Design and Development of Sound Absorbing Panels using Biomass Materials

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Abstract

Manufacturing of sound-absorbing panels typically uses synthetic materials such as fiberglass and wool fibers. In this paper, biomass as acoustic absorbing materials were considered as an alternative to synthetic materials because it can provide a more economical perspective to the supply of sound-absorbing materials. In this study, three (3) fibrous materials were used as the main component of the sound-absorbing panels. These materials include coconut (cocos nucifera), corn (zea mays), and banana (musa balbisiana). Moreover, this paper aims to manufacture sound-absorbing panels made from local biomass materials and determine its characteristic potential as acoustic sound absorbers using a custom-made impedance tube. To test the potential of the biomass materials as sound absorbers, its individual sound-absorbing coefficients were measured. In the impedance tube results, the data obtained from the biomass materials were compared to the data obtained from the conventional material. All the panels made from biomass materials were able to absorb sound significantly and level the characteristic qualities of sound absorbers made from conventional materials. Therefore, improving the design of the impedance tube and fabrication of panels can increase the sound absorption coefficient of the manufactured materials.

Keywords
sound-absorbing panel, biomass materials

1. Introduction
This study involves the design and development of sound-absorbing panels made from the biomass materials. The study focuses on the capabilities of biomass materials as sustainable acoustic sound absorbers. This paper is an investigation of the potential of biomass materials as a major component in the manufacturing of sound-absorbing panels. It is based on the foundation of acoustic absorption. The usual materials that are used in the market are fiberglass and wool fibers. In this paper, the properties that affect the potential of biomass materials as sound absorbers are explored. Biomass materials are organic materials that originate from living organisms. Mostly, the potential of biomass material as a sound absorber is dependent on its fibers (Bastos et al., 2012). In the manufacturing of the panels, three fibrous materials will be used as the main component of the sound-absorbing panel. Potential fibrous materials include coconut (cocos nucifera), corn (zea mays), and banana (musa balbisiana).

The study has a wide range of applications. Sound absorbing panels are usually used for sound reductions or soundproofing in rooms. The measure of how much a sound-absorbing panel can absorb is called the sound-absorbing coefficient. To test the potential of the biomass materials, their individual sound absorbing coefficient will be measured. The measurement will be done using an impedance tube. An impedance tube is a standardized testing device that measures the sound-absorbing coefficient of a material. The device tests wave at normal incidence. A comparison between the conventional sound-absorbing materials, such as Rockwool and biomass materials are conducted to test the potential of biomass sound absorbers. The study determines if the level of biomass materials surpass the characteristic qualities of sound absorbers made from conventional materials. In assumption, if the biomass materials do not level to that of the conventional materials, this study is still useful as long as the structural integrity of these materials is not affected. This will have an environmental impact because it can lessen the use of materials that are not as abundant as biomass and lessen the use of materials that takes large amounts of energy to process.

The objectives of the study are to determine the characteristic potential of biomass material to be a sound absorber and to manufacture sound-absorbing panels made from local biomass materials in the Philippines using a revised standardized process.

The researchers should be able to determine how biomass materials panels absorb sound, know the properties that affect the potential of biomass materials as sound absorbers using a custom testing procedure, and acquire the necessary acoustical characteristics of the biomass materials based on the application of the absorption coefficient.

Biomass as an acoustic absorbing material is an alternative to the conventional absorbers that provide a more economical perspective to the supply of sound-absorbing materials. This study will show that for the same amount of sound absorbed using conventional and alternative materials, biomass is cheaper and readily available in the market. This will solve shortages in materials in the manufacturing of acoustic absorbers. Biomass materials based on its sound absorption characteristics can be considered as a major component in the production of sound-absorbing panels. With these characteristics of biomass materials, it will provide additional applications of sound absorbers and eventually benefit the field of engineering as well as the music industry. This study will be greatly helpful for future researches that concerns biomass as a sound-absorbing material. This study is particularly about the potential of biomass materials as a major element in the manufacturing of sound-absorbing panels. Biomass materials in the form of organic fibers which have potential as sound absorbers are the focus of this research. This study is limited only to the biomass material's sound absorbing properties, thus, other properties of the said material such as its thermal properties are not included in this research. The shape and size of the sound absorber is not a concern of the study. The study focuses on the biomass material incorporated in the sound absorber. The testing of the material is limited to a custom-made testing procedure inspired by the Impedance tube method. The data gathered will be focused on the frequency reduction and the sound-absorbing coefficient of the material.

