is defined as follows[19]:

$$R = \frac{H_{12-e^{jks}}}{e^{jks}-H_{12}} e^{j2k(l+s)} \quad \text{... (1)}$$

where k = 2πf/c is the wave number; *l*, the distance between microphone 2 and the front of the test sample; and *s*, the distance between the two microphones. The normal incidence (α_n) and the specific impedance ratio (Z/C) were calculated using following equations [20-21]:

$$\frac{Z}{C} = \frac{1+R}{1-R} \quad \ldots (2)$$

$$\alpha_n = 1 - |R^2| \quad \ldots (3)$$

where Z and C are the density and speed of sound in the air respectively.

Average sound absorption coefficient was calculated as explained in previous studies[22,23], as shown below:

$$\text{Avg. SAC} = \sum_{i=63}^{6300} \alpha_n. \quad \ldots (4)$$

2.1.2Density

The density test was performed according to ASTM D4018 standards. The developed composite was weighed using a digital scale, and volume was calculated from the measured dimension. The density is then calculated using the following formula:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad \ldots (5)$$

where mass, volume and density are expressed in gram, $cm^3$and g/cm^3respectively**.**

2.1.3Pore Size Distribution

The pore sizes of the cattail-luffa fibre board were determined using a capillary flow parameter based on the principle of liquid extrusion porosimetry technique. A specimen of 18 mm in diameter was wetted with silicone oil (viscosity 10 cst) to its saturation point. The specimen was then placed within a sample probe (a circular chamber) and then sealed, followed by a flow of dry air into the chamber through the specimen.

2.1.4 Swelling Thickness of Cattail Fibre Board

The thickness swelling of the composite was evaluated as per ASTM D 5229. Before testing, the thickness of each sample was measured. All samples were immersed in distilled water at 27 °C. After 24 h, the sample was taken out and dried before its thickness was measured. The thickness value of the samples was taken. The dimension stability test was continued for several hours until the constant weight of samples was obtained.

3 Results and Discussion

Density, pore size, swelling thickness and Avg. SAC of cattail fibre board have been studied. The response surface approach has been used to develop the mathematical relationships that link density, pore size, swelling thickness and avg. SAC as a function of rice stubble ash loading, NaOH treatment and spray pressure level. All the outcomes of the experiments conducted are tabulated with measured responses in Table 2.

To analyse the effects of process and material variables with observed responses, following regression model can be adopted:

$$Y_i = f(X_1, X_2, X_3 \ldots\ldots\ldots\ldots\ldots X_n) \pm \varepsilon_i$$

where $X_1, X_2 \ldots\ldots X_n$ are independent variables (process parameters);Y_i are observed depended variables; and $\varepsilon$is residual error, which is the difference between actual and observed value.

From the ANOVA results (Table 3), the sum of the squares and quadratic of every variable where the p-

Table 2 — Experimentally observed density, pore size, swelling thickness and avg. SAC of composite samples

Run	Surface treatment %	Filler size, µm	Pressure level psi	Density, g/cc	Pore size, µm	Swelling thickness %	Avg. SAC
S1	6	150	45	0.08	105.0	19.3	0.18
S2	6	150	45	0.09	66.0	11.9	0.18
S3	4	150	30	0.06	103.5	17.7	0.19
S4	8	150	60	0.09	74.0	12.7	0.19
S5	8	200	45	0.09	95.0	13.6	0.22
S6	6	150	45	0.08	101.0	16.2	0.23
S7	6	150	45	0.06	105.2	18.2	0.23
S8	4	150	60	0.07	101.4	16.9	0.15
S9	4	200	45	0.09	70.0	12.1	0.15
S10	8	150	30	0.08	96.0	13.8	0.26
S11	6	100	60	0.08	105.0	18.0	0.14
S12	6	150	45	0.08	92.8	14.3	0.19
S13	6	200	60	0.08	100.8	16.3	0.16
S14	6	100	30	0.08	99.0	15.9	0.25
S15	4	100	45	0.07	76.4	11.9	0.19
S16	6	200	30	0.07	108.8	19.6	0.19
S17	8	100	45	0.08	98.0	15.9	0.22

Table 3 — Statistical parameters and regression coefficient for density, pore size, swelling thickness and avg. SAC of composite (ANOVA output)

