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The Potential of Selected Agricultural Wastes Fibers as Acoustic Absorber and Thermal Insulator Based on their Surface Morphology via Scanning Electron Microscopy

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ABSTRACT

Natural fibrous materials have been studied to address noise and high heat indices, but many of the existing studies about natural fibers do not sufficiently support their claims of better acoustical and heat insulating materials. Thus, this study investigated the surface morphology of easily available agricultural materials, such as coconut husks, banana pseudostem, and sugarcane husk for their potential as sound absorbers and thermal insulators. Fiber pads from the materials were constructed and analyzed for noise reduction coefficients, thermal insulating performance, water absorbing capacity, and flame tolerance - using the methods specified in the American Society for Testing Materials. Herein, scanning electron microscopy (SEM) was applied for analytical imaging of the agricultural materials. Noise reduction coefficients (0.80 dB and 0.92 dB), (0.75d B and 0.78 dB), and (0.50 dB and 0.35 dB), each at 800 Hz and 440 Hz, and heat reductions of 2.56 °C, 1.71 °C, and 1.24 °C were obtained from coconut husk, sugarcane husk, and banana pseudostem, respectively. The coconut husk also gave the highest water absorbing capacity and high flame tolerance of 56%, compared to that of sugarcane husk (49%) and banana pseudostem (32.67%). The morphology of the coconut husk, after SEM application revealed more diverse microporous cells with varying shapes and sizes compared to that of sugarcane husk and banana pseudostem. Thus, results indicate that porosity affects the noise and heat reduction indices of the fibers. The more porous the material is, the better is its potential as sound absorber and thermal insulator.

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***Keywords*:** Agricultural wastes fibers, Recycling, Coconut husk, Sugarcane husk, Banana pseudustem, SEM, Analytical imaging, Surface morphology

1. INTRODUCTION

Global warming is expected to have far-reaching, long-lasting and, in many cases, devastating consequences for the planet Earth. For some years, global warming, the gradual heating of Earth's surface, oceans and atmosphere, was a topic of heated debate in the scientific community. Today, the overwhelming consensus of researchers is that global warming is real and is caused by human activity, primarily the burning of fossil fuels that pump carbon dioxide (CO_2), methane and other greenhouse gases into the atmosphere. This problem was then associated to the noise pollution since high temperature causes everything in an unease condition leading to the production of too much sounds.

One of the most immediate and obvious effects of global warming is the increase in temperatures around the world. The average global temperature has increased by about 1.4 degrees Fahrenheit (0.8 degrees Celsius) over the past 100 years, according to the National Oceanic and Atmospheric Administration (NOAA).

In addressing the above mentioned problems, various materials had been used, particularly commercially available sound absorbers and heat insulators. But not knowingly, these synthetic materials contained and had been treated with hazardous materials and chemicals that could harm human health.

Various readily available materials like natural fiber materials are increasingly being used for different purposes in many specialised applications. As technology moves continuously, environmental noise and high temperature cause many negative effects, according to a recent statistical study which revealed that a percentage of the population was suffering from (53%) headaches, (36%) high blood pressure, (40%) anxiety, (36%) hearing disabilities, (15%) cardiovascular diseases, (67%) irritability, and (61%) insomnia [8]. In response to these, there are several methods for mitigating noise and thermal problems via reused sound absorption materials and thermal insulators. But then, methods that have been used before focused on the utilization of synthetic materials, such as glass wool, rock wool, asbestos, have disadvantages because they are hazardous for lungs and eyes [18].

Bamboo fibers have been used as solution to the said problems [12], as well as the absorption coefficients of four fibre assemblies," cashmere, goose down, acrylic fibre and kapok" [21]. These materials are natural and acrylic fibers. Natural fibers have distinctive internal structures that influence the sound absorption coefficients and thermal insulating performance, which are measured according to the density, thickness and sound frequency and temperature to check the contribution of natural fibre against air and actual heat.

In a particular study, a new particle board was manufactured using durian peel and coconut coir fibers to achieve the lowest thermal conductivity to decrease heat transfer into a space [10]. When it comes to the heat reduction, these agriculture wastes are an economical and interesting option that could be a smart way to insulate ceilings and walls. After a year, the proponents have improved and developed their particleboard of low thermal conductivity manufactured using a mixture of durian peel and coconut coir at an optimum ratio of 90:10 (coconut coir to durian) by weight [11].

On the other hand, the sound absorption potential of industrial tea leaves waste and later developed into three different layers with or without a single backing layer of woven textile cloth to test its experimental properties of sound absorption was also evaluated [5]. The data of their study indicated that the sound absorption properties increased by increasing the thickness of the layer of single backing cotton cloth. Therefore, the result of the study means that the natural and renewable material has positive sound attenuation properties and most importantly, this action could never harm human health.

In addition, the feasibility of composite from coconut coir, with addition second-hand tube rubber, for sound and heat absorption material has been also studied [15]. The effect of adding second-hand rubber particles and sway of polyurethane were properly observed and investigated as a possible substitute of industrial and metal fibers to obtain the higher coefficient absorption of sound and heat. Also, the capacity of sound absorption of natural coir fibre, using the Delany-Bazley model for three coir fibre samples by increasing the thickness, corresponding to an increase in the absorption coefficient has been explored [3].

The performance appeared to be more promising at lower frequencies.

The sound and heat absorption coefficients of fresh and synthetic coconut fibers can be mixed with a binder and the analysis was performed using the typical "Delaney-Bazley and Biot-Allard analysis". The results of the study revealed that the binder additive is not sufficient to improve the absorption coefficient for lower frequencies, so to improve the sound absorption properties; the added materials must be able to improve properties, such as "stiffness, fire retardant, anti-fungus and flammability" [9].

The application of natural fibrous materials that are readily available in the locality gives a lot of benefits. These materials are renewable, sustainable, affordable, less hazardous to health and lighter in weight, as well as environmentally friendly in comparison to other synthetic substances. In addition fact, different ancient plant substances and the new substances at acoustic porosity have been compared, in order to develop a high quality product - perfect to become safer, lighter and thinner output. In advantage to synthetic materials, these substances are smoother to build up environment, hence using organic substances appeared to be better to decrease noise [2].

In connection to the above mentioned facts and related studies, this current study also investigated and morphologically analysed microporous cell structures located at the surface of the different agricultural wastes like coconut husks, banana trunk fibers and sugarcane husks via Scanning Electron Microscopy (SEM) instead of synthetic materials that could harm human health. The chosen agricultural wastes are abundant in the Municipality of Pinamalayan, Oriental Mindoro, since the town is one of the main producers of coconut and banana in the province. Meanwhile, large plantations of sugarcane were also established in the said locality.

