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Effect of Fiber Content and Chemical Modification on Sound Absorption of Bagasse Fiber – Filled Polyurethane Composite

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KeyWords

KeyWords: Noise Pollution, Polyurethane, Sugarcane Bagasse, Mercerization, Acetylating, Polymer Composite, Sound Absorption Coefficient

ABSTRACT

Sugarcane (*Saccharum Officinarum*) residue from Savanna Sugar Company in Numan local government area, Adamawa State, Nigeria was used as reinforcing filler in the preparation of natural fiber reinforced polymer composites for sound absorption application with polyurethane as the matrix. In order to determine the effect of fiber content and chemical modification of the natural fiber on sound absorption of the polymer composite, the prepared fiber was divided into three (3) portions, the crude (raw), mercerized and acetylated parts. 5% w/v of NaOH was used for mercerization process while mercerized fiber was further treated with 10% w/v of acetic acid and 14% w/v of acetic anhydride for acetylating. Four (4) fiber loading compositions of 5, 10, 15 & 20 wt% for the crude, mercerized and acetylated fibers were utilized while 100% pure matrix was used as control. The matrix and fiber were compounded using open molding casting technique (free rising foaming method) after magnetic and mechanical stirrers were used to attain homogenous mixture. Samples of the pure matrix, crude and treated composites were subjected to sound absorption coefficient measurement within the frequency range of 50-1600 Hz according to ASTM E1050-10. The results obtained revealed that both the Alkali and acetylating treatments carried out were successful in modification of the fiber. The crude fiber composite with 20wt% fiber loading has the best sound absorption coefficient of 0.925 which can be compared with materials in sound absorption class A, while mercerized and acetylated composites recorded low sound absorption coefficients in the range of 0.068-0.386 and fall in class D, E & F. The newly developed composite materials in class A and D have better sound absorption coefficient than the pure matrix and can be used for sound absorption applications in buildings.

I. INTRODUCTION

In recent years, noise has become an undesirable feature of the environment due to increased human activities. Apart from increase in world population, high level of industrialization has contributed to high level of noise pollution, making it worrisome. Noise pollution has negative effects on human health, it is one of the nuisances that decrease quality of human life; it disturbs sleep, interferes in complex task performance, modifies human behaviour and also causes annoyance. Noise pollution can have serious consequences on human health and can affect human body in three different ways; physical, physiological and psychological. The physical effects are direct effcts on peoples's health, such as loss of hearing. Physiologically, noise pollution adversely affects health resulting in stress while psychological related effects are distractions and annoyance [1, 2]. Amongst the noise pollutants in most of urban areas in developing countries are noise from vehicle traffic, pressure horns, construction industries, machineries, religious worship institutions and home power generating sets [3]. Reduction of noise pollution has been a major challenge due to lack of noise screens/acoustic ceiling tiles in most homes, offices and other buildings due to to high cost of acoustic materials. There is also challenge of environmentally disposal of sugarcane bagasse generated in sugar factories in Nigeria and there is no commercial scale usage of the by-product except to incenerate. Therefore the use of bagasse in the production of sound absorbing composite material will help combat the existing problems of both waste disposals in sugar mills, noise pollution in our environment and also add value to the by-product. Materials currently in use for noise reduction are variety of non-biodegradable synthetic sound absorbers, despite adequate performance, their production and after use disposal contribute to environmental pollution. Most of these materials are fibrous in nature. Synthetic fibers such as fiber glass, glass wool or rock wool are used as raw materials. Despite their good performance for acoustic purposes, they are quite expensive and not sustainable [4-6].

One of the effective solutions in noise control is based on the use of a variety of noise reduction materials with special structure in trems of transmission route [7].

Sugarcane (Saccharum officinarum) is commonly found in equatorial countries such as India, Pakistan, Malaysia and Indonesia, and tropical countries such as Brazil [8]. In some West African countries like Nigeria, sugarcane can be cultivated almost in all the states locally but commercially it is produced in; Katsina, Taraba, Kano, Adamawa, Jigawa, Kaduna, Kebbi, and Sokoto state [9]. In 100% of sugarcane, the resulting bagasse varies from 23%-40% [10]. Currently in Nigeria, a portion of this waste is utilized for energy production in sugar nills; anorher part is burnt in order to clear the field. Some efforts have been made to use the waste in the production of paper [8, 11].