Parameter	Prob>F	Lack of fit	Predicted R^2	R^2	Adjusted R^2
Density, g/cc	0.0002 (Significant)	0.0687 (not significant)	0.60	0.97	0.93
Pore size µm	0.0016 (significant)	0.1099 (not significant)	0.26	0.94	0.86
Swelling thickness %	0.0016 (significant)	0.3043 (not significant)	0.42	0.94	0.86
Avg. SAC	< 0.0001 (significant	0.4208not significant	0.64	0.97	0.94

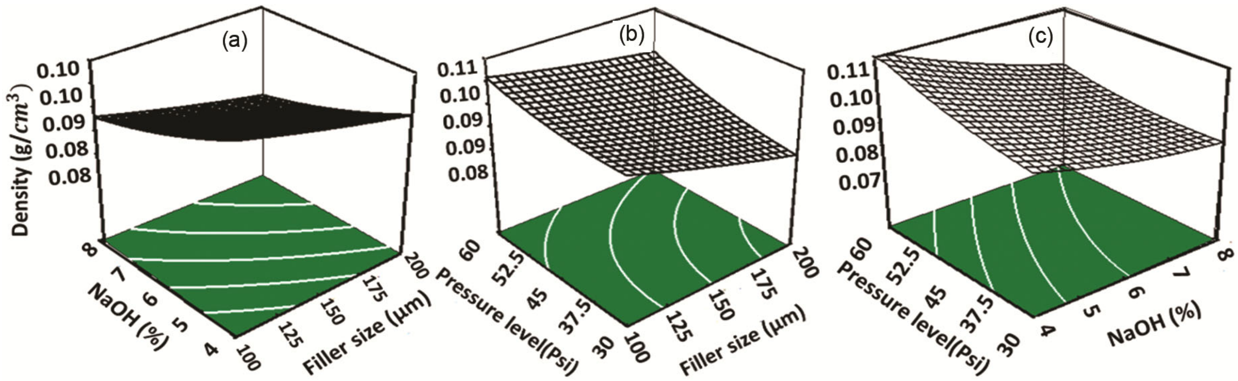

Fig 2 — Effect of (a) filler size andNaOH, (b) pressure level and filler size and (c) pressure level andNaOHon density of fibreboard

variable and F-value describe the ratio of the respective suggested square impact and the suggested square error (write here that the quadratic model is significant considering all the factors) are observed. The insignificant or the "lack of fit" with a p-variable of 0.05 for all responses indicate that the model is satisfactorily equipped with the data. The R^2value observed for density, pore size, swelling thickness and avg. SAC responses are 0.97, 0.94, 0.94 and 0.97 respectively, indicating the model's suitability to the experimental data.

The adjusted R^2(owed for various predictors within the model) values are 0.93, 0.86, 0.86 and 0.94 respectively, which is fairly high. The expected R^2 values are 0.60, 0.26, 0.42 and 0.64 respectively, which is quite lower than the R^2, value.The R^2, adjusted R^2, and expected R^2 values confirm a robust interrelation between observed and expected values, which confirms utility of experimental analysis. Multiple regression evaluation is used to decide the coefficients in the second-order polynomial equation, primarily based on the experimental results. Thus, the analytical expressions have been derived by processing them in the Design Expert Software and are represented as shown below:

Density =+0.17 −1.4× filler size + 0.01375 × NaOH (%)− 2.0 × pressure level +3.50× filler size ^{2}−1.56 × NaOH (%) ^{2} +1.6 × pressure level^2 +2.5× filler size × NaOH (%) +3.33× filler size ×pressure level+8.33×NaOH (%) ×pressure level …(6)

Pore size = +40.63 +0.24 × filler size+10.95 ×NaOH (%) +0.080 × pressure level -2.15-004×filler size^2−0.17×NaOH (%) ^{2} -0.02× pressure level^2−0.05× filler size ×NaOH (%) +7.22E-003× filler size × pressure level +0.038 ×NaOH (%) × presure level …(7)

Swelling thickness = −4.42 +0.094× filler size +0.93 ×NaOH (%) +0.45 × pressure level +1.161E-00 × filler size^2 +0.083 ×NaOH (%) ^{2}−5.47E-003 × pressure level^2−9.74E-003×filler size × NaOH(%) −7.69E-004×filler size × pressure level −3.19E-003× NaOH (%) × pressure level …(8)