Thus, the study aimed to develop a green technology-based product in the form of natural and innovative sound absorber and thermal insulator made from natural fibers of coconut husks, banana trunk fibers and sugarcane husks to address high heat index and noise pollution not only in the locality of Pinamalayan, Oriental Mindoro, but also for the entire country and to the world.

2. MATERIALS AND METHODS

Collection and Preparation of Materials

The different agricultural wastes, like coconut husks, banana pseudostem fibers and sugar cane husks were gathered at Nabuslot, Pinamalayan, Oriental Mindoro, Philippines.

The materials were sun dried for five days to get rid of insects, dampness and odors. Meanwhile, other materials in the current study were the closed box (preferably with surface dimension of 30 cm × 30 cm), sound meter, Bluetooth speaker (or with stereo jack), laptop, mechanical glue (strong hold), and a tablet or android phone that produced the constant sound. In addition, miniature design of residential house was utilized wherein the insulating materials from the different agricultural wastes were placed on its ceiling part for the actual tests that were executed.

Likewise, digital thermometers, and timing device, preferably a clock, were used in the conduct of the study. Samples of the different agricultural wastes used were verified at the National Museum-Botany Division in the Philippines.

Creating the Sound Absorbing and Heat Insulating Pads

In making the sound absorbing pads, the dried materials (like coconut husks, banana pseudostem fibers and sugar cane husks) were cleaned by removing foreign fibers and other dirt. Using scissors, each sound absorbing material was cut according to the dimensions of 30 cm × 30 cm and was attached together using multi-purpose adhesive spray. The thickness of the materials that was attached to the test board measured 5 mm. Meanwhile, additional pads were made from the same agricultural wastes and were also utilized in the heat insulating performance test.

Experimental Procedures

Surface Morphology Analysis

Hitachi TM3000 table top microscope (Scanning Electron Microscope) was used in the generation of micrographs of the different agricultural wastes. The SEM apparatus was turned on and connected first to a laptop computer. Small parts of the samples of different agricultural wastes were cut according to the desired size that was suited on the circular metal platform of the SEM. Magnifications were focused on the possible microporous cell structures on the surface of the samples. The micrograph generation was done in different magnifications and sections of the inserted samples. All the obtained micrographs were saved on the connected laptop computer for proper documentation and further analysis.

Flame Test

Flame test was conducted to distinguish factor of safety, an essential category that illustrates on the conductivity on fire [16]. In testing how the different agricultural wastes responded to flame, the researcher referred onto the presented guidelines on ASTM E84-93. The researcher also made modifications in the procedure to have the comparison among the waste materials, and they were subjected to direct flame exposure for observation on time of smoke and actual flame occurrence. TC-3200 Digital Thermometer, connected with a Type K-8 mm thermocouple probe, was used in determining the temperature of the flames. Samples were given at 5 mm × 5 mm dimension with a uniform thickness of 5 mm. Three alcohol lamps were used in testing the three agricultural wastes. The lamps were lit until all display the same

intensity of flame. The time of appearance for the smoke and flame coming from each agricultural waste was recorded properly [7].

Water Absorbing Capacity (WAC) Test

The test on the percentage of WAC of each experimental sound absorbing material was executed in the School's Chemistry Laboratory. The sound absorbing materials were weighed (in g) first (W_d) during their dry state, and then after soaking them to water giving their wet condition (W_w). Any excess water after soaking was allowed to flow first before getting the mass. Ten samples were prepared for each agriculture waste which were executed within ten trials. The formula that was used for Water Absorbing Capacity (WAC) in percent is: Water (%) by mass = (wet mass – dry mass / dry mass) × 100. The results were recorded for tabulation.

Sound Absorbing Capacity Test

In testing each sound absorbing pad, a blue toothed speaker was turned on to its maximum volume. The sound frequency and volume were kept the same throughout. 440 Hertz and 800 Hertz produced from Pro Audio Tone Generator were used because they are most audible to the human ear. The speaker was connected to a tablet which produced the constant sound via bluetooth connection. The speaker was then placed in a test box that was insulated with coconut husk and other test materials (for the other set-up). A decibel meter was placed beside the test box at 20 cm (**Figure A**). The distance between the decibel meter and test box was kept the same for every test. Pro Audio Tone Generator was used and created a constant sound on the speaker. The reading on the decibel meter was noted down. The test was done with ten trials and average was measured. The whole procedure was repeated using different materials (for 440 Hertz and 800 Hertz).

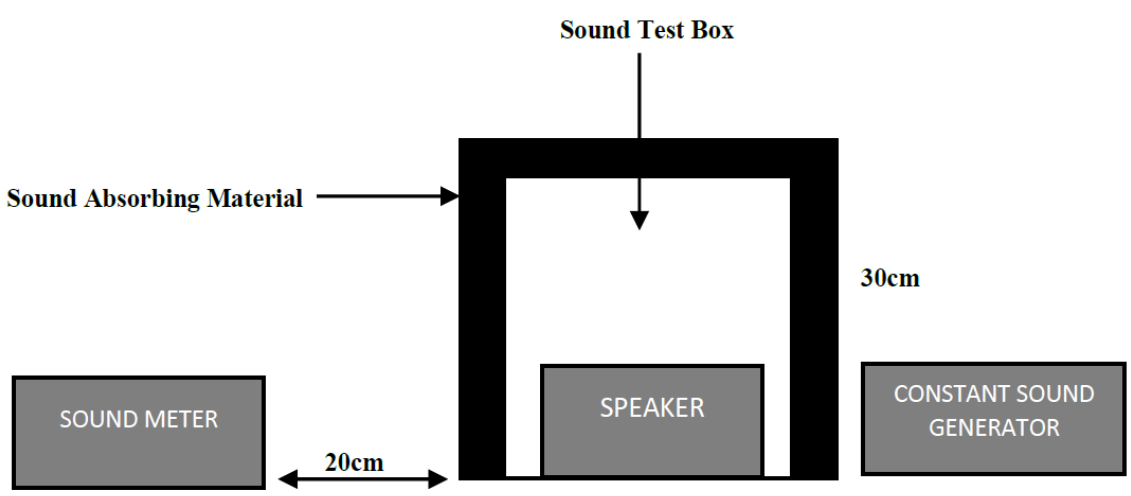


Figure A. Diagram for Sound Absorption Test

The Noise Reduction Coefficient (NRC) of each agricultural waste material that was used was also calculated using the Sound Pressure Level (SPL) in decibels (dB). The decibel drop for each trial was used in the actual calculation of NRC following the formula,

$$C = 1 - 10^{-\left(\frac{d}{20}\right)}$$

wherein *C* is the coefficient and *d* is the decibel drop.

