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Acoustic Performance Evaluation of Sugarcane Bagasse Using Ambient Sound Meter and Scanning Electron Microscopy

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Abstract: Non-stop research is afoot to replace synthetic materials with green-materials for sound absorption purposes. Employing of agricultural waste as building materials has been a successful trend throughout the years. This research targets to utilize sugarcane bagasse (SB) fibers as sound barriers with sodium silicate as an adhesive. The SB fibers were treated in an alkaline solution for delignification and to improve the surface morphology. The SB fibers were casted into sheet and further tested for sound transmission loss. Experimentation revealed that the fabricated sheets can be viable option as a sound absorbing medium. A tubular porous structure was observed through Field Emission Scanning Microscope (FESEM). It has the capability to be used as a low-cost, biodegradable, and eco-friendly acoustic material as compared to glass wool and other synthetic acoustic materials.

Keywords: Acoustic material, Alkali-treatment, Ambience, FESEM microscopy, Low-cost, Natural fiber, Performance, Sugarcane Bagasse, Sustainability

I. INTRODUCTION

Noise has now emerged as a synonym for nuisance in today's developing world. With increasing competitiveness and thereby the growth of stress levels, any unwanted sound triggers the frustration levels of individuals. It has been proved that uncontrolled acoustic pollution for prolonged intervals of time can cause hearing impairment and can also disturb communications by distorting speeches[1]. It can cause sleeping disorders which results in discomfort and consequently affects the physical and mental health of the people [2]. Therefore, it was in the opinion of the researchers that there is a need for a low cost sound absorbing material that can be economically utilized by all sectors of the society.

Many researchers have already pitched in their findings on sustainable materials [3]. Majority agrees that the commercially available synthetic panels are sufficient to overcome the acoustic needs of the society, yet there are concerns for the environmental impact of those materials. Rockwool, Glass wool and mineral wool have effective acoustic results but they have been a source of lung disease and skin irritations and hence have been prohibited from use in many countries [4].

It has been observed that production using natural fibers or recycled materials have a lower environmental impact than conventional one's [5] India being an agricultural nation is also the second largest producer of sugarcane in the world. For every 10tons of sugarcane, 03 tons of bagasse is produced. According to the Indian Sugar Mills Association it was predicted to produce 376.905tons of sugarcane by the year 2021 and thus generating equivalent amount of bagasse as agricultural waste. Since SB cannot be used as a manure or cattle feed without processing, it becomes a huge task to dispose such large quantities. This research has aimed to utilize the SB fibers as the base material for developing an eco-friendly, renewable substitute for the acoustic needs [6]. In a research exploring the sound absorbing properties, it was found that natural fibers mixed with appropriate binders such as sodium silicate, can be casted into particle boards and can be used as recyclable acoustic panels which can reduce impact on the environment [7]. The choice of sodium hydroxide was based on the research data which concluded that it improves the wettability and surface morphology of the natural fibers without damaging the cellulose content and de-lignifies the fibers thus acting as a dispersing agent[8]. Whereas the choice of sodium silicate was based on the adhesive properties of sodium silicate and the fact that they are silica based which complement the nature of bagasse [9]. Sodium Silicate also acts as an insecticide as it repels insects due to its smell [10]. It also renders fire retardant and water proofing characteristics [11] There have been recent advancements on the usage of natural fibers as a perspective substitute for synthetic fibers. Table 1 represents the comparison between natural and synthetic fibers based on the technical and environmental aspects. There have been concerns on the decaying and rotting of the natural fibers under moisture conditions [12].

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Many studies targeted on evolving the natural fibers have reported on fibers as Arenga pinnata fibers, Betung bamboo, coconut coir and many others and have explored their prospects to be used as raw materials for acoustic panels [13,14]. Natural materials can be substituted to synthetic materials because of their acoustic performance and as they are available in market at competitive prices [15].
In this study the potential for using SB was analyzed by exposing it to alkali-treatment and then lining it on the surface of a test box with sodium silicate solution which acts as an adhesive. Morphological features of the fibers were studied using a Field Emission Scanning Electron Microscope (FESEM) [16]. The changes due to chemical treatment were visible and contributed to the acoustic properties of the material.

Table 1.
Comparison Between natural Fibers and Synthetic Fibers [17].

Aspect	Property	Natural Fibers	Synthetic Fibers
Technical	Mechanical properties	Moderate	High
	Moisture sensitivity	High	Low
	Thermal sensitivity	High	Low
	Resource	Infinite	Limited
Environmental	Production	Low	High
	Recyclability	Good	Moderate

II. RESEARCH SIGNIFICANCE

The study of Sb fibers using alkali-treatment and their combination with sodium silicate to provide an eco-friendly solution represents the research gap identified by the authors. Reference literature presents the material characteristics [5,18] but they failed to present the economic relation between them. Through this study an indigenous method of testing has been established which can be used for screening the acoustic potential of the materials in the preliminary stages of testing.
Therefore, this research adds to the present depiction and exploration of SB considering several parameters (cost, environmental impact, sound absorption, transmission loss) for providing a low cost acoustic solution.

III.METHODOLOGY

This research proposes a preliminary screening method for selection of an acoustic material using an indigenous method of testing. There are other methods as per ASTM E90-09 (2016), ASTM E492-09 (2016) e1, ISO 10140-2, ISO 16283-1 which include testing using Impedance tube, Air flow resistivity technique and Acoustic Chamber method. The sample was tested at four frequencies- 125Hz, 250Hz, 500Hz, 1000Hz. The sound absorption coefficient and transmission loss [18] were recorded and a graph representing the visible change in noise reduction was presented.

