A STUDY OF ACOUSTIC PROPERTIES OF COCONUT COIR AND VERMICULITE COMPOSITE AS NOISE INSULATION IN VEHICULAR APPLICATION

by

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ABSTRACT

Coconut coir and vermiculite composite is a promising front on the research on natural fiber sound insulation panels. Vermiculite particles are introduced in the matrix to prop up the pores in the coconut coir fibers thus allowing for sound energy to be dissipate as it passes through the pores. Since the composite can be compressed considerably while still maintaining the pores, the acoustic performance can rival that of conventional noise insulation materials but with added value of sustainability and possible cost savings. By using a mix of 7:2:1 ratio of coconut coir fibers to vermiculite particles to PVA binder in weight percentages, an improvement of 18.7% can be seen with the acoustic absorption coefficient with respect to the control sample. The 8:1:1 variations also sees an improvement of over 16% but in both cases, chopped fibers were used with an average length of 60mm. In the long fibers specimens, only 8% improvement was seen with the 8:1:1 variation and the 7:2:1 variation was only marginally better than the former.

CERTIFICATION OF APPROVAL

A Study of Acoustic Properties of Coconut Coir and Vermiculite Composite as Noise Insulation in Vehicles

by

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Approved by

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January 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or people.

MUHAMMAD DANIAL BIN MOHD ZIAN

Table of Contents

List of Figures

List of Tables

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND STUDY

Noise attenuation is one of the most overlooked aspects in design. It is not until it causes too much disturbance to the user or nuisance to the surrounding environment will the noise be taken seriously and insulated to a more tolerable degree. However, noise can be more than just unpleasant especially if exposed for a prolonged period of time. Studies done by medical researchers have conclusively state that noise can also affect productivity, mental health and even the ability to concentrate during a task [1]. As noise exposure awareness increases in the work place, governing bodies such as Center for Disease Control (CDC) has released a guideline in 1998 regulating the maximum sound intensity and allowable exposure time without hearing protection [2]. In vehicles, porous absorbers are used to attenuate noise radiating from the car frame, engines, wind resistance and even the road. Porous absorbers are preferred because of the flexibility of the materials and the space limitation of the vehicle.

However, current materials in use for noise attenuation raises up a lot of questions in terms of environmental and sustainability issues. Many research teams have studied locally sourced natural fibers such as bamboo and Oil Palm Empty Fruit Bunch (OPEFB) as an alternative to synthetic fibers [3] [4]. Natural fibers are biodegradable and most of them are waste product of other manufacturing processes. Current treatments of agro-waste are limited to incineration, composting and small industries of fiberboard manufacturing. As such, the availability of these agro-waste makes it very suitable for further development [5].

The current noise insulation primarily used in vehicles consists of a mixture of synthetic fibers on some parts while using compressed felt on others. The acoustic performance of compressed felts are less than that of synthetic fibers but it is the currently the cheaper alternative. Coconut coir is another fiber being underutilized and it shows a very promising results as a suitable replacement for compressed felt as it has been shown to rival synthetic fibers in acoustic absorption performance [6].

1.2 PROBLEM STATEMENT

Since the 1970s, synthetic fiber-based sound insulation have been replacing most of the asbestos-based sound insulation but even so, these synthetic fibers are non-biodegradable and cause a lot of problems in the landfill as well as its contribution to CO_2 emissions [7]. As such, there is a need to look into a more biodegradable alternative to synthetic materials as sound insulation panels. Natural fibers have been identified to be a suitable candidate to replace synthetic fibers because of its abundance and durability.

Sound absorption panels should be able to perform effectively as noise attenuation tools but not at the cost of health. Synthetic fibers currently being used are harmful to the health of the workers who install them without proper personal protective equipment especially glass wool [8]. By using natural fibers, the risks can be reduced significantly for the workers and they can work in a safer environment.