Heat Insulating Performance Test

The researcher used a method specified by the ASTM C726-93 which gave a standard procedures in testing the heat insulation performance of the different agricultural wastes, since there are not available instruments to address such a test (Standard Test Method…, 1999 & Standard Specification for Reflective…, 2012 [7]). An improvised apparatus (miniature cabin) was made to simulate the actual performance of an insulating material where varying variables were regulated and controlled to attain desirable results.

The miniature house was applied with the agricultural wastes as thermal insulators and was put under the sun in a position where the same amount of heat radiation from the sun was received. TC-3200 Digital Thermometer that was connected with a Type K-8 mm thermocouple probe was used for (**Figure B**) temperature readings.

The probe of the thermometer was put inside the miniature house through a small hole in the roof for the temperature readings inside while another digital thermometer was set outside. The observation on the temperatures was done on a thirty-minute interval from 11:00 am up to 4:00 pm. The observation was conducted for 5 days. Average readings of the recorded temperatures were noted [7].

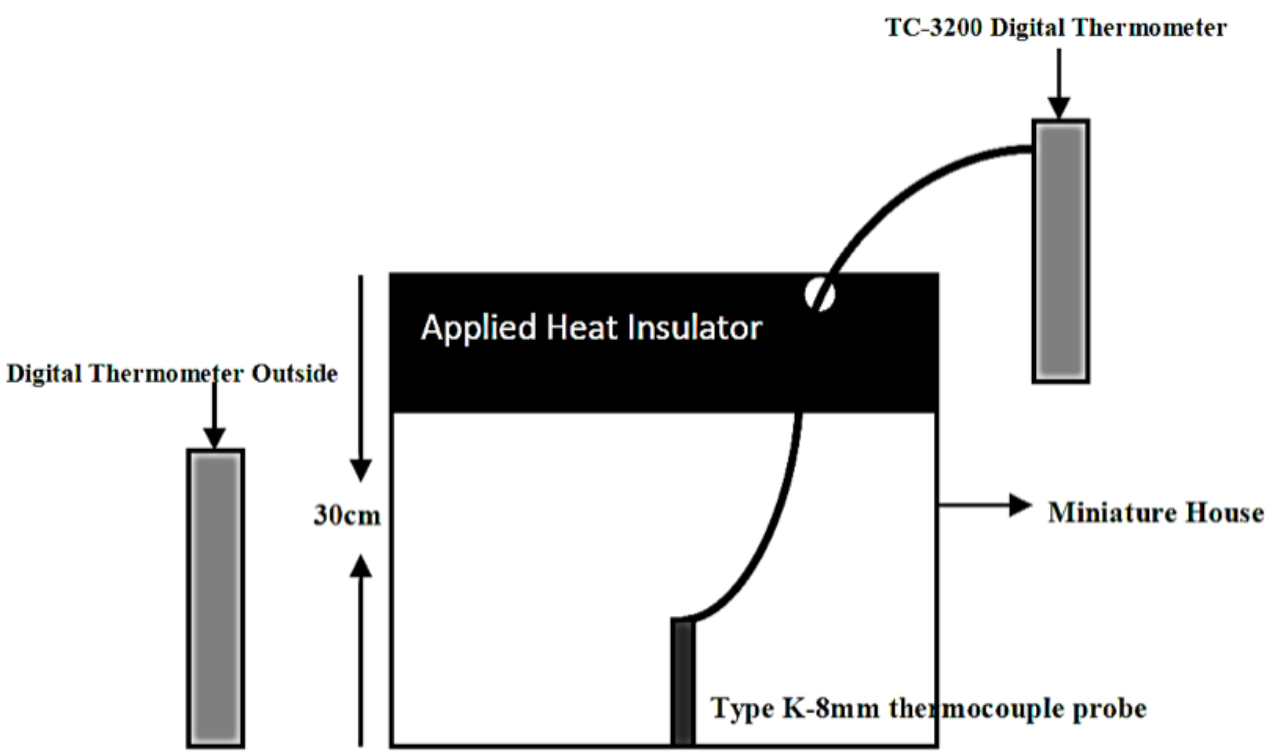


Figure B. Diagram for Heat Insulating Performance Test

Risk and Safety

In collecting the different agricultural wastes, the use of sharpened tools like bolo required of great supervision from adults to prevent serious cuts. Wearing of chemical splash goggles, chemical-resistant gloves and laboratory mask were recommended during the flame test. Water source in the laboratory was assured and checked before performing the test.

Data Analysis

Mean/averages were used in comparing results of sound absorbing capacity and thermal insulating performance of the different agricultural materials that were utilized in the study. Meanwhile, One-Factor Analysis of Variance (ANOVA) was applied in determining the possible differences that had been obtained from the results of the experimentations.