2. Methodology

The study involves the manufacturing and testing of sound-absorbing panels made from biomass materials using a standardized testing device that measures the sound-absorbing coefficient of the materials. The following are the methods employed by the researchers.

2.1. Impedance Tube

The gathering of the values of the sound absorption factors within a variety of biomass materials will be done using the impedance tube method. The values that will be gathered from the impedance tube method will be obtained using the two-microphone transfer function method (International Standard, ISO 10534-2, 1998). Using this method makes the fastest way in obtaining the values of the normal incidence factors from tiny samples in which makes the assembly and disassembly of the samples on the impedance tube equipment with ease.

Meanwhile, the gathered data from the experiments using this method will represent different values in different varieties of test centers, which are the effects of the different setups made in the preparation of the materials, most especially the sample materials. In assumption, the difference of the data of the similar type of sample gathered from the different test centers will have a very large gap in relation to the value of the resistivity flow of the material. It can say the larger the flow resistivity of the material, the larger the difference of results from a different variety of test centers. The impedance tube method will be used for measuring the sound absorption characteristics of the fibrous materials. The schematic diagram for the impedance tube with the two-microphone transfer function method is illustrated in Figure 1. A loudspeaker is the source of the sound and is attached at the end of the impedance tube while the sample material is located at the other end of the tube. The loudspeaker creates random sound waves that are fixed and spreads as plane waves in the tube and then reaches the material sample on the other end of the tube and reflects to the surface (Niresh, 2016).

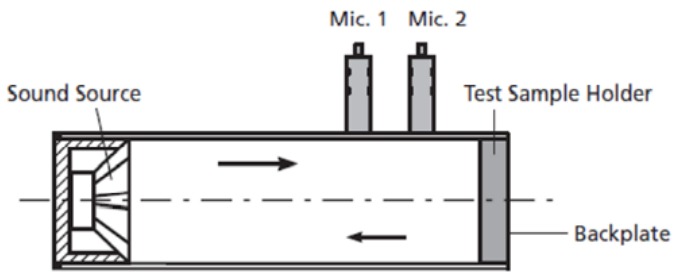

Figure 1. Two-microphone transfer function method

2.2. Testing of Impedance Tube

For the experimentation, the usage of the impedance tube method will be implemented due to its compactness, and cost-effectiveness. Impedance Tube can accurately measure the sound absorption coefficient according to ISO and ASTM standards. Basically, there are good materials for every range of frequencies and this study requires identifying those frequencies using the impedance tube method with a two-microphone setup wherein the sound of a given frequency is made with the use of a signal creator. This method is well fit for small size objects exposed to plane waves at normal sound incidence (ISO 10534-2, 1998). According to ASTM E 1050- 98 (1998), “Normal incidence sound absorption coefficients are more useful than random incidence coefficients in certain situations”. It is mainly used to predict the effect of placing a specific material in a small enclosed surface, for example, an impedance tube. The method using the impedance tube has numerous advantages compared to the other methods. The impedance tube itself as the equipment has a lesser size and that makes it be used occasionally compared to the other methods that use a larger size of equipment. Only a small size of the sample is needed to proceed to the experiment. Another advantage of the impedance tube is that the absorption coefficient can be determined as well as the impedance surface of the sample materials.

Additionally, the impedance tube method determines the characteristics of the material by the sound produce at normal incidence to the sample material. The characteristics of the sound-absorbing materials can also be measured at random incidences which provide results by applying a correction on the properties at normal incidence. Inaccurate results may occur in determining the sound absorption characteristics of an assorted mixture of materials because of the difference in the formations or structures of each part of the material. The determination of the properties on a large range of frequency using this method requires two different samples. Pure types of materials were used as samples for the impedance tube method. The separation or cutting of the sample material can produce errors because of the circumferential air gaps that occurred between the sample and the tube.

Figure 2. Impedance tube setup

2.3. Manufacturing of Sound Absorbing Panels

The researchers will be producing their own panels without the use of machines. Handmade panels can be made into three types – uni-fiber, multi-fiber, and mixed fiber. They differ in the variance of fiber/s used and the number of layers. The first type of panel is the uni-fiber panel, which contains multiple layers of a single type of fiber. The second type of panel is the multi-fiber panel, which contains multiple layers of two or more different types of fibers. The last type of panel is the mixed fiber panel, which comprises of two or more fibers in a single layer. The choices of the fiber of the researchers are those that are abundant and available in the country, which may be coconut husk fiber, corn husk fiber, or banana trunk fibers (Bastos et al., 2012).