Sound absorbing materials normally absorb nearly all the sound energy striking them and reflect very little. Consequently, the materials have been discovered to be very suitable for control of noise. There are different types of sound absorption materials, their absorption capabilities depend on some factors such as frequency, composition, thickness, surface finish and mode of mounting. However, materials that have high value of sound absorption coefficient are usually porous which contain cavities, channels or interstices so that sound waves are able to pass through them [12,13]. The purpose of absorptive materials is to convert impinging acoustic energy into heat. The energy content of sound wave is normally very small; therefore, the amount of heat generated is also small. Viscous-flow effect and internal friction are the two mechanisms by which energy is dissipated in sound absorptive materials. The structure of an effective sound absorber consists of a series of interconnected pores or void, through which sound waves propagate [13].

Most building materials have acoustic properties that will reflect, absorb, or transmit the sound striking them. When sound wave intracts with a surface of a wall or ceiling, a part of energy is reflected, another part is absorbed and the other part is transmitted through the wall. The incident waves are those waves that are being projected to a definite material which can either be reflected or transmitted. The amounts of energy going to reflection, absorptoion, or transmission depend on the acoustical performance of the material surface [14].

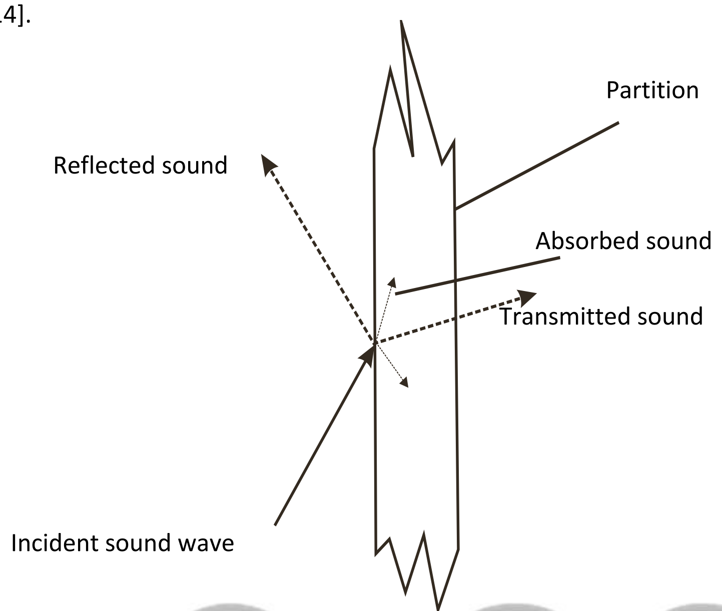

Figure 1. Interaction of sound wave on material

In this study, sugarcane bagasse was subjected to chemical modifications, namely- mercerization and acetylation. The sound absorption coefficients of the composites produced with raw, mercerized and acetylated fiber were compared to that of the pure matrix.

I. MATERIALS AND METHODS

2.1 Materials

Polyurethane in two parts #24 and #25 for the matrix were obtained from Fiber Glast Developments Corporation. Crushed sugarcane bagasse of mixed varieties B4719 (50%), Sp716180 (15%), M1400 (20%) ans Co957 (15%) were collected from Savanna Sugar Company, Numan Local Government Area of Adamawa State. NaOH pellets, acetic acid and acetic anhydride were obtained from chemical store.

2.2 Methods

2.2.1 Fiber purification, sizing and chemical modifications

10 kg of crushed fiber was soaked in water for 45 minutes and washed several times in clean water to get rid of sugar remnant and other waste soluble impurities present on the fiber surface and then dried. 710 microns size of fiber was obtained by using standard sieves and the fiber particles were divided into three portions. The first part was named crude fiber. The other two portions were kept for chemical treatments.

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The two parts of the purified fiber were mercerized by immersion in 5% w/v NaOH solution for 48 hours at room temperature. The fiber was then washed in distilled water and dried for 48 hours under sunlight [12]. The resultant fiber was divided into two parts; a part was named mercerized fiber while the other portion was used for acetylation.