Finally, coconut coir fibers has a lot untapped potential as sound absorption material because the mode of acoustic attenuation for these fibers has not been fully understood. Despite being extensively studied, the results can often be contradictory between researchers. Nonetheless, a varying set of data can help researchers to understand and characterize the potential of the variety of fibers in Malaysia.

1.3 OBJECTIVES

The main objectives for this project are:

i. To design and fabricate a coconut coir - vermiculite composite sound absorption panel as an alternative to its synthetic fiber counterpart and determine its acoustic properties.

ii. To test and analyze the acoustic absorption performance of the coconut coir hybrid composite against various frequencies of sound waves with reference to testing standards.

1.4 SCOPE OF STUDY

This study focuses on the acoustic properties characterization of a composite made with coconut coir and vermiculite to be used as sound insulation in vehicles. Since vehicles have weight and space limitations, this is study is only limited to porous type absorbers to be investigated. The testing method being used is with reference to ISO 10534-1.

Although other factors such as durability, cost and compatibility with other parts are key factors, they will not be addressed in this study and is a prospect for future studies.

1.5 RELEVANCY OF THE PROJECT

Vehicles are basic requisite in the modern world and is no longer a luxury item. Since most people commute to work on a daily basis, excessive noise exposure due to traffic can be detrimental to the human mind. Especially in cities, traffic jams are becoming more common and thus, proper noise insulation in vehicle should not be sidelined even with cheaper cars.

By developing cheaper sound insulation material utilizing agricultural waste product, the overall cost of such feature in cars can be reduced. Coconut coir fibers and vermiculite sound absorption material can also reduce the material wastage by using agro-waste as the raw material and has an added advantage of being biodegradable and safe to install even without special personal protective equipment.

CHAPTER 2
THEORY AND LITERATURE REVIEW

2.1 CONCEPT OF SOUND

Sound in general, is a vibration or disturbance which propagates in an elastic medium – solid, liquid or gas. Noise on the other hand, is defined as any unwanted sound being perceived within the audible range of a human being. Sound propagates through the air as the pressure fluctuates above and below the atmospheric pressure and this is called sound pressure measured in Pascals (Pa). As the air pressure fluctuates in a longitudinal wave, the number of variations per unit of time can be measured as frequency and has the unit of Hertz (Hz). A person with a healthy hearing can perceive anywhere from 20 Hz to 20 kHz but the upper limit decreases with age. Pure tones are sound generated with only a single frequency. Pure tones very rarely exist in practical application but rather exists in a mixture of tones from a broad range of frequencies. This wide mixture of frequencies is called broadband noise.

Another important parameter of sound is the wavelength. Since sound is also a form of wave, its wavelength (denoted by λ) can be calculated as the quotient of the speed of sound by the frequency of sound. Wavelength is the distance travelled by the pure tone during a full period or one cycle as shown in Equation (2.0). The human ears can detect sound wavelengths from 7 mm to 17 meters long wavelength of sound. Note that the human ears can hear a wide range of sound as mentioned earlier but the range of frequency most sensitive to human hearing is between 500 Hz to 2000 Hz [9].

$$Wavelength, \lambda = \frac{Speed\ of\ sound, v}{Frequency\ of\ sound, f} \quad \text{Equation (2.0)}$$

In practical sense, manifests itself as broadband noise and propagates omni-directionally. The source of noise can be anything from machinery, wind, impact or humans, cumulatively. Even though sound energy decreases exponentially with distance from the source, other factors such as geometry can also play a role in amplifying the perceived noise. For instance, in an enclosed room, reverberation can amplify the initial sound and create an unpleasant environment for the habitants. This becomes more so apparent in vehicles where occupants are exposed to loud sounds and prolonged exposures. Without proper noise attenuation, occupants can be susceptible to impaired judgment and inability to focus at the task on hand [1].