Avg. SAC=+0.26 −1.3E-004 × filler size -0.03 ×NaOH(%) + 2.46E-004 × pressure level +3.66E-007× filler size^2 + 4.89E-003×NaOH(%) ^{2}- 4.31E-005 ×pressure level^2−2.78572E-00 × filler size ×NaOH(%) + 1.80E-005× filler size × pressure level −1.36E-004 × NaOH(%) × pressure level …(9)

3.1 Effect of Filler Size, NaOH (%) and Pressure level on Density of Composite

The interconnectivity effect and interaction between added filler size and NaOH treatment (%) given at constant adhesive spray pressure 45psi, on the composite density are plotted and shown in Fig.2(a). The optimum density is observed at 0.09 g/cm^3 when NaOH (%) is kept at 6 %. The density of the fibre board decreases as filler size is increased from 100µmto 200µm. Small-sized grains are expected to offer more compact packing in the composite structure during the compression process, which finally results in a higher density of composites, as also reported earlier [23,24]. The density of the fibreboard is increased from 0.07g/cm^3 to

0.1 g/cm^3 by increasing the pressure level of the spray nozzle from 30psi to 60 psi, as shown in Fig. 2(b). It may be due to the high impregnation and more deposition of resin on the surface of fibrous materials. Figure 2(c) shows the effect of pressure level and NaOH treatment on density.It indicates that as the pressure level increases, the resultantdensity increases, while density decreases by increasing the NaOH concentration.

3.2 Pore Size Distribution

The relationship between filler size and NaOH pre-treatment on the fibreboard for the mean pore size is shown in Fig. 3(a), keeping the pressure level constant at 45 psi. The board pore size is increased to 96.3μm by increasing the NaOH treatment to 8%, which increases the surface area of lignocellulosic fibrous materials.

The pore size in the fibre board is decreased from 100.3μm to 75.4 μm by increasing the pressure level of spray nozzle content from 30 psi to 60 psi [Fig. 3(b)]. It may be attributed to the high impregnation of the resin into the fibrous structure and the filling of available free space. The pore size is increased to 108.9 μm by increasing the filler size. The increased particle size leads to the increase in number of pores, as reported in the case of rice husk ash[25]. The effect of pressure level and NaOH treatment on pore size is shown in Fig. 3(c), which indicates that porosity is increased from 67.4μm to 96.7μm by increasing NaOH (%). The effect of pressure level follows the same trends as shown in Fig. 3(a). The effect of NaOH treatment and filler size is clearly visible on the pore size of the acoustic board.

3.3 Thickness Swelling

The effect of filler particle size and NaOH treatment on fibre board thickness swelling is shown in Fig. 4(a), keeping a constant pressure at 45 psi. Thickness swelling is increased up to 18.1 %, when NaOH (%) is increased up to 8% due to the increasing surface area of lignocellulosic fibrous materials.

The thickness swelling of fibre board is increased from 12.8 % to 19.5 % by increasing filler size from