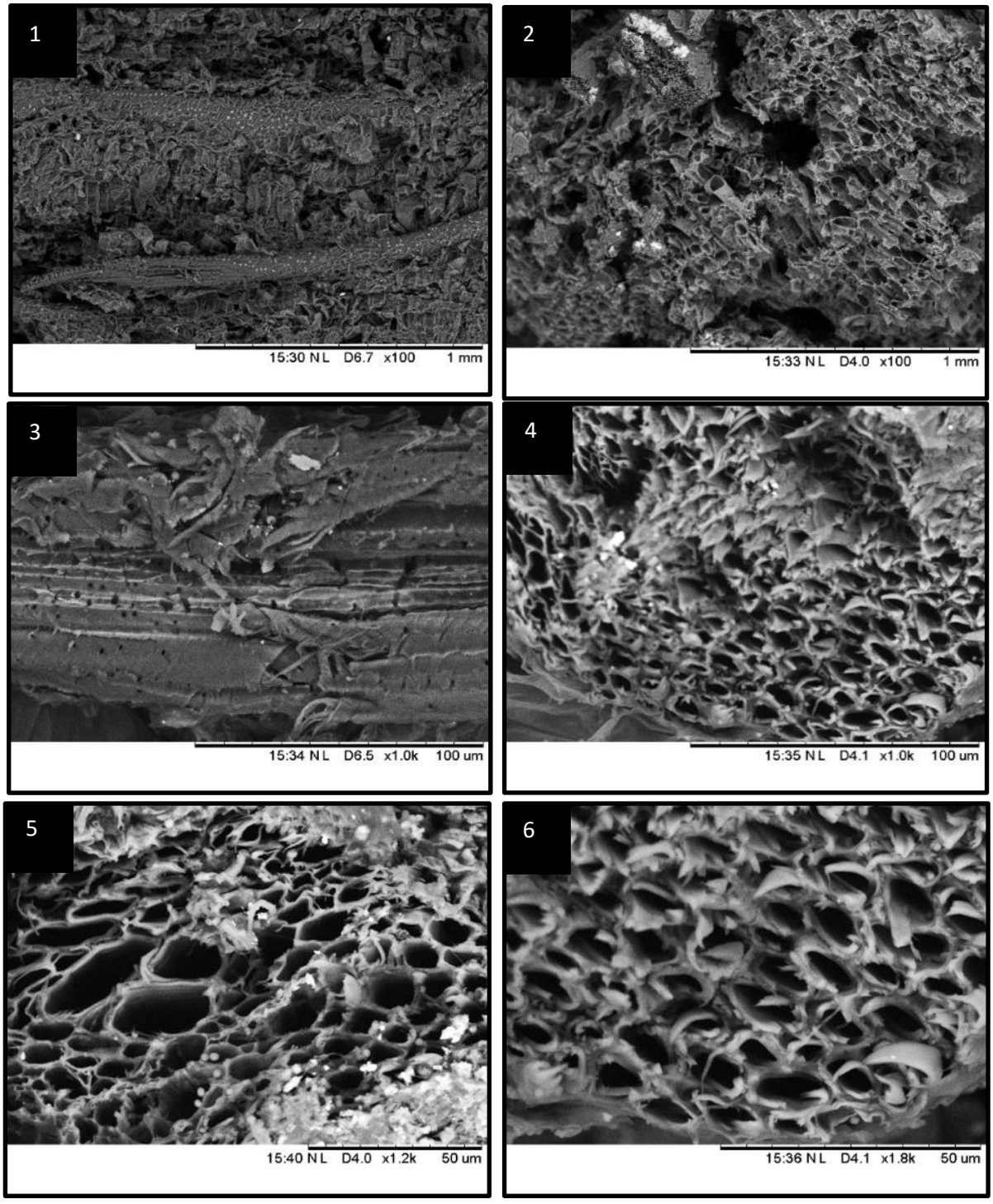
3. RESULTS AND DISCUSSION

Figures 1-6 show the SEM micrographs of the surface morphology of the coconut husk exhibiting the microporous cell structures on it. Images also portray the magnified rough and fibrous surface of the sample. A more detailed cross-sectional surface of the coconut husk showing micro holes are evident in Figures 4 to 6 at 1000×,1200×, and 1800× magnifications, respectively. Some of the microporous cells of the samples are in elongated circular shape or ellipse, the rest are irregular in shapes. Meanwhile, Figure 3 shows a slight longitudinal structure of the fibrous surface of the coconut husk but this doesn't contain all sections of the surface of the sample.

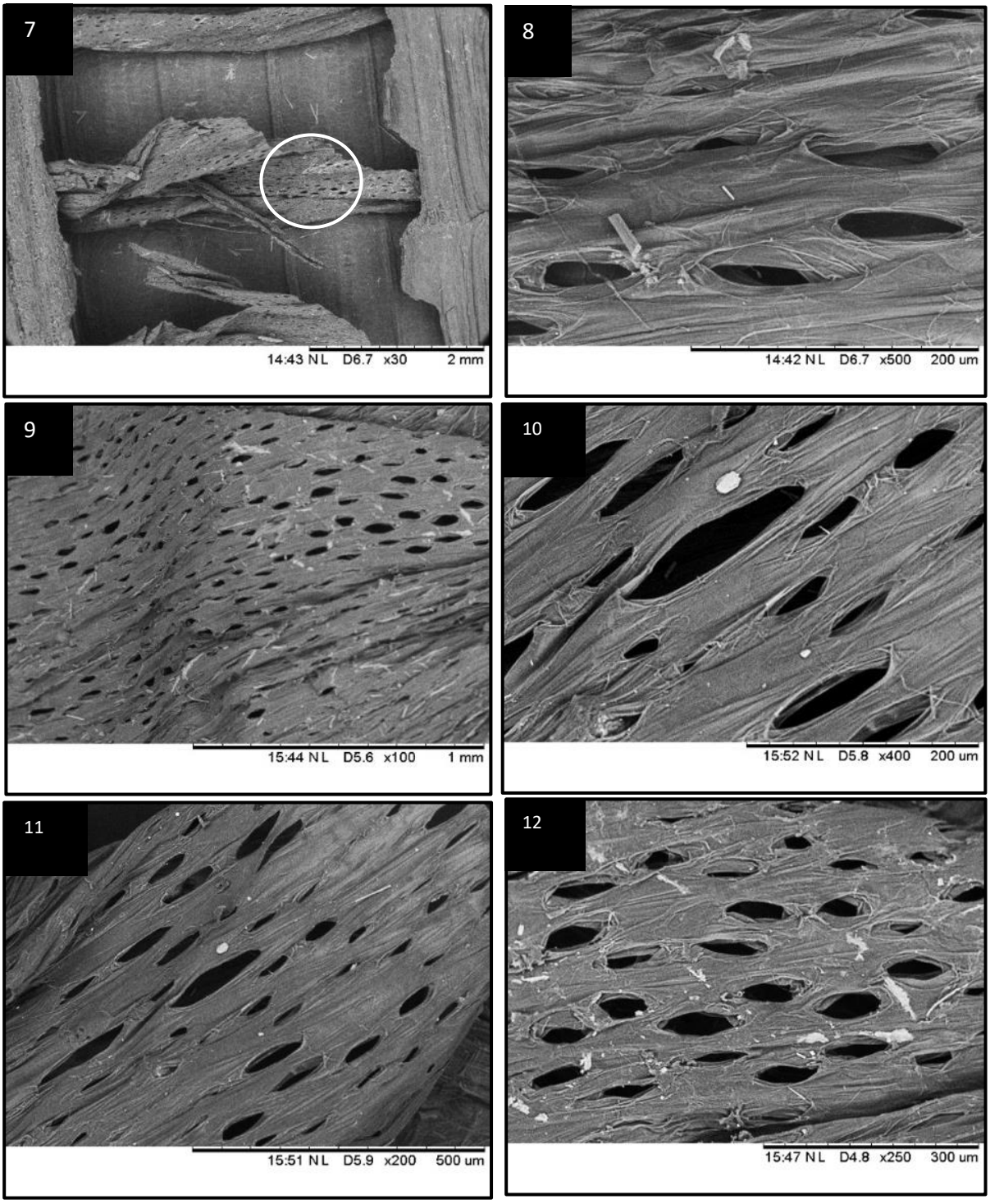
Figures 7-12 show the generated SEM micrographs for the surface morphology of the samples of banana pseudostem. Figure 7 portrays a slightly folded and tied structure of the surface section of the sample given at 30× magnification. This simply shows that the surface of the banana pseudostem is not monopolized by a lot of microporous cell structures. Meanwhile, a more magnified and detailed images at 100× to 500× magnifications are presented in Figures 8-12. These images showcase the oval-shaped microporous cells on the surface of the sample. It can be seen on the images that there are ample spaces among the microporous cells. Majority of the sections magnified in SEM shows smooth surfaces compared to the roughness exhibited in coconut husk. There are no groups and layers of microporous cell structures in banana pseudostem.