For this research, the researchers chose to limit the study by using one type of panel – the uni-fiber panel and the three fibers mentioned will be utilized namely (1) a coconut husk fiber panel, (2) a corn husk fiber panel, and (3) a banana trunk fiber panel. There are two main aspects to consider in producing the panel: compatibility and treatment (Bastos et al., 2012). The first one is that the fibers must be compatible with their respective binding agents. The second is there is a choice of chemical or thermal fiber treatment. The panel will be made up mostly of the fibers to ensure that no other factors will affect the performance of the acoustic panel. Only adhesive additives will be the other component to the manufacturing of panels. The panels will be ideally made up of 1 kg of each fiber with a surface area of 0.3 m^2 (Bastos et al., 2012) and will be bonded by adhesive additives.

Figure 3 shows the process of creating the panels. The first step is cleaning the fibers; this is done to reduce the amount of impurities in the fibers that may cause degradation of the panels. After cleaning, multiple layers of fibers are aligned to form a panel. For the fibers to stick together, a binding agent made from acrylate and water is applied. The binding agent is applied until all the fibers are attached to each other. To produce a good adherence with the fibers, the layers are extended and pressed one after the other and later dried by means of sunlight and wind.

Figure 3. The manufacturing process and sound panel

2.4. Pearson Correlation Statistical Analysis

The analysis of data contains the comparison of the gathered values of the absorption coefficients of every sample material that were used in the experiments using the equations of the model for the fibrous materials as per ISO standards. The conduction of the conclusions and recommendations will be made through the review of the theories and applying it in the results and the data gathered from the experiment. Concluding the experiment with the gathered values for the absorption coefficient gives recommendation on what materials suits the best for the applications and conditions.

The Pearson correlation statistical analysis will be done to have a more concrete conclusion on the relationships of the variables. The frequency and the sound absorption coefficient will be the two variables to be analyzed. The Pearson correlation coefficient is calculated using the formula below:

$$r = \frac{\sum_i (X_i - \bar{X})(Y_i - \overline{Y})}{\sqrt{\sum_i (X_i - \bar{X})^2} \sqrt{\sum_i (Y_i - \bar{Y})^2}} \quad (1)$$

The coefficient, r, will range from values -1 to +1. The closer the value is to -1 the stronger the negative relationship is between the two variables. The closer the value is to +1 the stronger the positive relationship is between the two variables.

3. Results and Discussion

3.1. Validation Study

The custom-made impedance tube is validated by comparing the measured sound absorption coefficient of a commercial panel with those measured from panels made from biomass materials. The impedance tube apparatus used a 3-in PVC pipe for measuring sound absorption at different frequency ranges. Different types of acoustic materials were used to validate the results as shown in Figure 4. It shows the acoustic materials used made from coconut husk fibers (cocos nucifera), corn husk fibers (zea mays), banana trunk fibers (musa balbisiana) and rockwool fibers, respectively.

Figure 4. Test samples

3.2. Testing for Sound Absorption Coefficient

The testing for the sound absorption coefficient was done using an impedance tube. Table 1 shows the sound level (in decibels) using the DIY Impedance Tube with the test samples: coconut husk fibers, banana trunk fibers, and corn husk fibers. The samples were cut from the original molded panel having the size of 3-in diameter for each sample. The samples were tested in different frequencies of sound: 250Hz, 500Hz, 750Hz, and 1000 Hz.

Table 1. Sound Levels of Biomass Materials

Material	Sound Level (dB) at 750 Hz	Sound Level (dB) at 1000 Hz
Coconut (23.02 g)	47.6	43.2
Banana (22.14 g)	46.6	42.4
Corn (19.17 g)	46.2	43

Table 2 and Table 3 show that the conventional material still has a higher sound absorption coefficient than the manufactured panels using coconut husk fibers, banana trunk fibers, and corn husk fibers. Though the manufactured panels showed an exquisite sound absorption considering its cost. The values of its sound absorption coefficient are not far from the conventional Rockwool material. The maximum difference of sound absorption coefficient is from the corn husk fibers and banana trunk fibers with 250 Hz frequency. The difference in sound absorption from the conventional Rockwool material is 0.04. The minimum difference of sound absorption coefficient is from the banana trunk fibers with 750 Hz frequency. The difference between the sound absorption coefficient from the conventional Rockwool material is 0.01.