IV. EXPERIMENTATION

A. Schedule

The flow chart given below represents the entire analysis schedule.

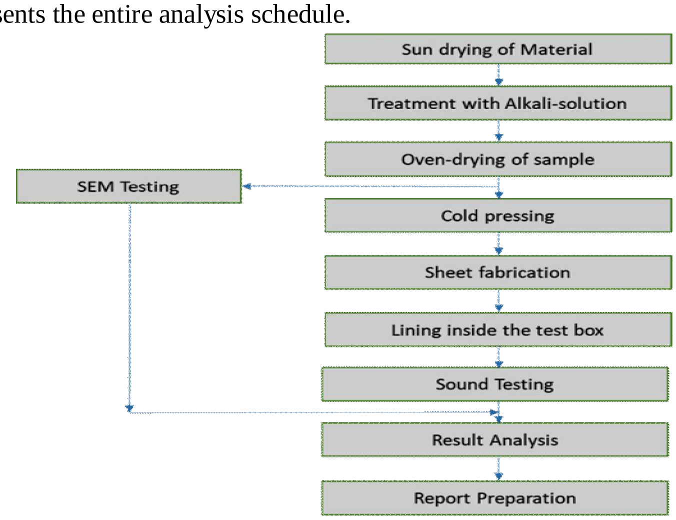

Fig. 1 - Flow chart representing experimentation schedule

B. Material: Procurement

SB was collected from street vendors. During the scorching heat of summers in India, sugarcane juice finds a large consumer base as it is a cheap source of refreshment and energy revival. This results in generation of large quantities of SB. It being difficult to dispose was happily given by the vendors. Other chemicals (sodium hydroxide and sodium silicate) were purchased from Bharti Scientific Store, Aminabad, Lucknow, Uttar Pradesh [Fig. 2].

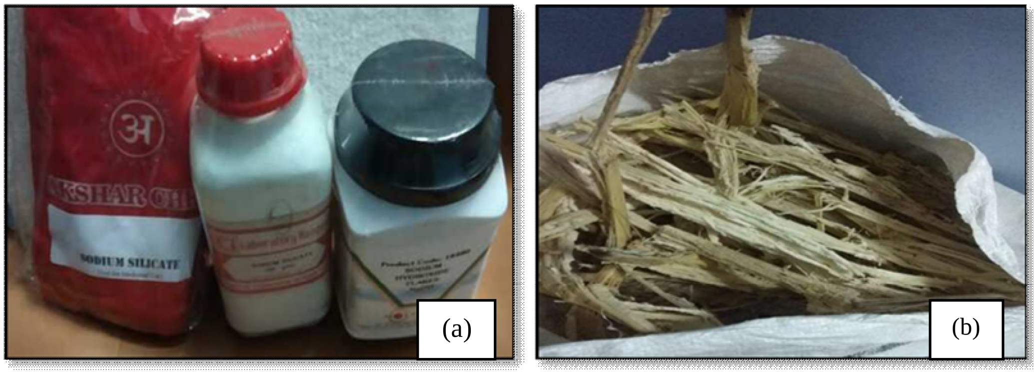

Fig. 2- Image of the procured material: (a) Chemicals, (b) SB

C. Material: Treatment

The procured SB was sun dried for 8hrs. to ensure removal of any moisture present in them. The SB sample was then chopped into manageable lengths of 10cms-15cms. At this stage the fibers were bundled up. A 5% concentration NaOH solution was prepared in 3000ml of tap water (pH 7.3) and was kept for heating on a hot plate. Figure 3 represents the preparations for treatment of sample. 40gms. of chopped bagasse was added to the solution. The sample was boiled for 180mins at 98°C. At this point, the sample was completely de-lignified and the dirt was separated from the fibers. The fibers were bleached and had dispersed. The fibers were air cooled and then washed under tap water (pH 7.3). Figure 4 represents the treatment of sample where in section (a) the initial alkali-treatment at 20mins after addition of heat and bagasse are visible; section(b) indicates the entire heating duration of 180mins; section(c) represents the air cooling duration which is dependent on the atmospheric conditions; section (d) represents the dispersed fibers after alkali treatment; at section(e) the water washed sample can be seen which shows the difference between treated and untreated SB fibers and their bleached condition; section (f) marks the soaked sample representation; section(g) shows the process of laying fibers in a vessel and section(h) the process of weighing before and after drying the sample are shown. It is necessary for preparation of graph to ensure complete drying. The changes in the color of the solution indicating the removal of dirt and lignin from the fibers has been depicted through Figure 5. The soaked sample was oven dried in a hot air oven pre-heated at 60°C for different intervals (ranging from 30mins to 10mins) to ensure complete drying. It was ensured by plotting a curve of weight loss after each drying interval to the point where the weight loss becomes constant thus indicating no presence of moisture [Fig. 6].