2.2 SOUND LEVEL MEASUREMENTS

Despite frequency being an important factor in determining noise attenuation properties, the measure of success for any sound dampening is ultimately the sound pressure level (L_p or SPL). Sound levels are actually represented by logarithmic scale in the units of decibels [10]. The logarithmic scale is used because the pressure waves are spread over a large range and thus it is more realistic to use such a scale. The unit decibels is also a relative unit of measure for sound pressure waves with respect to the reference value p_{ref} = 2 x 10^{-5} Pascals. To obtain the value of sound pressure level, equation (2.1) is used.

$$L_p = 20\,log\left(\frac{p}{p_{ref}}\right) \qquad \text{Equation (2.1)}$$

The value of p_{ref} is obtained as the smallest detectable change in sound pressure and value of p is the measured sound pressure. SPL in simple terms describes the intensity of the sound pressure waves being produce with respect to the reference value. During noise attenuation, these levels will be monitored for any reduction and will determine the effectiveness of the dampening.

The measurements of SPL can be gathered using one of two ways. First, is by utilizing a sound meter which has a specialized software to compensate for the sensitivity of human hearing. The units being measured is in decibels-A (dBA) where the A is denoting the type of rectification being used. Other types of rectification are available for different industries such as the C-scale which is used in aviation [9] [10].

The second method of measurement is by using a microphone which only feeds raw data for a software to analyze. Both methods are valid but the former is preferred for in-situ measurement but whereas the latter is preferred for accurate laboratory conditions. During the measurements, the ambient temperature must also be taken into consideration as air temperature can also affect the readings. The relation between air temperature and the speed of sound is given as Equation (2.2) below and valid from ranges exceeding 0°C to 50°C.

$$v_{air} = 331.4 + 0.6\,T_c \quad \text{Equation (2.2)}$$

Although the speed of sound is independent of the sound amplitude, it is a good measure to characterize both at the same time for consistency in the measurement [11].

2.3 METHODS OF SOUND ATTENUATION

Sound attenuation can be done in many ways depending on the frequency range and available hardware. For low frequency sounds, the more effective method of attenuation is by utilizing panel absorbers [12]. The performance of panel absorbers peaks from low frequencies but slowly deteriorate towards the higher frequencies where porous absorbers outperforms the former. Most acoustically optimized set-up combines two or more methods such as resonators, traps, absorbers and enclosures. However, the most common method used is porous absorbers since it attenuates the frequencies most sensitive to human hearing. Absorptive materials reduces the amplitude of sound waves by providing acoustic impedance and converting the acoustic pressure waves into heat energy within the material, thus lowering the intensity of the reflected wave [13]. Since sound behaves as a wave, the ratio of sound intensity being absorbed, I_a, to the reflected wave sound intensity, I_r, is given by Equation (2.2) to be the sound absorption coefficient, α.

$$Absorption, \alpha = \frac{I_a}{I_r} \quad \text{Equation (2.2)}$$

The efficiency of porous absorbers are reliant on three main factors which are fiber size, tortuosity and porosity [13]. Smaller fiber diameter in bamboo fibers have been found to increase the sound absorption coefficient [3]. This is because the sound waves can easily penetrate the surface of the porous absorber and into the pores of the material. In the same research, it was found that the smaller fibers means more material can be packed per unit volume and thus make it denser, which is another factor which can increase acoustic impedance. However, this is only true until a certain point where a denser pack makes it harder for the acoustic waves to traverse within the material. This threshold is dependent on the material and the ability of the material to hold up the pores within it.

Tortuosity by definition is the degree of twist and the nature of having many turns. It is commonly used to describe diffusion especially in porous media but it can be very complex to measure accurately unless using computer aided models and samples with uniform shapes such as nano-sieves and micro porous medias. However, greater tortuosity of the absorber will enhance the acoustic absorption performance of the material as the waves will traverse a longer path and the friction between the pores will gradually drain the sound energy to heat energy [12]. By this virtue, all high quality porous absorber used for acoustic attenuation is made from open cell foam instead of closed cell foam.