Acetylation was done by first soaking the last portion of the fiber in distilled water for 60 minutes, filtered and placed in a flask containing 10% w/v acetic acid for 30 minutes. It was then placed in another flask containing 14% w/v acetic anhydride solution and a drop of concentrated H_2SO_4 was added and allowed for 70 minutes at 30^oC. The fiber was then washed with distilled water until is acid free and dried prior to usage [13]

(i) Crude fiber (ii) Mercerized fiber (iii) Acetylated fiber

Figure 2: Crude, mercerized and acetylated bagasse fibers (710microns particle size)

2.2.2 Composite formation

The samples were prepared through the free rising foaming method. 16g each of liquid polyurethane kits, part A and B were mixed to prepare the pure polyurethane samples. Appropriate quantities, by weight, of part B was added to the required amount of bagasse fiber and mixed with magnetic stirrer for 30 minutes at 1000 rpm. Then part A was added to the mixture and stirred at 1500 rpm with mechanical stirrer for 15 seconds. The mixture was gently poured into PVC cylindrical mold of 100 mm diameter by 40 mm high. The mixture expanded and then cured at room temperature for 12 hours prior to demolding, after which the samples were prepared for sound absorption coefficient measurements [15, 16]. The fiber contents 0, 5, 10, 15 and 20 wt % was used to prepare samples PUF, A1, A2, A3, A4, B1, B2, B3, B4, C1, C2, C3, and C4 for crude, mercerized and acetylated composite respectively.

(i) 100mm diameter PVC molds (ii) Samples fabrication

Figure 3: Samples production and molds

III. RESULTS AND DISCUSSION

The sound absorption coefficients of the specimens were assessed according to ASTM E1050-10 in frequency range 50-1600 Hz. This frequency range is simply an average of all frequencies within the third-octave band which is frequencies of human hearing. The frequency range has also been selected to satisfy the fundamental constraint that had been highlighted by ASTM. According to the standard, the usable frequency range depends on the diameter of the tube and spacing between the microphone positions.

The sound absorption coefficients of pure polyurethane foam (base matrix) and various polyurethane composites are shown in figures 4 to 6.

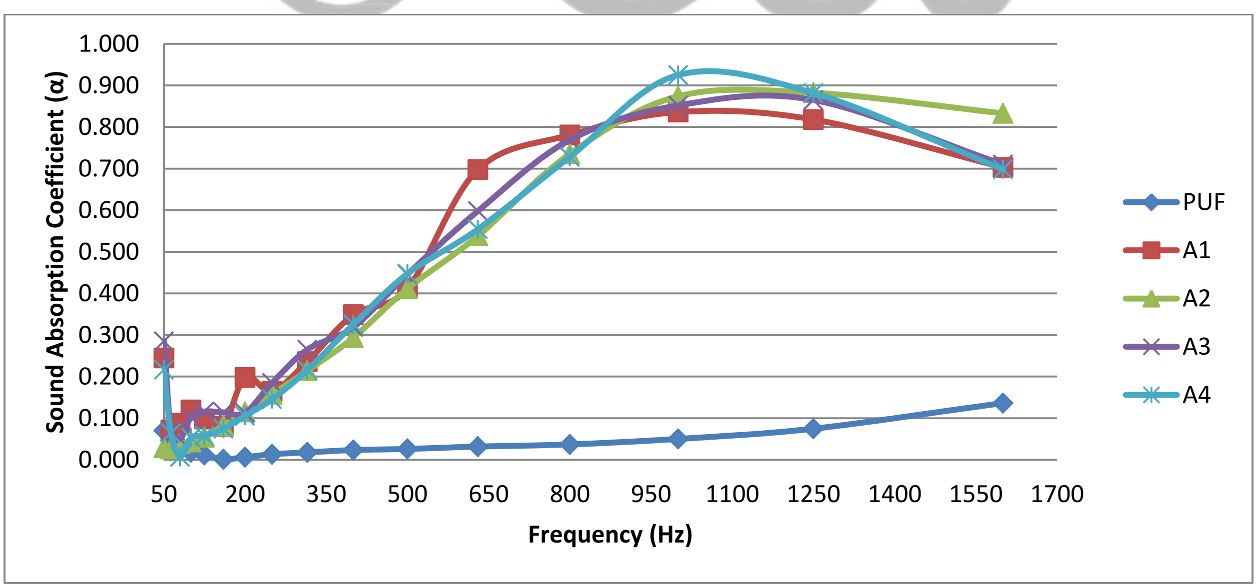

Figure 4: Sound absorption coefficients curves for base matrix and crude fiber composites with various fiber loadings