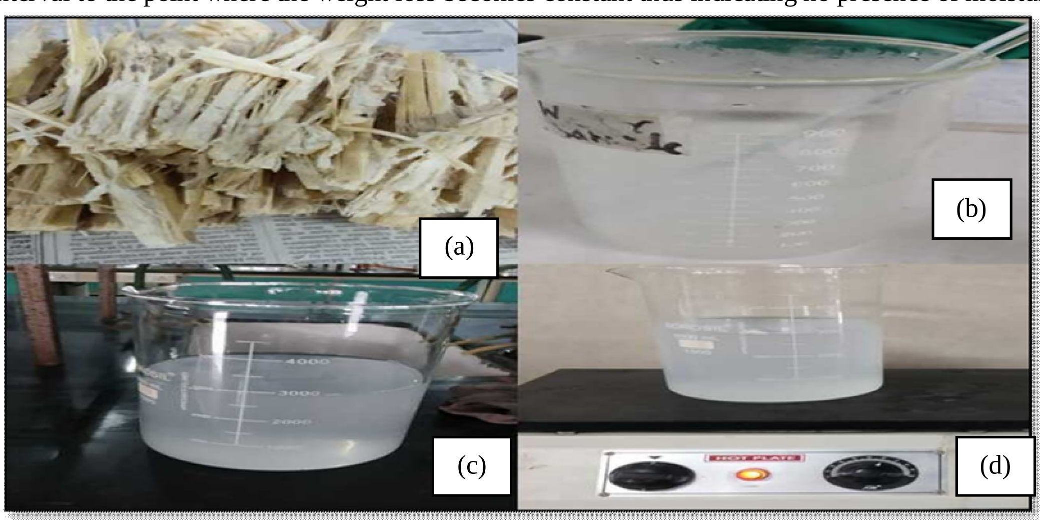

Fig. 3- Images of- (a) Chopped SB, (b) NaOH dilution, (c) NaOH soln. 5% conc. (d) Work Assembly

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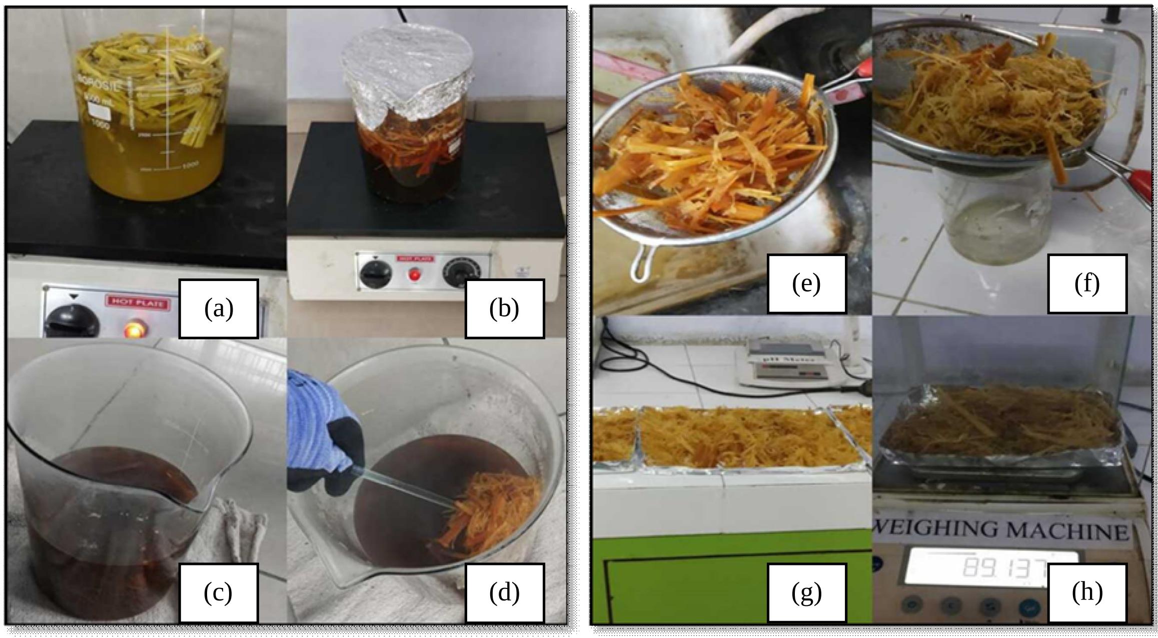

Fig. 4- Representation of entire alkali-treatment process (detailed description above)