Shown in **Figures 13-18** are the generated SEM micrographs of the surface morphology of the samples of sugarcane. Rough longitudinal structures are evident on the surface of the sugarcane as depicted on Figures 13 and 14. On the other hand, variations of sizes of microporous cells are found on cross-sectional areas of the sugarcane. Sub-groupings of microporous cells are also evident in the presented images. It can be seen in Figure 15 that another small clustering of microporous cells lie around the large openings of microporous cells. Meanwhile, a more magnified images of microporous cells structures of sugarcane are presented in Figures 16-18 at 500×, 800×, and 600× magnifications, respectively.

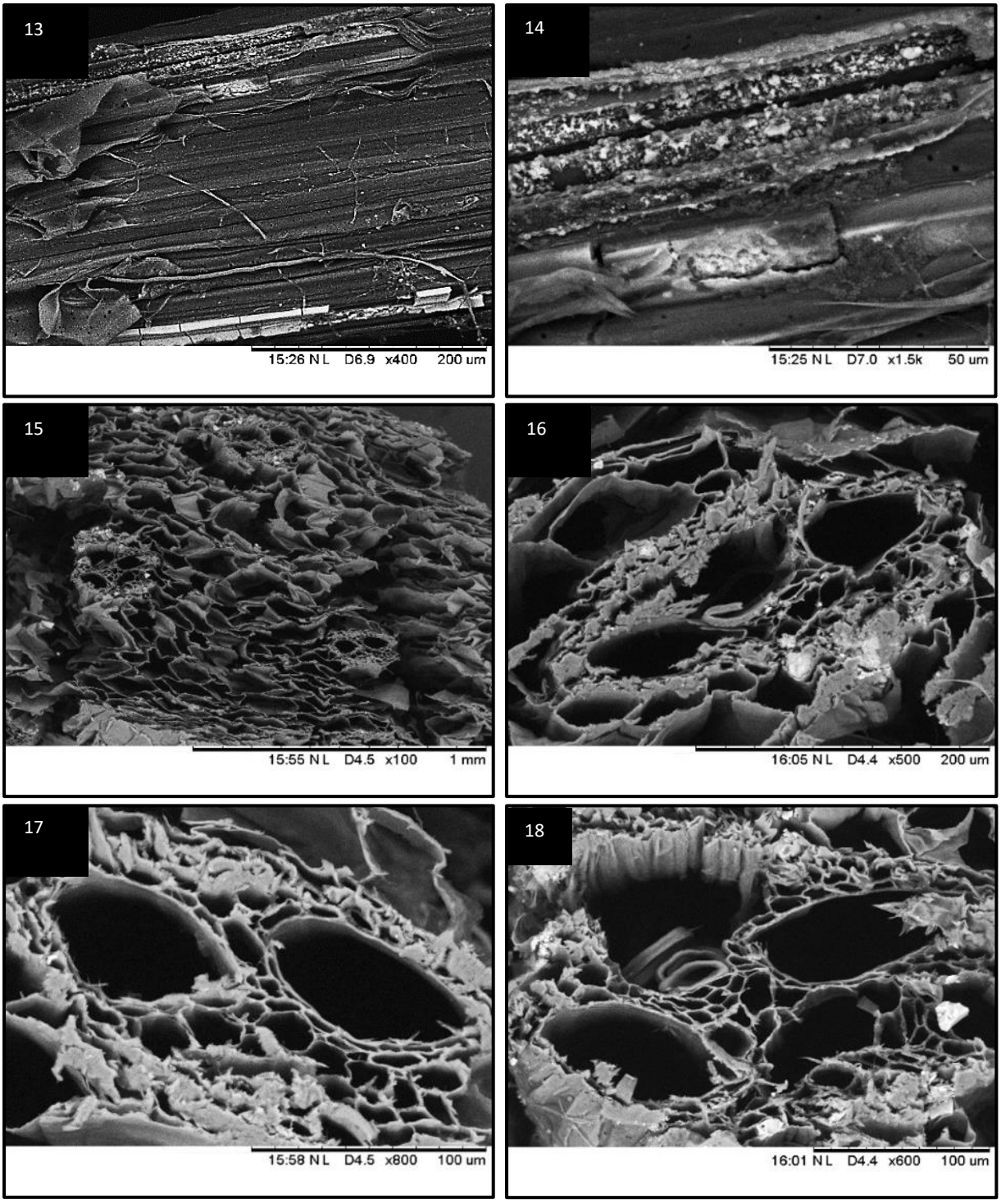
Figure 19 depicts the results of the water absorbing capacity (in percent) of the samples of the different agricultural wastes (Coconut husk, Banana Pseudostem, and Sugarcane). Based on the Figure, the average water absorbing capacity of coconut husk, banana pseudostem, and sugarcane were 56%, 32.67%, and 49%, respectively.



Figures 1-6. Surface morphology of the coconut husk. (1) SEM micrograph of surface structure of the coconut husk at 100× magnification; (2) SEM micrograph of surface structure of the cross-sections of coconut husk at 100× magnification; (3) Magnified rough and fibrous surface of the coconut husk at 1000×; (4-5) Cross-sections of the surface of coconut husk showing micro holes/compartments at 1000×, and 1200× magnifications; (6) Microporous cells presence with length measurements (in µm) at 1800× magnification.



Figures 7-12. Surface morphology of the banana pseudostem. (7) SEM micrograph of surface structure of the banana trunk at 30x magnification; (8-11) SEM micrographs of surface structure of the banana pseudostem showing the presence of microporous cell structures at 500×, 100×, 400×, and 200× magnifications; (12) Microporous cells presence with length measurements (in µm) at 250× magnification.