Figure 4 shows the correlation between the sound absorption coefficient and wave frequency for the samples with and without varied percentage of crude fiber in frequency range of 50 to 1600 Hz. It can be seen that the souns absorption characteristics of the pure polyurethane foam and the composites vary, to a large extent with wave frequency. The sound absorption coefficients of the composites generally increased with frequency within 80 Hz and 1000 Hz and then decrease as the frequency is increased to 1600 Hz. This behaviour could be ascribed to the specific characteristics of the materials in absorbing and reflecting sound energy at certain frequencies. Sound absorption coefficient of a material depends on the material and the frequency of the sound which strikes the surface of the material. The behaviour of the composites is in agreement with the report of Elammaran et. al [17]. The plot for the pure polyurethane foam shows the maximum peak value of sound absorption coefficient of 0.136 at frequency of 1600 Hz. As the crude fiber content loading is increased from 0 to 20 wt% (PUF-A4), the sound absorption capabilitities of the samples also increased from 0.136 to 0.925 within the frequency range under consideration. As the frequency is increased, the values of absorption increase with initial fluctuation. Comparing the peak of the plot of pure polyurethane and that of the composites, it could be seen from the figure that all the composites performed better than the base matrix, the sample with lowest percentage of fiber shows lower values of sound absorption coefficient. Whereas the base matrix exhibit a continued increase in sound absorption with frequency increase, the composites generally increase in sound absorption with frequency up to some peak values which occurred at frequency between 1000 Hz and 1250 Hz. The composites with least and highest fiber loadings (A1 &A4) peaked at 1000 Hz, while A2 and A3 at 1250 Hz. The value of maximum peak of individual composite plot does not indicate much difference with most of the peaks being above 0.830 and close to 1, indicating average range of 0.041. This low range indicates that the sound absorption coefficient is not affected to a large extent by the percentage of the fiber present in the composites of same thickness. The maximum value obtained is 0.925 for the sample with 20 % fiber loading (A4) at the same time when the sample with 5% loading (A1) had a sound absorption coefficient of 0.836. All the plots for the composites (A1, A2, A3, & A4) also show that the sound absorption coefficient value declines between frequencies of 1250 to 1600 Hz after reaching the respective peaks. The values of sound absorption coefficients recorded indicate that addition of crude bagasse fiber is efficient in absorbing sound waves at medium frequencies, particularly above 250 Hz. At very low frequencies, below 250 Hz, the results revealed that sound absorption coefficients of 0.001. 0.072, 0.026, 0.050 and 0.007 were obtained. This is an indication that the samples with and without varied fiber loadings are not able to absorb sufficient incident waves and reflected most after striking the samples at the said frequency range. This result is in agreement with the report of Chunhu et. al [18], that low frequency sound waves are very difficult to absorb because of their long wavelength.

It was observed that the polyurethane foam with 25 mm thickness, with or without varied percentages of crude bagasse fiber used in this study are not able to absorb low frequency sound waves efficiently, therefore, is inefficient for low frequencies applications as reported by Seddeq [19]. To improve the absorption or reduction of low frequency sounds, the materials used should be thicker so as to provide enough time for sound waves to transform into heat when passing through the obstacles within the materials. The formulation of polyurethane foam with different crude bagasse fiber loadings was able to enhance the sound absorption coefficient in the medium frequency range without altering the thickness of sound absorbing materials. The behaviour of the composites could be adduced to the increasing compactness of the structure obtained in the composite when amount of fiber in it increases, in which the compact structure reduces the size and volume fraction of air voids and make the air passage much narrower and more tortuous. Consequently, sound wave is made to travel longer distance in the structure which results in further reduction of sound energy. This is also in agreement with the observation by Elammaran et. al [20].