Finally, the porosity of the bulk sample is an important factor. As a general rule, the porosity must be great enough to allow movement of the air particles through the material but at the same time restrictive enough to allow the sound energy to dissipate as heat. The porosity relates closely with the fiber diameter and also affects the tortuosity of the bulk material. As multi-layer absorbers were also studied, it can be seen that surface porosity is easier to manipulate than the bulk porosity because as the sample is formed during preparation, the core less compressed than the surfaces. As such, a simple addition of an air gap will drastically improve the performance of the material [6]. The calculation to measure the porosity, φ, of the material is given as Equation (2.3) [14].

$$Porosity, \varphi = 1 - \frac{\rho_{bulk}}{\rho_{fiber}} \qquad \text{Equation (2.3)}$$

2.4 COCONUT COIR FIBERS

Coconut coir fiber are found in abundance in Malaysia and researchers have already looked into it as acoustic absorbers [4]. Many different fibers have varying amount of cellulose, lignin and ash content which can be the main criteria for choosing the fiber for usage. Higher lignin content makes the overall structure stronger but it is less flexible compared to the ones with lower lignin content [5]. It also has excellent water absorption properties – being able to absorb up to 104% of its weight in water. It also has an average density of 2057 kg/m^3 with fibers with average diameters of 0.48 mm [15].

The effects of coconut coir fiber compression on the acoustic absorption coefficient (AAC) was previously studied and found that compressed fibers increases the performance of panels at the lower frequency range [15]. This fact is in conflict with earlier findings which showed that fibrous mat compressions decreases sound absorption properties [16]. A preliminary study of coconut coir fibers was also done using WinFLAG™ software to determine the performance of multi-layered fibers with air space in between the sample and the backing plate using the ASTM E1050-98 [6]. It was concluded that the addition of more layers will shift the AAC peak to the lower frequency of the sound spectrum.

Coconut coir is one of the less popular option compared to Oil Palm Empty Fruit bunch (OPEFB) because it is a smaller industry in the country. However, it still creates an appreciable amount of agro-waste because coconut has an integral part in Southeast Asian community. Coconut coir has also a lot of other uses such as gardening mulch, material for outdoor doormats and reinforcement in bio composite materials. This versatile material is very durable for outdoor use and exposure to sunlight as it does not decompose easily under UV exposure but only through bacterial decomposition in the soil. It is this characteristics which makes it very suitable for use as a potential sound absorbing material.

2.5 METHODS OF TESTING

Several methods of testing are available to obtain numerical values of the acoustic absorption coefficient (AAC). The AAC is indicative of the material's ability to absorb or reduce the intensity of incident sound waves at various frequencies. Three prominent methods used in the industries to investigate the AAC is the ASTM C423 reverberation room method, ASTM C384 Standing Wave Impedance Tube method and ASTM E1050 Two Microphone Impedance Tube method. All the methods have their distinctive differences in reading [17].

The ASTM C423 reverberation room method is the most accurate, having use a large room to measure the reverberation and then a small sample of porous absorber is added to the room as shown in FIGURE 1. The AAC is measured as a function of decay rate of the echoes. The main drawback to having this method of measurement is the large sample size needed to analyze the effectiveness of the material as an acoustic absorber. The results would often be distorted by external noise and other variables to be controlled. This method also requires a lot of complex monitoring equipment and calibration to obtain an accurate reading.

FIGURE 1. Example of a Reverberation Room [17].

Another method commonly used is the ASTM C384 Standing Wave Impedance Tube method. By using an impedance tube, a sine wave can be generated at discrete frequency intervals to produce a standing wave within the tube. Typically, the frequency selected will be in 1/3 octave bands for accurate readings or full octave bands for a more broad reading. A movable microphone is installed to record the highest and lowest pressure difference (SPL) which coincides with the anti-node and node, respectively. This difference is related and called the Standing Wave Ratio (SWR) and is shown in Equation (2.4). By using this method, the microphone need not be calibrated and this makes the method very reliable but time consuming because of the discrete frequencies of operation. This SWR can be used to determine the reflectance ratio which is shown in Equation (2.5). Finally, the Acoustic Absorption Coefficient (AAC) can be determined for that specific frequency as shown in Equation (2.6) [11].