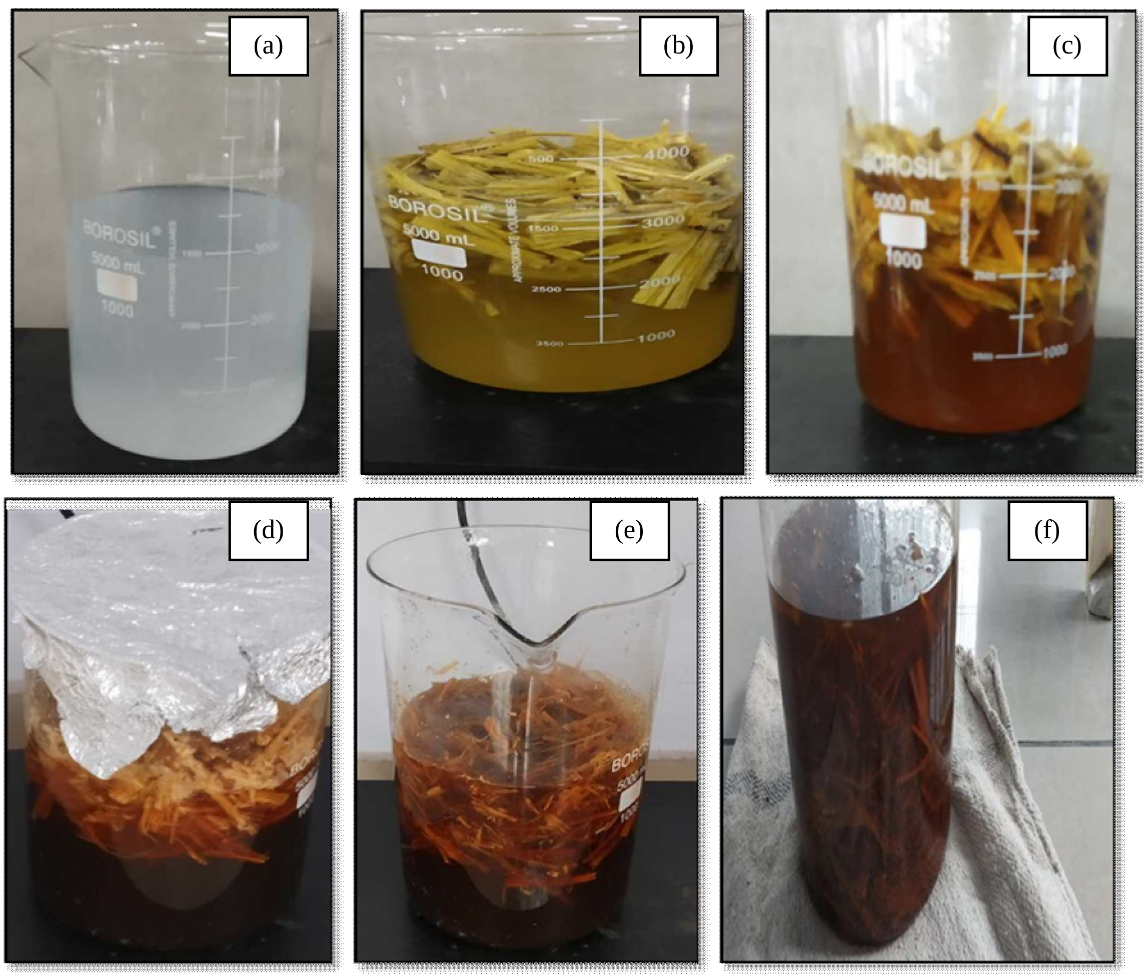

Fig. 5- (a) initial stage; (b) after 20mins; (c) after 60mins; (d) after 120mins; (e) after 150mins; (f) after 180mins

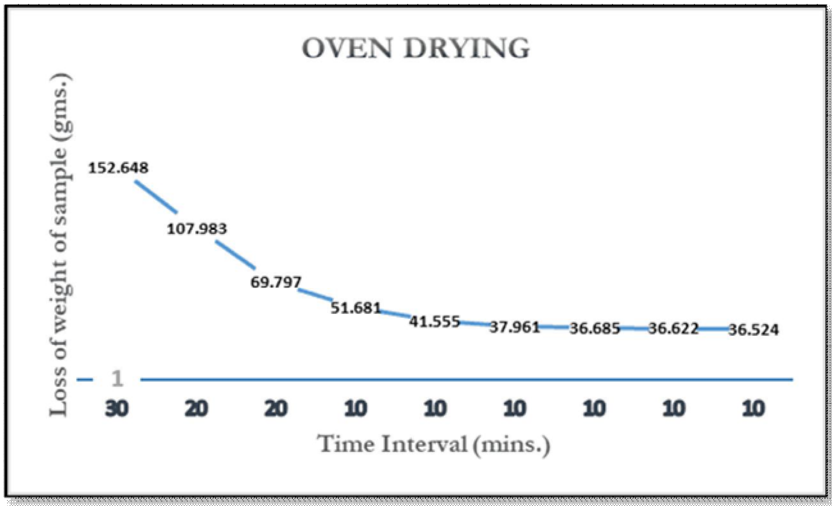

Fig. 6- Graph representing oven drying process

D. Material: Microscopic Analysis

After oven-drying the sample, the treated sample was subjected to optical microscopy on a JEOL Field Emission Scanning Electron (FESEM) (Jeol Limited, Tokyo, Japan). Longitudinal views, cross-sectional views and a study of the surface morphology of the sample was conducted at different magnifications and accelerated voltages.

The following observations were made during SEM analysis-

1) A tubular porous structure had developed as a result of the alkali treatment. [Fig. 7]
2) After removal of lignin from the surface, the surface has become cleaner and the cellulose has developed projections that improve the inter-facial bond. [Fig. 8]
3) The fibres have completely separated from their bundles thus improving the porosity of the sample. [Fig. 9]
4) The individual fiber diameter ranges from- 1.88µm to 3.75µm. [Fig. 10]

It can be inferred from the microscopic analysis that the alkali-treatment has proven successful in improving the surface characteristics of the sample and have rendered the features (porosity and surface roughness) that contribute to the acoustic qualities as a sound absorber.