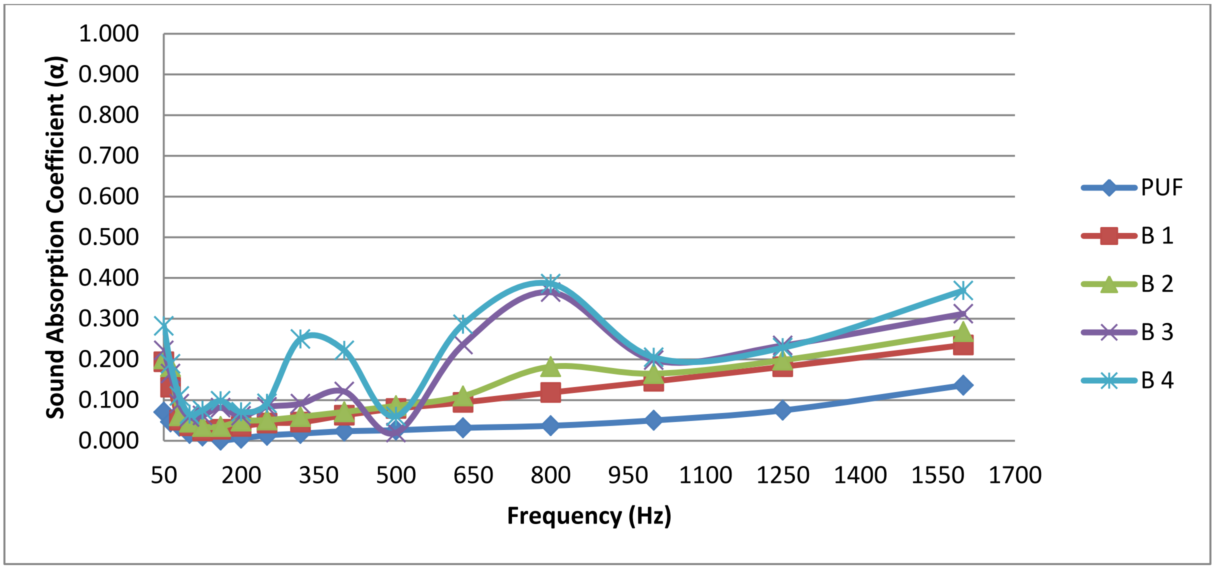

Figure5: Sound absorption coefficients curves for base matrix and mercerized fiber composites with various fiber loadings

Figure 5 shows the sound absorption of the base matrix and composites with different amount of mercerized fibers at frequencies 50 – 1600 Hz. From the figure, it can be seen that the base matrix exhibits same trend as discuseedd in figure 4. Addition of 5 wt% (B1) of mercerized fiber in polyurethane system does not change the sound absorption characteristics of the composite meaningfully, as the values initially decrease from 0.194 to 0.025 between the frequencies of 50-125 Hz and then increased steadily from 0.028 at 160 Hz to a peak value of 0.235 at 1600 Hz. Increasing the fiber content of composite from 5 wt% to 10 wt% (B2) also shows similar trend, having absorption coefficient of 0.201 to 0.035 between 50 – 160 Hz and then increased gradually from 0.048 to 0.182 within 200 Hz and 800 Hz then decreased to 0.165 at 1000 Hz, before obtaining a peak value of 0.268 at 1600 Hz. Further increase in the fiber content of the composite to 15 wt% (B3) shows that the acoustic absorption of the sample also decline initially and fluctuations apperared with different degree as the frequency increases. The absorption of the composites decreases from 0.222 to 0.058 within 50 and 100 Hz and then increased steadily to 0.121 at 400 Hz then fluctuates between 0.020 and 0.234 within the frequencies of 500 Hz and 1250 Hz and then recorded a maximum value of 0.312 at 1600 Hz. Increasing the fiber content from 15 wt% to 20 wt% loading (B4) indicates a similar trend in acoustic absorption charactreristics with the sample B3. The sound absorption coefficient curve obtained for the sample B4 is similar to the behaviour of the sample B3. In this case, the acoustic absorption of B4 decreases from 0.282 t0 0.065 within the frequencies 50-100 Hz recording fluctuations over the frequency range of 125-1600 Hz having peak value of 0.386 at 800 Hz. Comparing the acoustic behaviour of the base matrix to the mercerized composited, B1, B2, B3 and B4, it was observed that addition of the treated fiber has negative impact on the absorption characteristics of the composites. It was noticed that the sound absorption coefficient of the mercerized samples increased with increasing amount of fiber content in the compositions. Alkaline treatment using sodium hydroxide has been known to be effective not only for surface modification of natural fibers used as reinforcement in composites but also increase the sound absorption coefficients of natural fiber composites [21]. In this study, it has given rather an unexpected outcome; which may be related to the variation in the properties of the bagasse fibers used, apart from the existence of various varieties; another reason could be maturity levels of the fibers (maturation period) which also affects the fiber properties to an extent [22].