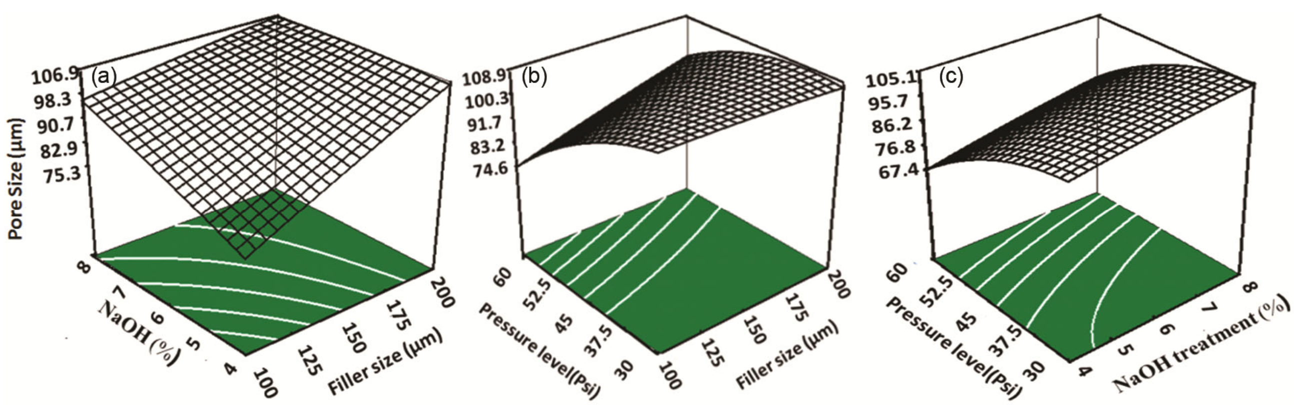

Fig. 3 — Effect of (a) filler size andNaOH, (b) pressure level and filler size and (c) pressure level andNaOHon pore size distribution of fibreboard

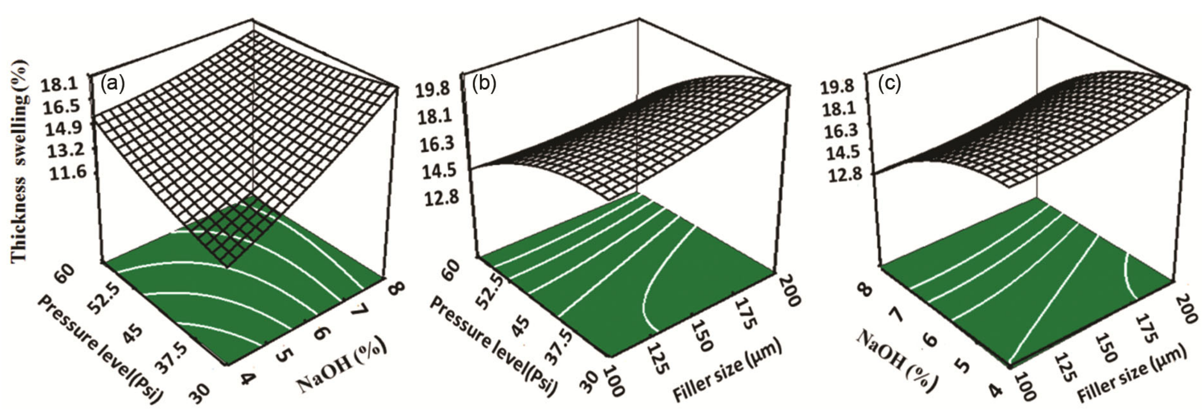

Fig 4 — Effect of (a) pressure level and NaOH, (b) pressure level and filler size and (c) filler size and NaOHon thickness swelling of fibreboard

100 µm to 200 µm [Fig. 4(b)]. The water resistance of acoustic boards decreases by increasing the content of coarse particles, which may be accredited to the high absorption of water into the fibreboard and the availability of more surface area in the fibreboard interior[26]. The thickness swelling is decreased due to high impregnation of the resin, resulting the blocking of the pores. The effect of pressure level and NaOH treatment on thickness swelling is shown in Fig.4(c), which indicates the effect of pressure level and filler size on thickness swelling.This follows the same trends as shown in the Figs 4(a) and (b).

The effect of NaOH (%), filler size and pressure level on the swelling thickness of the acoustic board are clearly visible.

3.4 Sound Absorption Coefficient

The pressure level of the spray kept constant at 45 psi to study the effect of NaOH (%) and filler size on average sound absorption coefficient (SAC) [Fig. 5(a)]. The Avg. SAC increases from 0.15 to 0.26 as filler size increases from 100µm to 200µm. Fine particles yield a composite with a smoother surface, filling empty spaces and sealing pores. Meanwhile, the medium and coarse particles produce composites without a solid bond, which improves the porosity and tortuosity, enabling sound waves to move through it more quickly.

Therefore, the sound absorption coefficient (α_n) improves as viscous shear, friction, and structural vibrations are occur, which results in a loss of incident sound energy[27]. The alkali concentration (NaOH %) is also found an essential factor in sound absorption [Fig. 5(b)]. The avg. SAC (α_n) is increased from 0.11 to 0.19 with the increase of NaOH (%)from 4 to 8, as also reported earlier [28].