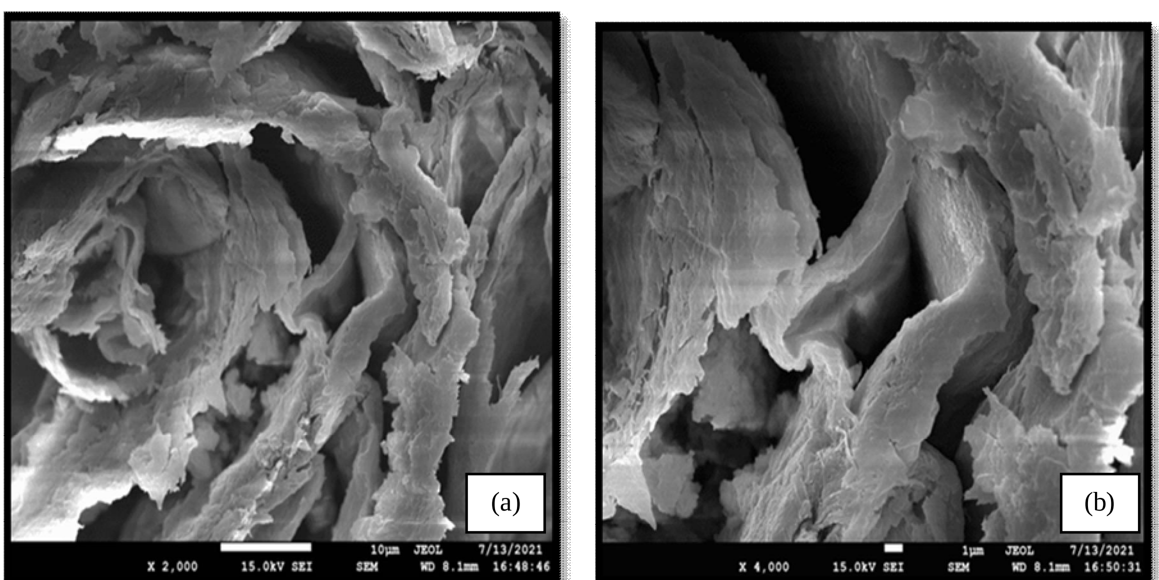

Fig.7 - SEM imaging displaying the tubular structure of the bagasse fibers developed as a result of NaOH Treatment at (a) 2000x and (b) 4000x

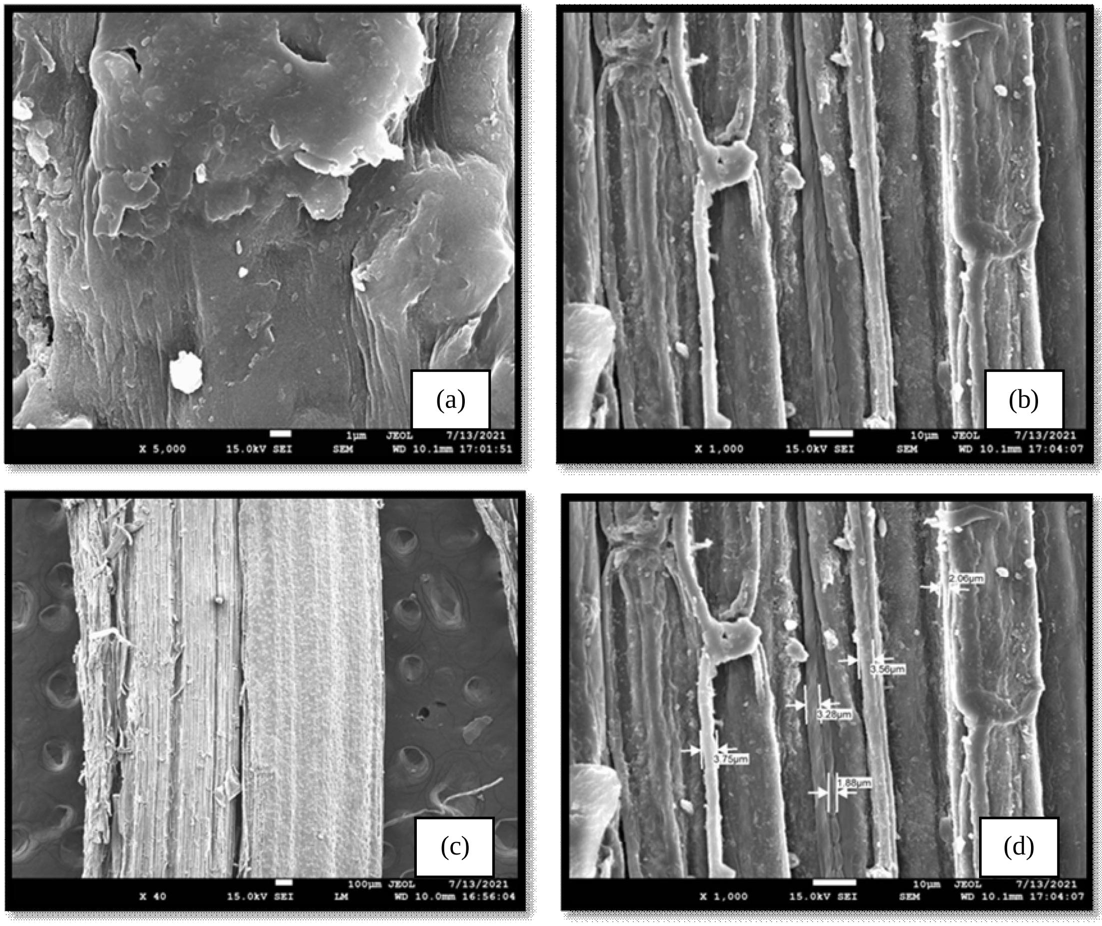

Fig. 8- SEM image- (a) 5000x Surface texture; (b) 1000x fiber projections; (c) 40x Fiber imaging; (d) 1000x Individual diameters