Table 2. Sound Absorption Coefficients of Biomass Materials

Material	Sound Absorption Coefficient at 750 Hz	Sound Absorption Coefficient at 1000 Hz
Coconut (23.02 g)	0.28	0.35
Banana (22.14 g)	0.3	0.36
Corn (19.17 g)	0.3	0.35

Table 3. Sound Absorption Coefficients of Conventional Material (Rockwool)

Material	Sound Absorption Coefficient at 750 Hz	Sound Absorption Coefficient at 1000 Hz
Rockwool (23.02 g)	0.31	0.38
Rockwool (22.14 g)	0.31	0.38
Rockwool (19.17 g)	0.32	0.37

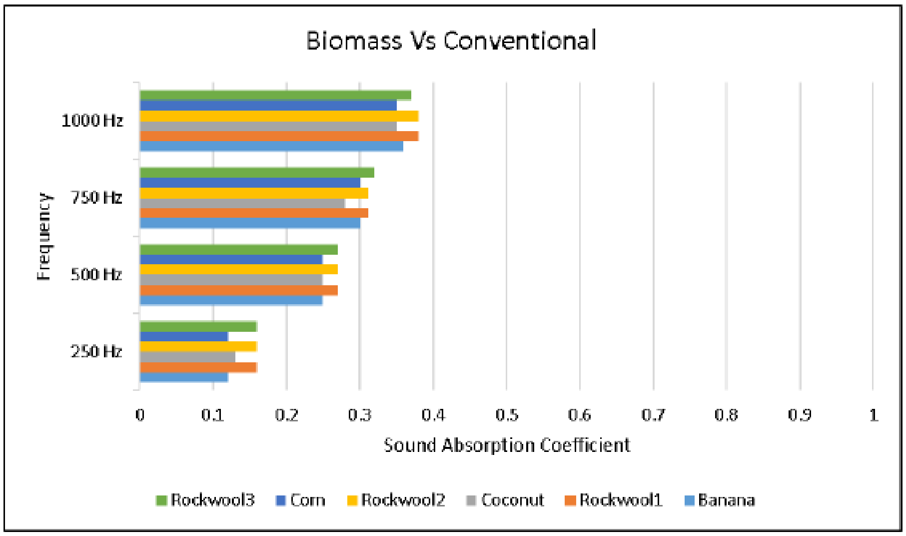

Figure 5. Graph of Measured Sound Absorption Coefficients of Biomass and Conventional Materials

Figure 5 shows a graphical representation of the calculated values from the testing of sound-absorbing panels using coconut husk fibers, corn husk fibers, and banana trunk fibers in comparison to a conventional Rockwool material. The sound-absorbing panels made from biomass materials had significant performances in terms of its sound-absorbing properties though the conventional material had a higher sound absorption coefficient compared to biomass materials.

Table 4. Summary of Data

Material	Thickness (m)	Density ($\frac{kg}{m^3}$)	Area (m^2)
Coconut	0.02	216.6667	0.3
Banana	0.012	347.2222	0.3
Corn	0.012	340.5797	0.3
Rockwool	0.05	138.8889	0.72

From the study, it is observed that low-density fiberboards possess a high sound absorption coefficient and noise reduction coefficient when compared with high-density fiberboards. It was seen that the sound absorption coefficient increases with a decrease in density and vise-versa.

For the experimental result, the absorption coefficient of the Rockwool insulation panel was high and close to the value of 1 as expected. For the panels made from biomass materials, the results show an excellent experimental setup with a good result when compared to the result of conventional material, which is the ideal case. Since a good sound absorbent material should have a high absorption coefficient value, the manufactured biomass panels can be considered as a good sound-absorbing material. The researchers can say that the results from the custom-made impedance tube using biomass materials as sound-absorbing panels agree well with those obtained from the panels made from Rockwool fibers.

Additionally, the researchers were able to determine the properties that affect the potential of biomass materials as sound-absorbing panels. They have determined that frequency has a significant relationship to the sound absorption coefficients of the biomass materials. The conclusion was based on the interpretation of the solution that resulted from the computation of the formula that was used. In the computation using Pearson's r formula for the sound absorption coefficient of coconut panel and frequency, the result of the r is 0.962110336. According to the study, the closer the result is to +1, the higher and stronger the relationship is between the two variables. The variables that were used in the computation were the frequency (variable x) and the sound absorption coefficients of the coconut panel (variable y).