Figures 13-18. Surface morphology of the sugarcane. (13) SEM micrograph of surface structure of the sugarcane at 400× magnification; (14) Magnified micrograph of sugarcane at 1500× magnification; (15-17) Cross-sections of the sugarcane showing the microporous cell structures; (18) Microporous cells presence with length measurements (in µm) at 600× magnification.

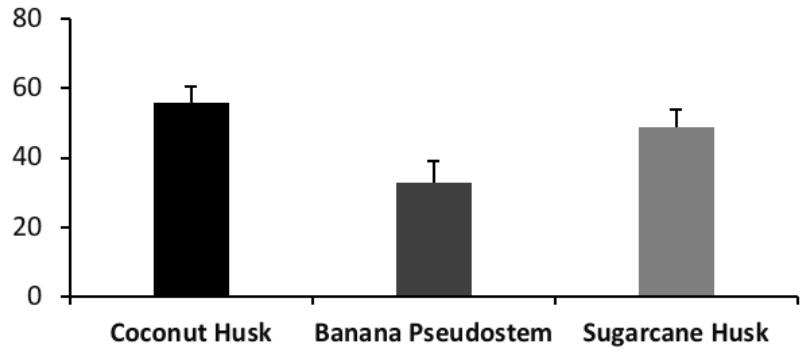


Figure 19. Recorded Water Absorbing Capacity (WAC) Percentage of three sound absorbing raw materials.

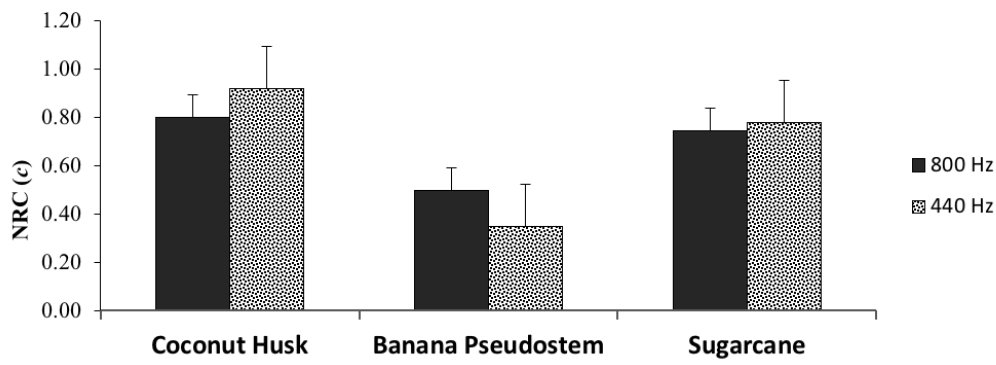
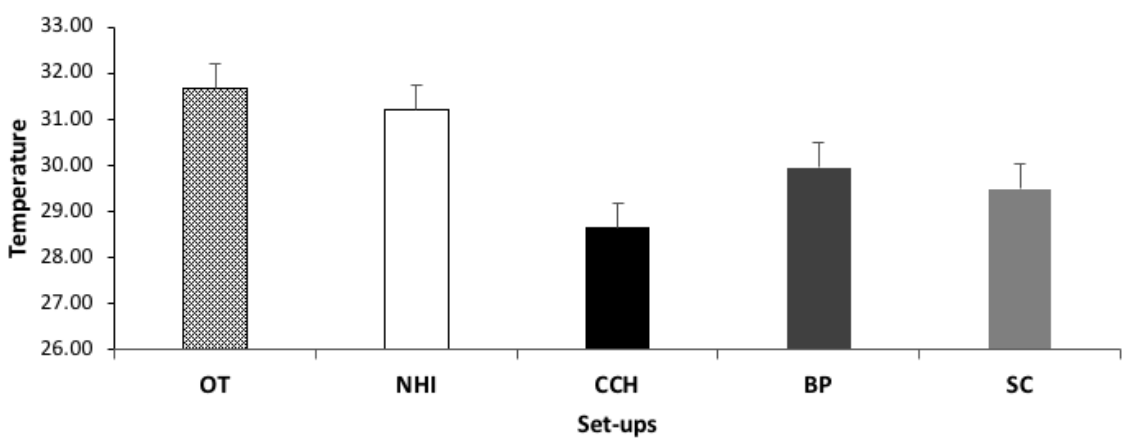


Figure 20. Results of the Noise Reduction Coefficient (*c*) of coconut husks, banana pseudostem fibers and sugar cane husks at 800 Hertz and 440 Hertz



Note: OT=Outside Temperature; NHI=No Heat Insulator; CCH=Coconut Husk; BP= banana pseudostem; SC=Sugarcane

Figure 21. Heat insulation performance of the different agricultural wastes (in °C) within 5-day observation from 11:00 am to 4:00 pm

Figure 20 shows the results for the Noise Reduction Coefficient (***c***) of the used agricultural wastes at 800 Hz and 440 Hz. It can also be depicted from the Figure that at 800 Hz, coconut husk, banana pseudostem, and sugarcane obtained ***c*** values of 0.80, 0.50, and 0.75, respectively. Meanwhile, for the 440 Hz, ***c*** values of 0.92, 0.35, and 0.78 were recorded for coconut husk, banana pseudostem, and sugarcane, respectively.

Figure 21 displays the recorded temperature readings (in °C) of the coconut husk, banana pseudostem, and sugarcane as compared with the Outside Temperature (OT) and the set-up with No Heat Insulator (NHI) applied. Results also portray that there is really a sudden decline on the temperature readings when the agricultural wastes are applied, as compared to the set-up without insulating materials used and on the outside temperature. Among the different agricultural wastes, the coconut husk (28.64 °C) exhibits more decline on the temperature readings followed by the sugarcane (29.49 °C), and then the banana pseudostem (29.96 °C).

Table 1. Results on Flame Test of the Different Agricultural Wastes at 1000-1200 °C

Intervals (in s)	*Agricultural Wastes*		
	Coconut Husk	Banana Pseudostem	Sugarcane Husk
0-5	smoke	smoke	smoke
6-10	smoke	flame	smoke
11-15	smoke	ablaze	smoke
16-20	smoke	Burned up	flame
21-25	flame	---------	flame
26-30	flame	----------	ablaze

Table 1 depicts the results of the flame tolerance test of the different agricultural wastes at 1000-1200 °C. Based on the above Table, the coconut husk appeared to have the longest time (in seconds) of tolerance to flame, followed by the sugarcane and lastly, the banana pseudostem.