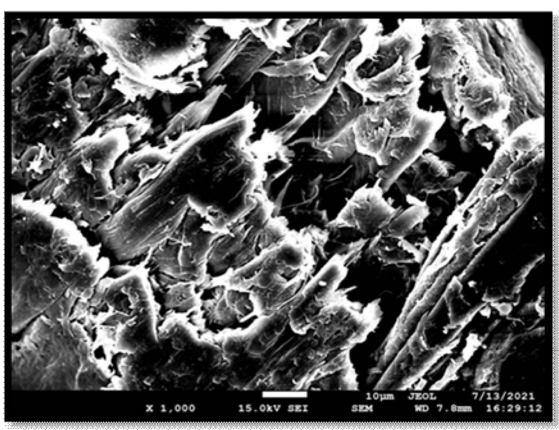

Fig. 9- SEM image of separated fibres

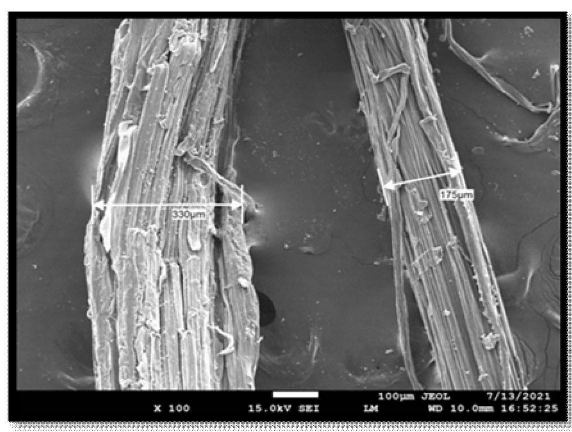

Fig. 10- SEM image of fibre diameter range

E. Material: Fabrication

The treated SB fibres were spread om a cement board of 1sq.ft. dimension and were covered with another board of same dimension. The sheet was cold pressed with 1kg as shown in Figure 11. weight to ensure even casting. Three sheet specimens of 10mm, 20mm and 30mm thickness were prepared. The sheets were cut and lined in a test box (170mm×105mm×65mm). All the six faces of the test box were covered with the prepared specimen using sodium silicate solution (prepared by diluting sodium silicate gel in lukewarm water to a thick consistency) [19] [Figure 12].

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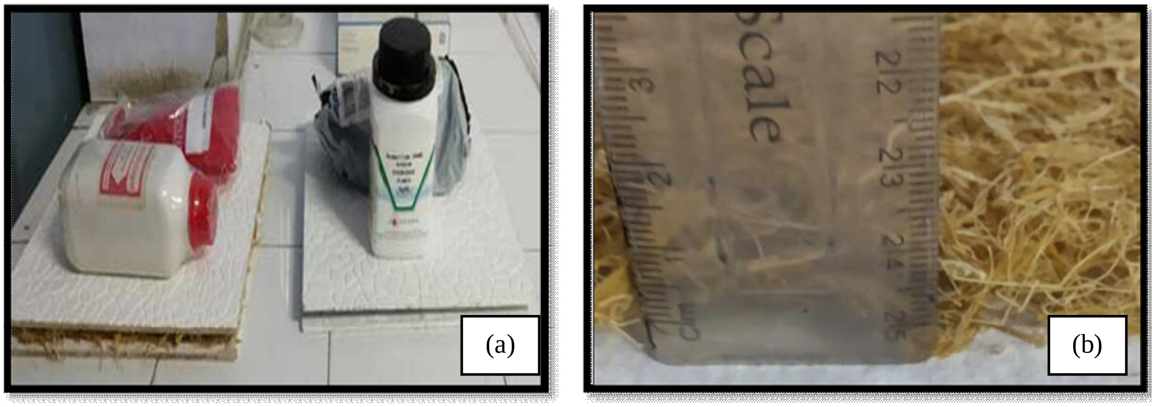

Fig. 11- Fabrication process- (a) moulding; (b) measurement

Fig. 12- Fabrication process stages- (a) moulded sheet; (b) cutting as per required size; (c) Adhesive preparation; (d) Lining in the test box

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F. Material: Testing

A home-grown method of testing has been established to record the performance of the material [20]. A test box lined with the treated material was prepared and the sound source in the form of a keypad mobile phone was kept inside the box [Fig. 13]. Sounds of frequency 125Hz, 250Hz, 500Hz and 1000Hz are generated using an online pure tone generator [21] for all three thickness linings (10mm, 20mm, 30mm). Using a Sound Level Meter- SLM 100 (Envirotech India Ltd.). The features of the SLM100 are depicted in Figure14 and Table 2 [22] An android application by the name Spectroid [23] are used to record the variation in the sound levels before and after inducing sound and applying barrier respectively. The transmission loss is recorded and the noise absorption coefficient is worked out based on the incident and recorded sounds through the barrier.