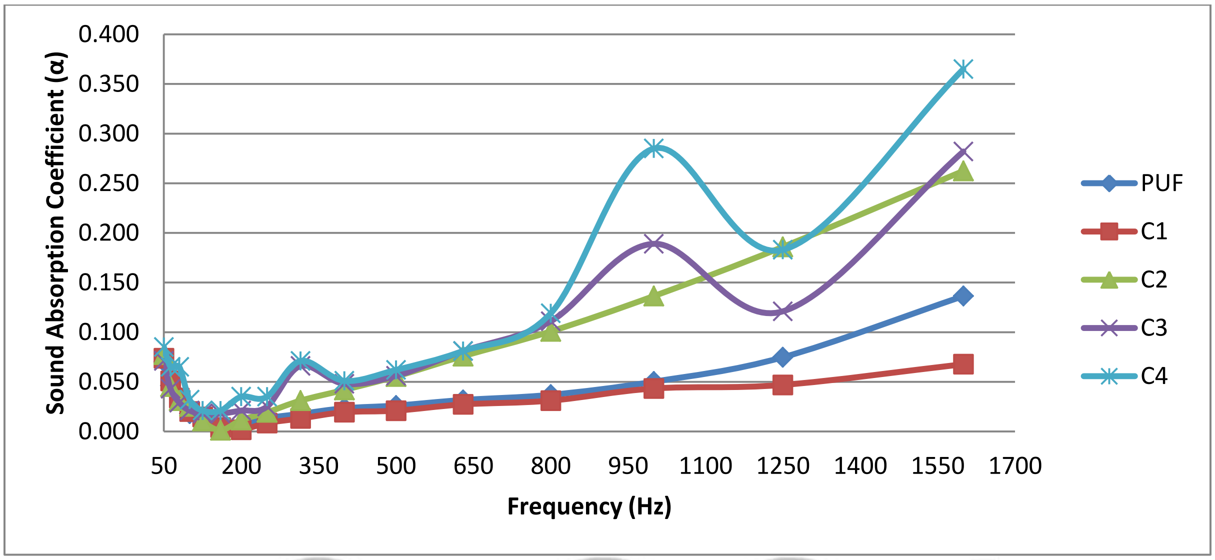

Figure 6: Sound absorption coefficients curves for base matrix and acetylated fiber composites with various fiber loadings

Figure 6 shows the sound absorption coefficient curves of pure foam and acetylated fiber composites. It could be seen from the figure, the curves of sound absorption obtained is similar to that of the mercerized fiber composites showing initial decrease in the values of absorption within the frequency range of 50-160 Hz with different degrees of fluctuations between 200 Hz and 1600 Hz. Sample with 5 wt% of acetylated fiber (C1) recorded a maximum absorption of 0.068 at 1600 Hz while sample with 10 wt% (C2), 15 wt% (C3) and 20 wt% (C4) acetylated fibers recorded maximum sound absorption coefficients of 0.068, 0.262, 0.282 and 0.365 respectively at frequency 1600 Hz. Comparing the performance of the composites with that of the base matrix, it was observed that no significant improvement in absorption characteristics was recorded as a result of fiber acetylation in the polyurethane mixtures. This shows that the further treatment of the fiber after mercerization could not impact positively on the acoustic absorption capabilities of the composites. This could be as a result of similar reason advanced for same trend in mercerized composites [22]. The results obtained for the acetylated composite samples also revealved that as the amount of the fiber is increased in the composition, the sound absorption coefficient also increased.

Based on the absorption classes described in the International Standard ISO 11654 (table I) the samples can be grouped as follows:

a. The crude composites A1, A2, A3 and A4 are described by high sound absorption coefficient values (0.836-0.925) for frequency range between 1000-1250 Hz are class A
b. The mercerized (B1, B2, B3, B4) and acetylated (C1, C2, C3, C4) composites have low sound absorption coefficient values (0.068-0.386) between the frequency range 800-1600 Hz are class D, E & F.

Table 1, Sound absorption class and absorption coefficient (Source: ISO 11654:1997).

Sound Absorption Class	Sound Absorption Coefficient
A	0.90; 0.95; 1.0
B	0.80; 0.85
C	0.60;0.65; 0.70; 0.75
D	0.30; 0.35; 0.40; 0.50; 0.55
E	0.15; 0.20; 0.25
F	0.00; 0.05; 0.10

Conclusion

The following conclusions can be made from the study.

1. Polyurethane-based sugarcane bagasse composites were successfully developed and their sound absorption performances in the frequency range 50-1600 Hz have been studied.
2. Crude composite demonstrates superior sound absorption coefficient. Crude composite with 20 wt% fiber content (A4) has the highest sound absorption coefficient of 0.925 within the frequency range of 1000 Hz and 1250 Hz and could be compared to class A sound absorbers.
3. The sound absorption performances of the modified composites are inferior to that of unmodified composites and mercerized composites B3, B4 and that of acetylated C4 could be categorized as class D sound absorbers
4. Based on classification of sound absorption materials, the likely area of application of composites A4, B3, B4 and C4 is in buildings such as residentilal and class rooms.

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