A constant filler size of 150µm is used while studying the effect of NaOH (%) and varying pressure levels of spray on the average sound absorption coefficient (SAC) [Fig. 6(b)]. Varying pressure levels of the sprayed resin have a notable impact on SAC, as it affects the distribution and penetration of the resin into the fibres, thereby influencing the sound absorption properties. However, NaOH (%) is again

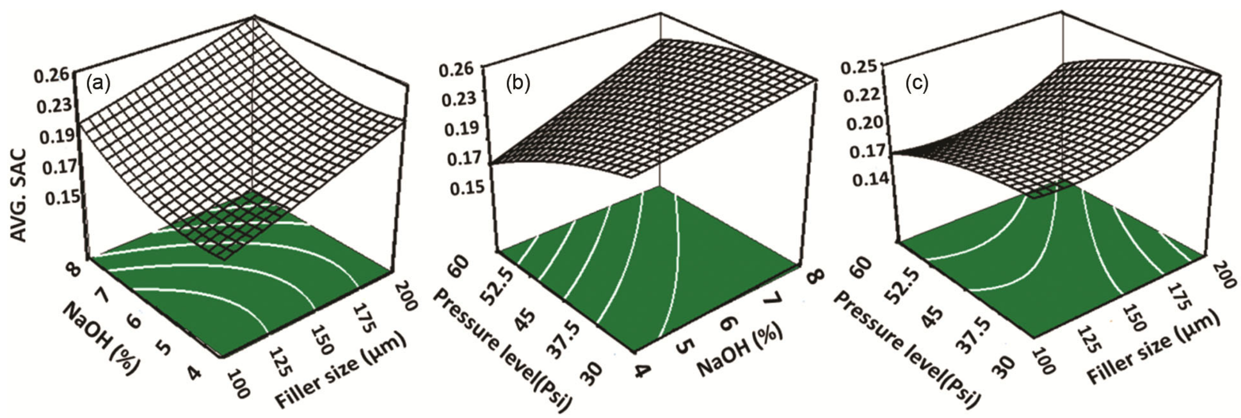

Fig 5 — Effect of (a) filler size and NaOH, (b) pressure level and NaOH and (c) pressure level and filler sizeon Avg, sound absorption coefficient of fibre board

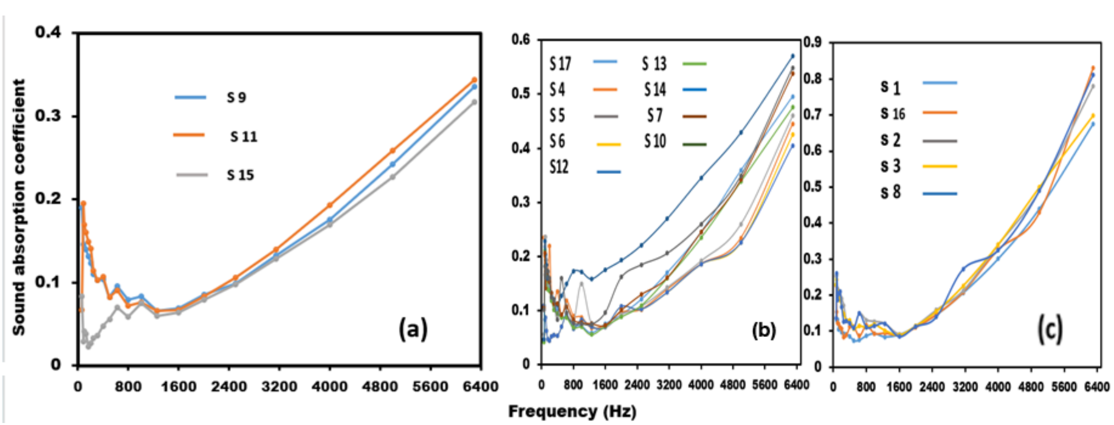

Fig. 6 — Effect of (a) high spray pressure, low NaOH and fine filler size, (b) moderate alkali treatment, spray pressure and filler size, and (c) low pressure level, coarse particle size and highNaOH on sound absorption of fibreboard

found to have a decisive effect on avg. SAC, that increases from 0.16 to 0.26 [Fig. 5(c)].