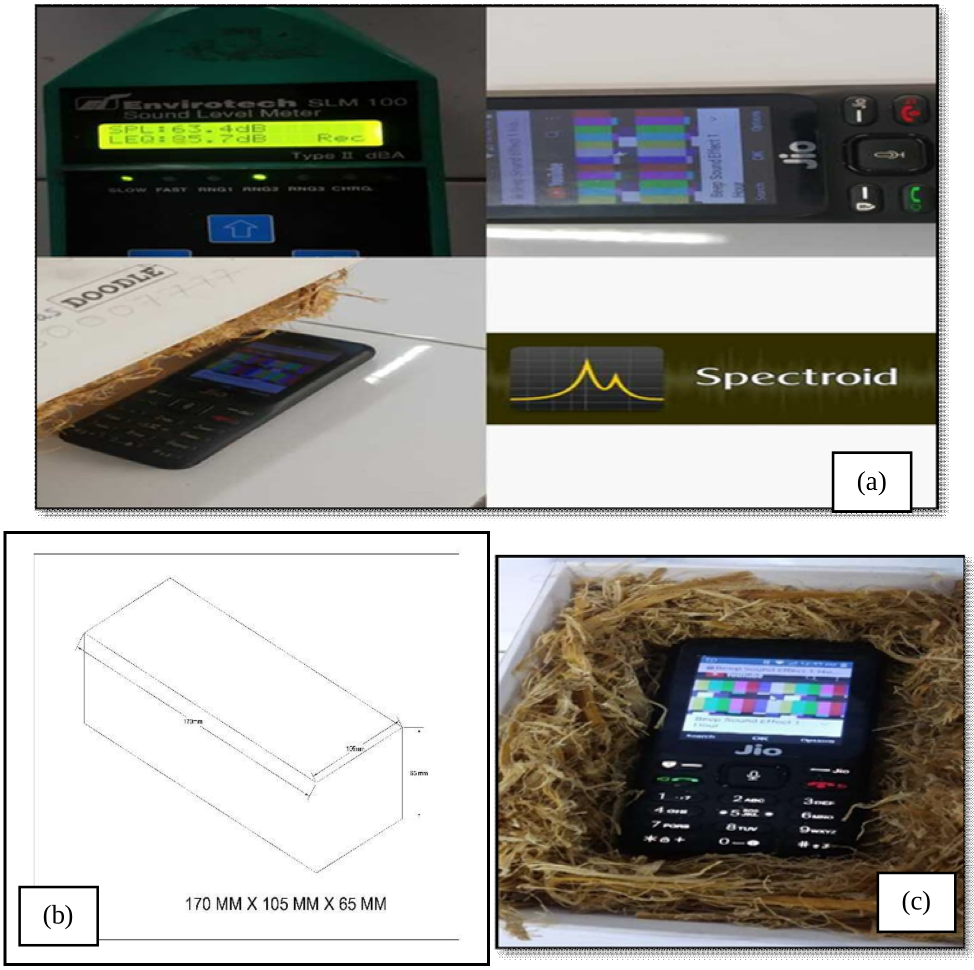

Fig. 13- Testing image- (a) equipment; (b) test box; (c) sound source inside the box

Fig. 14- SLM 100 sound meter

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Table 2
Features of SLM 100 [22]

SL. NO	FEATURE	DESCRIPTION
1	Accuracy / Class	Type II designed for field use Conforming to BIS 15575 (Part1) 2005
2	Measurement range	34 to 134 dB in three 50 dB overlapping ranges
3	Error indication	Over Range, Under Range and Low Battery
4	Time Weighting	SLOW and FAST as per IS 15575 (Part1) 2005
5	Measurements	Sound Pressure Level (SPL), MIN SPL, MAX SPL, LEQ, Sound Exposure Level (SEL) and run time continuously available on the display by selecting appropriate display screen
6	Operation Modes	Continuous and Recording In Continuous Mode SLM100 displays the current SPL level, LEQ, SEL etc. for the duration of current session of operation. In Recording Mode, current values of above parameters are displayed on the screen and LEQ, MIN SPL, MAX SPL, and SEL values integrated over a minute are recorded in the built-in data logger. The SLM100 allows the user to record multiple files making it possible to make a detailed survey at several locations before downloading data to a PC for Analysis
7	Memory Capacity	In built data logger can store more than 24 hours data (at 1 minute intervals) in non-volatile Flash Memory
8	Software	Windows compatible Software that allows data download to a PC and makes the data available in an Excel Spreadsheet for analysis and report preparation

V. RESULTS AND DISCUSSION

A. Cost Analysis

Table 3
Cost of Materials Used For Preparation

Sl. No.	Description	Price (INR/kg)	Source
1	Sugarcane Bagasse (SB)	2.21	U.P. Co-operative Sugar Federation Ltd.
2	Sodium Silicate	13	Market Review
3	Sodium Hydroxide	29	Market Review

The entire cost of the final product was dependent on the cost of the input materials.

Table 4
Cost comparison of prepared sample with commercial fibers (10MM)

Sl. No.	Description	Rate (INR/sq.ft.)
1	Prepared Sheet	8.055
2	Rock wool	12.077
3	Glass wool	13.935
4	Fiberglass	50

The cost of the prepared product was less than the commercially available non- eco-friendly synthetic fibres thus proving a success on the economy parameter of comparison. The choice of using SB was a major aspect in controlling the cost of the specimens and being an agro-waste it also helped in keeping the environmental impact in check.