In the computation using Pearson's r formula for the sound absorption coefficient of the banana panel and frequency, the result of the r is 0.961053991. The variables that were used in the computation was the frequency (variable x) and the sound absorption coefficients of the coconut panel (variable y). Lastly, in the computation using the Pearson's r formula for the sound absorption coefficient of corn panel and frequency, the result of the r is 0.952284335. The variables that were used in the computation was the frequency (variable x) and the sound absorption coefficients of the corn panel (variable y).

It can be concluded that there is a very high positive relationship between the two variables: frequency and the sound absorption coefficients of the biomass materials. All the results fell into the 0.70 or higher range which is equivalent to a very high positive interpretation. This could mean that the relationship between the two variables is very significant.

4. Conclusion

The researchers have manufactured sound-absorbing panels made from biomass materials. They have utilized three fibers and produced coconut husk fiber panel, corn husk fiber panel, and banana trunk fiber panel. The panels were made up of 1 kg of each fiber with a surface area of 0.3 m^2, and a binding agent for the panel to stick together. Moreover, the panels were made up mostly of the fibers to ensure that no other factors will affect the performance of the acoustic panels. Based on the experiment, the sound-absorbing panels made from local biomass materials had significant performances in terms of its sound-absorbing properties. The manufactured panels were able to absorb sound and acquire necessary acoustical characteristics based on the application of the absorption coefficient. But compared to the measured sound absorption coefficient of the conventional material, the biomass materials were not able to surpass the characteristic qualities of sound absorbers made from conventional materials. Although the biomass materials do not surpass that of the conventional materials, this study is still useful considering that it can lessen the use of materials that cause pollution to the environment as well as materials that take large amounts of energy to process.

Similarly, a custom-made impedance tube was assembled using ASTM and ISO standards as references. One of the objectives of this study is to manufacture sound-absorbing panels made from biomass materials using a custom testing procedure that will demonstrate the measurement of sound absorption and compare the result to conventional materials. The assembled impedance tube includes a full range loudspeaker, PVC pipe, signal source, test sample, an omnidirectional microphone, and other essential elements to conduct the absorption experiment effectively. To acquire the necessary data from the experiment, the researchers have used a laptop and mobile phone for digital frequency analysis. The overall performance of the two-microphone method is good except that the researchers had trouble finding an accurate result for measuring the absorbed sound level of the materials.

In addition, the testing for the sound absorption coefficient was done using the two-microphone method. A thick layer of the Rockwool insulation panel was used and considered to absorb a large amount of sound. For the panels made from biomass materials, different layers of thicknesses were manufactured since the fiber materials have different volume and density. The volume of the coconut husk fibers is much larger than the volume of an equal mass of banana trunk fibers or corn husk fibers. This means that the coconut panel is less dense than that of banana and corn panels. As defined in the paper, a material is said to be very sound absorbing if it has a high absorption coefficient. The sound absorption coefficient, a dimensionless number that ranges from zero equal to one, is the amount of sound energy being absorbed or reflected by the material. Hence, assuming a material has a value close to 1, then it is considered a highly sound-absorbing material.

To aid future researchers in further developing this study, it is recommended that in creating the panels, they should divide the raw materials into portions that would make the adhesive spread more evenly throughout. They should also make sure that the raw materials used are mixed properly with the adhesive or else it may result in the final product to shed, hence, making the surface rough. It is also strongly suggested that the raw materials be cut into small pieces so that the adhesive will, again, easily spread.

In constructing the impedance tube, the researchers recommend that the microphones to be used must be identical to avoid any errors in receiving the vibrations. It should be noted that making use of an omnidirectional microphone is a great investment. It receives sound from all sides; thus, it will be clearer compared to the straight type of microphone which is commonly used in videokes. Moreover, with regards to the speakers, purchasing a full range type is highly recommended. This is so that frequency it can produce will have a wide span, about 100 Hz to 3, 000 Hz. Lastly, the researchers should experiment with quiet locations so that the surrounding sounds will not affect the results of the test.

It is recommended that before working on the actual testing procedure for the determination of sound absorption coefficients of the test samples, the impedance tube setup must be tested first to know if the tube produces an accurate or in any case an acceptable result. To check if the setup works correctly, the conventional material or Rockwool insulation panel must be tested first since the said material is considered as a highly absorptive material.

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