Alkaline treatment modifies the structure and surface of the fibres, which helps to eliminate a large amount of hemicellulose, cellulose, lignin, and other impurities that leave behind voids and roughness on the fibre's surface[29]. This shows that the rough surface of the fibres increases the frictional losses of the propagating sound waves in the media, which results in high sound absorption coefficients, as also observed earlier[30]. The avg. SAC significantly increases from 0.16 to 0.25, as the filler size increases from 100µm to 200µm, which is attributed to larger filler sizes resulting in a more porous structure.This allows for better sound absorption. From the above experimental observation, it can be concluded that NaOH (%) and filler size affect the sound absorption coefficient (α_n) of the acoustic panel most significantly.

Samples S9, S11, and S15 consist of high resin spray pressure, finer filler size, and low alkali treatment, thus exhibiting a low sound absorption coefficient (α_n). The sound absorption coefficient (α_n) of these samples is found lower than that of other samples and does not exceed the SAC at 0.4 at a high frequency of 6300 Hz [Fig. 6(a)]. A similar observation is also reported for polyester and polyamide nonwoven-based acoustic absorbers in earlier work[31].

Our findings suggest that fine particles create a smoother surface, filling empty spaces and sealing pores. Interestingly, this results in a better SAC than the specimens using medium and coarse-sized fillers when the frequency is lower than 1000 Hz. This higher SAC, compared to kenaf fibre-reinforced thermoset composites of similar type, can be attributed to the smoother surfaces created by finer-sized particles. These surfaces potentially increase the reflected sound energy, consequently reducing sound dissipation as the incident energy cannot penetrate the composite[32]. Composites prepared using medium-sized particles with surface treatment show an excellent sound absorption coefficient (0.6) [Fig. 6(b)] that is comparable with commercial acoustic mats at high frequencies. As the used filler size increases, the sound absorption coefficient also increases linearly in the frequency range 2000 - 6300 Hz. At a low-frequency range (up to 1600 Hz), filler size does not influence sound absorption significantly. It has also been observed that as the treatment intensity is increased, sound absorption is also increased due to high specific surface area availability on the fibre surface, as also confirmed by the previous works[31]. Additionally, the acoustic fibreboards are found to contain a large number of open pores throughout the surface that must interact with and absorb the incident sound waves.

When the sample is prepared with lesser resin application, a coarser particle size (200 µm) with intense alkaline treatment shows high sound absorption at a wide frequency range. The sound absorption coefficient is increased up to 0.83 [Fig. (6c)], which is greater than that of recycled cotton /polyester air-laid nonwoven fabrics [22]. The increase in porosity, when the pressure level of the nozzle decreases causes the sound waves to penetrate the sample smoothly, thus enhancing the absorption performance of the low-density sample.

3.5 Optimization of Pore Size, Density, Thickness Swelling and Avg. SAC

The effect of NaOH %, spray gun pressure and rice stubble ash particle size on the density, pore size and thickness swelling of the fibreboard composites has been analysed for product development and optimization purposes. The preferred density of the composite should remain on the lower side. The optimization is performed by a response optimizer tool of design expert software. The lowest density, optimum pore size, thickness swelling and Avg. SAC of the fibreboard are achieved at 0.07 g/cm^3, 93.7µm, 13.2 % and 0.25 respectively, in a sample consisting of 8 % NaOH, 177.3 µm filler size and 37.2 psi pressure level (Fig. 7).

3.6 Surface Morphology of Fibreboard

The surface morphology of the cattail fibreboard is shown in Fig. 8. It is clearly seen in the SEM photographs that pores are available throughout the surface, which results in the availability of free space for optimum sound absorption. The effect of alkali treatment, rice stubble ash and spray bonding are different, but the combined effect of these parameters maintains sufficient porosity throughout the surface. As the alkali treatment increases, the pore size is also increasing. The pore shape or size is irregular and shaped as expected. However, in fibrous web, the pore size distribution is relatively uniform and small, as can be visually observed. The rice stubble ash content in acoustic panel composite reflects its effect on pore size; as the particle size is finer, pores become blocked or narrow, as can be seen in Fig. 8 (SEM).