4. DISCUSSION

Surface Morphology

The results of the Scanning Electron Microscopy (SEM) micrographs show the surface morphology of the coconut husk, banana pseudostem, and sugarcane. The micrographs further affirmed the abundance of microporous cell structures present particularly on the cross-sectional surface of the coconut husk sample and sugarcane. These microporous cell structures are more evident in Figures 4-6, 9-12, and 16-18, wherein all parts of the surface of the samples

are composed of various tiny holes that function as micro compartments which are good in trapping sound waves. On the other hand, the micrographs also revealed the fibrous network structures on the surface of the coconut husk with the appearance of many pores. The microporous cells found on the surface of the samples of agricultural wastes varied in sizes (lengths in μm) and with irregular shapes and different layers and groups for coconut husk and sugarcane. Various groupings of microporous cell structures are shown in Figures 2 and 15. These layering and groupings of microporous cells in the coconut husk contain more micro compartments doubling their original number. Figures 4-6 and 16-18 were magnified sections of the microporous cell groups found in the surface of the fibrous agricultural wastes. Meanwhile, there were no layering of microporous cell structures on the surface of the banana pseudostem.

Irregular shapes of the microporous cell structures are also shown in the surface of the coconut husk, banana pseudostem, and sugarcane. They appeared to have shape variations based on the group they belong (for coconut husk and sugarcane), however, the banana pseudostem shapes were mostly elongated due to the stretches happened during natural dehydration, as shown at Figures 10-12. In the coconut husk, Figure 5 was the magnified micrograph taken from Figure 2 where shapes were also mostly elongated but with curved dimensions unlike the microporous cells demonstrated at Figure 6 which had slightly rounded features mixed with the elongated ones.

Meanwhile, sugarcane contained a number of large pores located at every grouping of microporous cell structures. This appeared to be consistent in all other small layering and another microporous cell groups found on it, as shown in Figures 16-18.

The results of the surface morphology of the coconut husk and sugarcane samples showed similarities in the schematic cross-section of a porous solid material presented in several studies [2, 17]. The presence of rough surface, closed, though open and blind pores were evident in the micrographs. A porous absorbing material is a solid that contains cavities, channels or interstices so that the sound waves are able to enter through them [2]. These cavities were present in the surface of the coconut husk sample. The banana pseudostem, however, demonstrated some presence of the microporous cell structures but with very limited channels or interstices.

The materials with a lot of microporous structures are good examples of an ideal sound absorbing material [20]. The holes that are given in different dimensions and structures in the generated micrographs of the different agricultural wastes affirmed the sound trapping capability of the materials. In this sense, the sound produced can easily be absorbed and the coconut husk had the good presence of these microporous cells, followed by the sugarcane then the banana pseudostem.

Because of the numerous micropores found on the surface of the coco husk samples, there is also a greater probability for the material to absorb a large amount of water. This is because the more microporous structures located on the surface of the material, the better water absorbing capacity there will be.

The image at Figure 7 showed that other sections of the surface of the banana pseudostem which were described as flat and rooted surface, did not consist of micro-holes or the microporous structures.

On the other hand, the micrograph at Figure 8 described other subsection of the banana pseudostem surface that consisted of porous structures. This gave implications that banana also contained microporous structures but located only in some defined surface sections and had not

been occupied the majority of its area. SEM images furtherly proved that dried banana trunk had more smooth surface sections as compared to the other fibrous raw material like coconut husk.

The raw materials that possess inconsistent microporous structures are more likely to absorb less water so as to absorb sounds [5]. Because of the insufficiency of the tiny compartments located on the different sections of the surface of a given material, the higher the tendency for the sound waves to go and travel elsewhere. Smooth surfaces of a particular material do not absorb sounds and do not hold the amount of water, either.

In the study "Experimental study of the absorption characteristic of some porous fibrous materials", highly porous materials are the ideal components for sound absorption [19]. The porosity of the material will be evident through its surface morphology, showing tiny holes or micro-compartments. Majority of the materials possessing these micro-compartments are those in rough and uneven surface structures.

The longitudinal and transverse sections of the sugarcane were shown in Figure 13. The surface morphology of the sugarcane contains elongated and straight compartments that were confined at the middle most section, while some coarsed-section were identified at the upper part of the micrograph. The roughness of the surface was also identified at the surface of the sugarcane.

On the other hand, tiny compartments and holes were also evident at the sides of the sugarcane image as shown in Figures 13-14. These little compartments are the microporous cell structures on the sugarcane that are responsible in absorbing sounds. Compared to that of the banana pseudostem, sugarcane has more defined cross-sectional microporous cells which were located at different tiny layering and groups just like the coconut husk. However, the surface morphology of the sugarcane did not only contain microporous cell structures but some areas with longitudinal sections as well.

In addition, the longitudinal sections also absorb sound but not as good as the microhole compartment cells [21]. Because they are elongated, sound waves can still travel in the longitudinal sections unlike on pure microporous structures or compartment cells, wherein the sound waves can easily be trapped on them.

Water Absorbing Capacity

Figure 19 shows the recorded Water Absorbing Capacity (WAC) percentage of coconut husk, banana pseudostem, and sugarcane. Based on the presented figure, the coconut husk gained the highest WAC of 56%, while 49% WAC was recorded for the sugarcane and the banana pseudostem obtained the lowest WAC of 32.67%.

The high WAC result for the coconut husk was supported by its morphology analysis. It can be deduced from its morphology that there were a lot of microporous cell structures on its surface. The abundance of micro compartments on coconut husk enable it to absorb greater amount of water. This simply means that the more porous the surface of the material, the more moisturized the material will be. On the other hand, results of water absorbing capacity for both sugarcane and banana pseudostem were also evident in their morphology analysis.

The sugarcane also exhibited the presence of microporous cell structures on its surface that is why the material also demonstrated quite higher moisture content. Meanwhile, since the water absorbing capacity was directly affected by the presence of microporous structures and micro compartments, banana pseudostem recorded a low moisture content as compared with

the coconut husk and sugarcane. This was simply because of the presence of large smooth surface that inhibited the occurrence of microporous cell structures.

The results gave then implications that materials with lots of microporous cell structures on their surface could exhibit better water absorbing capacity. The micro- compartments trap water that could lead to greater percentage of moisture content – the same case with sound waves [13].

Flame Test of the Different Agricultural Wastes at 1000-1100 °C

Based on the obtained result, the coconut husk commenced 19 seconds for its smoke appearance and after 20 seconds before the actual flame was observed. Meanwhile, the banana pseudostem exhibited smoke appearance in just 4 seconds and had flame after 5 seconds, showed ablaze within 11-15 seconds, and burned-up after 20 seconds. On the other hand, result of the sugarcane was closer to that of the coconut husk which showed that smoke was evident at about 15 seconds after direct flame exposure.