B. Sound Absorption Coefficient (SAC)

The sound absorption coefficient of materials is correlated with frequency, and it varies with different frequencies.[24] It is the ratio of the incident and the absorbed sound energy.

$$\alpha = \left(\frac{Ea}{Eo}\right)$$

where, α = Sound Absorption Coefficient
Ea= Total absorbed sound energy
Eo= Overall sound energy subjected

The value of the SAC becomes 1 when the total subjected sound energy has been absorbed by the barrier. It is an ideal case scenario. All values above 0.2 are acceptable to be classed as a sound absorption material [25].

TABLE 5
SAC FOR DIFFERENT THICKNESS OF SPECIMEN

Sl. No.	Sample Thickness	125Hz	250Hz	500Hz	1000Hz
1	10mm	0.09	0.12	0.14	0.19
2	20mm	0.13	0.19	0.27	0.34
3	30mm	0.19	0.31	0.37	0.43

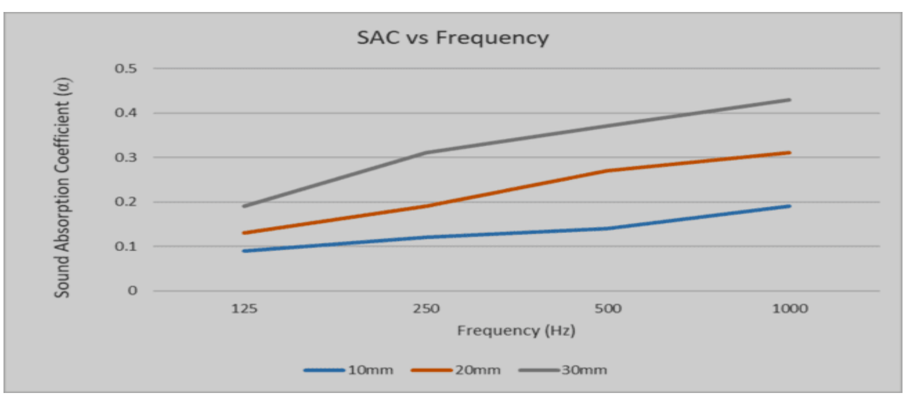

Fig. 14 Graph representing SAC vs Frequency

As observed, the maximum absorption was seen in the frequency range 500Hz to 1000Hz with the peak value achieved at 1000Hz for 30mm sample. It can be concluded to say that SB is suitable for upper mid values of the octave band.

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C. Sound Transmission Loss (STL)

Sound Transmission Loss (STL) depicts the amount of sound, in decibels (dB), that is secluded by a material or partition in a particular octave or 1/3 octave frequency band. The number of decibels stopped by an acoustic barrier relate to the acoustic peformance of the material. It is measured at different frequencies [26]. Figure 15 displays the method of recording where the difference of sound levels inside and outside the test box is recorded.

$$T.L. = (Ii - Io)$$

where, T.L.= Transmission Loss
Ii = Input Sound
Io = Output Sound

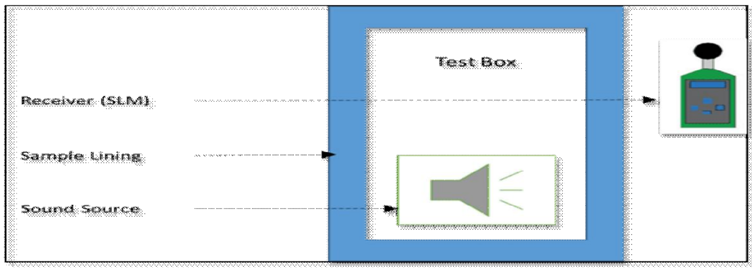

Fig. 15- Method of recording STL

Table 6
STL Caused by Different Thickness of Material

Sl. No.	Description	Sound Frequency			
		125Hz	250Hz	500Hz	1000Hz
1	Specimen 10mm	4	7	8	8
2	Specimen 20mm	11	13	15	17
3	Specimen 30mm	18	22	24	27
4	Glass Wool (20mm)	25	29	33	36
5	Rock Wool (20mm)	23	25	29	31
6	Fiberglass (20mm)	18	21	22	22

The transmission loss of the prepared sample is less than the commercially available fibers but the performance of 30mm sheet is comparable to that of the synthetic fibers. From the difference in performance among the sheets it can be said that the sound transmission loss increases with the increase in thickness. In noise engineering, it it a fact that the lower frequencies are difficult to absorb [27]. In this reference the performance of the prepared sheet was satisfactory for lower frequency levels.

VI. CONCLUSION

Bagasse –silicate additive sheets were successfully fabricated and preliminarily investigated. Experimental results suggest that it has good acoustic properties and is effective in reducing noise pollution at mid-octave frequencies (500Hz -1000Hz). Maximum absorption was observed by 30mm SB specimen for 1000Hz. The growth in sound absorbing capacity of the sample towards higher frequencies indicates that it may more effective in absorbing Upper level frequencies of the octave band. 10mm sheet was found to be 42% cheaper than the most widely used glass wool. Although glass wool has higher SAC but they were comparable to the prepared sample given the cost and environmental impact. Thus this innovative sound absorption sheet showed its viability as a low-cost and eco-friendly acoustic solution in comparison to glass wool and other synthetic fibers.

VII. ACKNOWLEDGEMENTS

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A. Funding

This research received no external funding.

B. Conflicts of Interest

The authors declare no conflicts of interest.

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