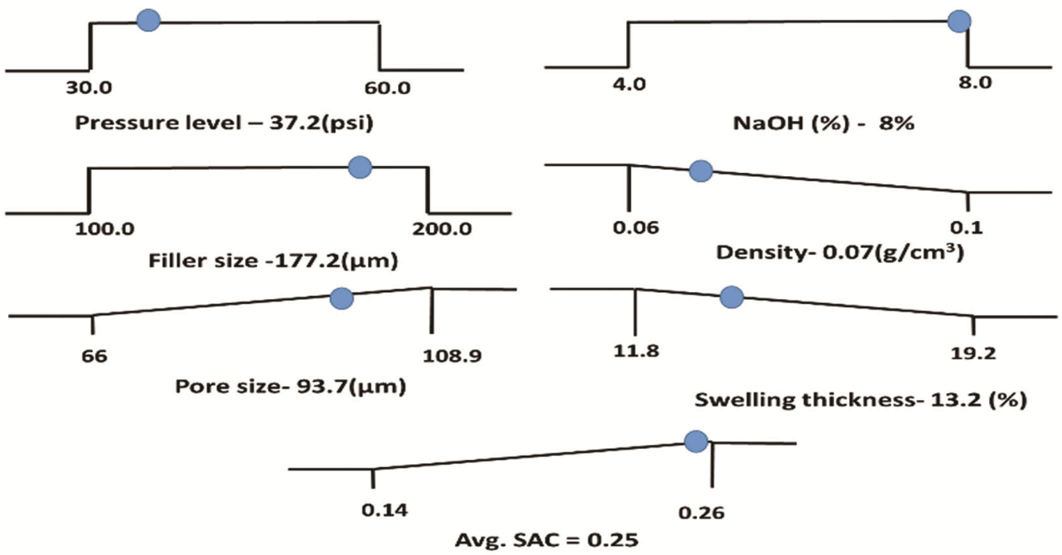

Fig. 7 — Optimization of pore size, density, thickness swelling and avg. SAC of fibreboard

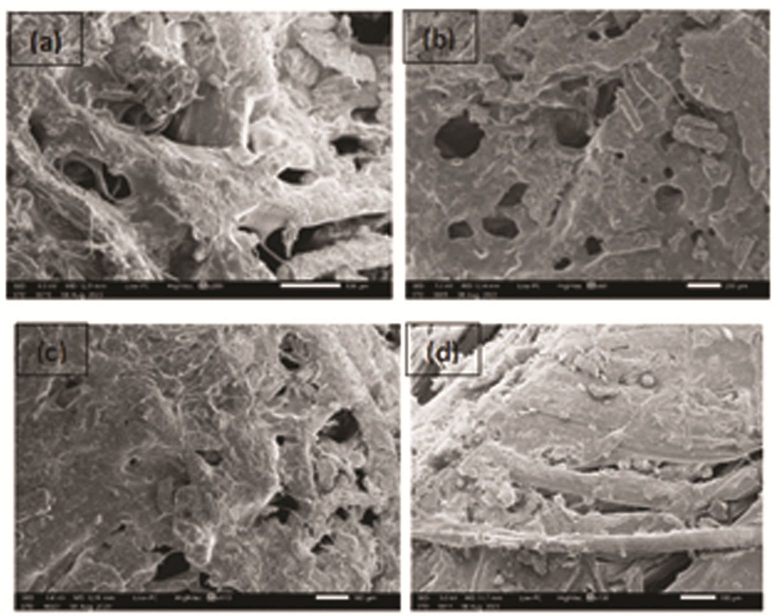

Fig. 8 — Surface morphology of fibreboard with varying spray pressure level from (a) 30 psi, (b) 45 psi and (c) 60 psi; and (d) filler distribution on fibre

4 Conclusion

The results demonstrate that the fibre-reinforced composites have high sound absorption capabilities, in general. The effect of alkaline treatment, particle size and pressure level of spray has been examined using a designed experiment and it is found that these parameters have a considerable impact on sound absorption performance. Medium and coarse particle sizes exhibit superior sound absorption coefficient, (more than 0.80). Cattail-luffa fibre-reinforced composites are good sound insulators at a wide range of frequencies and effectively absorb medium to high-frequency sounds. The experimental findings of the current studies are appropriate and prove the utility of such sound-absorbing insulating materials. These boards exceed the standards of commercial wood planks, ordinary planks, and plywood used in buildings as non-structural panels to absorb sound. Finally, this study demonstrates that cattail may be used to create economically feasible, eco-friendly sound absorption materials with satisfactory performance that can replace synthetic fibres and commercial wood-based acoustic panel materials.

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