Flame at sugarcane was then appeared within 16-25 seconds and the ablaze started after 26 seconds of the 30-second flame test. Results then gave implication that the coconut husk appeared to be of high tolerance when it comes to flame exposure, followed by the sugarcane while the banana pseudostem exhibited low tolerance in flame. Flame test result also revealed that material with a lot of pores like foams appeared to have a lot of absorbed water which hindered easy penetration of flames on its surface [16].

In the current study, the coconut husk had a high water absorbing capacity and had a good tolerance on flame. The surface morphology of the surface of each material was also associated with the results of the flame test. Presence of lots of microporous cell structures, which was evident on coconut husk, mainly triggered a good performance on WAC.

Noise Reduction Coefficient (*c*) of the Different Agricultural Wastes

Based on the presented results in Figure 20, the coconut husk, banana pseudostem, and sugarcane had a value of 0.80, 0.50 and 0.75 respectively as result for the Noise Reduction Coefficient (NRC) at 800 Hertz. Meanwhile, NRC readings at 440 Hertz resulted to 0.92, 0.35, and 0.78 for coconut husk, banana pseudostem, and sugarcane, respectively.

It can be deduced from the results that the coconut husk exhibited the highest noise reduction coefficient, followed by the sugarcane and then the banana pseudostem for both, 440 and 800 Hertz. The testing on coconut husk showed that it had good acoustic properties at low and high frequencies and can be used as an alternative replacement for synthetic-based commercial product [22]. By using the porous layer and perforated plate backing to coconut coir fiber, the sound absorbing panel shows a good potential to be an environmentally friendly product.

On the other hand, the sugarcane was also capable of exhibiting sound absorption (or noise reduction) but not as better as the coconut husk, while the banana pseudostem had the least noise reduction coefficient. The results on the sound absorption capacity of the materials used were also directly associated with the results of their morphology analysis using the scanning electron microscopy. It was found through the generated SEM micrographs that the coconut husk had a lot of microporous cell structures that helped in trapping sound waves that led to a better sound absorbing capacity. The results were the same with that of several studies, wherein the coconut husk demonstrated better sound absorbing capacity [2].

The reason primarily for this good performance of fibrous materials is the presence of various microporous cell structures on its surface. Porosity is actually demonstrated through the percentage of the moisture content or water absorbing capacity of the material.

It can then be implied that the noise reduction coefficient of the different agricultural wastes (coconut husk, banana pseudostem, and sugarcane) really differed from one another. This means that they also have different sound absorbing capacities, as supported by their surface morphology.

Heat Insulating Performance of the Different Agricultural Wastes

Meanwhile, based on the data presented in Figure 21, the heat insulation performance of the different agricultural wastes were based on their recorded temperatures which were given as follows: coconut husk had 28.64 °C, banana pseudostem had 29.96 °C, and sugarcane had 29.49 °C. As compared on set-ups with no heat insulating material and the outside temperature condition, the set-ups with insulating materials showed a decline on the recorded temperatures. The coconut husk reduced 2.56 °C of heat inside the miniature house, 1.71 °C for the sugarcane, and 1.24 °C was reduced by the banana pseudostem. These were higher reductions on heat as compared to the set up with no applied heat insulator which only reduced heat by 0.47 °C, as per reference on the recorded temperature outside.

Among the three tested agricultural wastes, it was found out that the application of the coconut husk appeared to insulate more heat, followed by the sugarcane and the banana pseudostem. The lower the recorded temperature, the higher the heat insulation performance. The three materials are said to have cellulose and fibers. The thermal performance of loose filled cellulose was compared favourably to other types of low cost insulation. The thermal conductivity of loose-filled cellulose is approximately 40 mW/m·K (an R-value of 3.8 per inch) which is about the same as, or slightly better than, the glass wool or rock wool. The cellulose insulation lost 26.4% less heat energy over time compared to the fiberglass insulation. It also was shown to tighten the structure more than by 30% [14].

The good performance of the coconut husk in the heat insulation is actually supported by its surface morphology, wherein the presence of numerous microporous cell structures are very evident. Heat is carried by subatomic particles moving in the form of electromagnetic waves. When an electromagnetic wave hits an object or substance, it transfers energy to its molecules. The molecules become excited by the transfer of energy and begin to move faster [1]. The mini cell compartments found on the surfaces of the different agricultural wastes, using SEM micrographs, affect the flow of heat.

These microporous cell structures caused the heat to move slower. This claim is also associated to the obtained results of the agricultural wastes on Water Absorbing Capacity (WAC). The more water absorbed by the material, the more microporous cell structures are present leading to a high heat insulation performance.

On the other hand, the coconut coir is mainly a multi-cellular fiber which contains 30 to 300 or more cells in its cross-section. Cells in natural fibers like coir refer to crystalline cellulose arranged helically in a matrix, consisting of a non-crystalline cellulose-lignin complex. Coir which stems from its structure has several valuable physical properties. Among its most useful properties were length, fineness, strength, rigidity, wetability, and resistivity [4]. This supports the findings that coconut husk performed better heat insulating capacity.

5. CONCLUSIONS

Based on the presented results, all agricultural wastes materials used contained microporous cell structures but of different conditions and sections. Microporous cell structures dominantly present on the surface of the coconut husk, make it a good sound absorber and thermal insulator. The coconut husk and sugarcane demonstrated a good appearance of microporous cell structures, particularly on cross-sections of the samples. Both of them had various tiny layers with groupings of microporous cell structures that could even double its original number. However, the sugarcane's microporous cell structures were combined with longitudinal sections that hindered the fast holdings of sound and heat. In contrary, banana pseudostem had also microporous cell structures mostly elongated but they are fewer compared with coconut husk and sugarcane because its surface was mostly composed of smooth texture.

On the other hand, the surface morphology analysis of the current study provided evidence that the microporous cell structures of the used agricultural wastes were directly affected by their porosity. The coconut husk had the highest water absorbing capacity (WAC) which supported its better tolerance to flame, the highest noise and heat reduction indices. The other fibers had lesser WAC which resulted in lesser tolerance to flame, and lower heat and noise reduction indices.

The current study also claimed that materials that absorbed more water, as supported by the microporous cell structures determined through morphological analyses, are also those with high sound absorption capacity and high thermal insulating performance. So, porosity of the materials is directly proportional to the sound absorbing capacity and heat insulation performance of different agricultural wastes used. Based also on the findings of the study, the coconut husk had the greater porosity so it also appeared to be a better sound absorber and heat insulator. Results also indicate that the morphology of the fibrous materials can be used as a basis in choosing better sound absorber and thermal insulators.

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