$$Standing\ Wave\ Ratio, SWR = \frac{AntiNode\ SPL}{Nodal\ SPL} \qquad \text{Equation (2.4)}$$

$$Reflectance\ Ratio, r = \frac{SWR - 1}{SWR + 1} \qquad \text{Equation (2.5)}$$

$$Acoustic\ Absorption\ Coefficient, \alpha = 1 - r^2 \qquad Equation\ (2.6)$$

Finally, the most popular method is the ASTM E1050 which uses the same setup as the ASTM C384 but utilizes the transfer function in the software to generate the frequencies and compute the AAC. This method is very popular because it gives a very fast result, albeit using significantly more complex apparatus. The microphone used must be calibrated well for magnitude to give an accurate reading. In this method, the AAC is projected as a continuous function based on Delany-Bazley’s model [18] and thus gives a more accurate reading especially at intervals of frequencies which could not be generated by the standing wave method.

In both the ASTM C384 and ASTM E1050, the impedance tube diameter plays a major role in determining the maximum frequency to be used. According to the manufacturer of the impedance tube, Brul and Kjaer, the tube set can be used to determine AAC up to 6.4 kHz.

CHAPTER 3
METHODOLOGY

3.1 MATERIAL PREPARATION AND MOLD FABRICATION

The proposed material to be used is coconut coir fibers with a vermiculite particles binded with polyurethane. However, after consideration of material handling and costing, it was decided that poly(vinyl) acetate would be the binder as shown in FIGURE 2. PVA is easier to handle as it is a thermoplastic instead of the polyurethane thermoset. PVA can also be diluted with water to facilitate mixing and ensuring total coverage of the coconut coir fibers during the molding process. Finally, PVA is also commercially known to work exceptionally well with porous media such as the coconut coir fibers and vermiculite with a working time of approximately 15-20 minutes under ambient temperature.

FIGURE 2. The PVA Binder being used for the composite.

Coconut coir fibers is chosen because it has good mechanical properties and is in abundance as a waste product of the coconut industry. Coconut coir fiber has the appearance of long, rough and uniform fibers as shown in FIGURE 2. By itself, coconut coir fibers are entangled in such a way that it clumps together in big patches and creates a lot of void between the fibers, which increases its bulk porosity. In this project, the fibers will be tested in both its original length and shorter fiber length, to pack more material and reduce the porosity of the bulk material. As it is from the supplier, the fibers are also clumped together with the coconut husk. The dust and mud must first be removed before further mixing to ensure proper binding and curing of the composite.

The fibers will first be soaked in water to clean it from any impurities which might inhibit the bonding between the fibers and the binder. After soaking, the fibers will be sun dried thoroughly and sorted out according to length. Since the test will be done on both long and short fibers, some of the fibers will go through the grinder after being dried. The dried fibers will then be weighed according to specification and mixing can then begin. Selection of 15 random fibers will also be done after the drying to measure the dry diameter of the fibers along with the density analysis using the buoyancy method and an electronic balance. Random samples are also selected for each possible test matrix to be sent for Halogen Moisture Analysis and verify the the material has been fully dried. This step is to also verify a consistent moisture content which is important during mixing in the next step.

FIGURE 3. Close up of coconut coir fibers

Vermiculite particles on the other hand has the appearance of a common pebble but lighter in weight because it is made from an expanded form of hydrous phyllosilicate. FIGURE 3 shows the physical appearance of vermiculite of different sizes. Vermiculite is an excellent thermal insulator as well as acoustic insulator because of the pores within its structure. Vermiculite will help brace the voids in the coconut coir fibers to stay open after compressing the material to the required thickness. The size of vermiculite varies anywhere from dust-sized to chunks as big as 6 mm. However, the particles are sieved through a 0.5mm filter to allow for effective use of vermiculite in the matrix. Threshold of 0.5mm is chosen because any smaller size will easily pulverize the vermiculite into dust and subsequently reduce the adhesion between the coconut coir fibers and the vermiculite particles. During mixing, the vermiculite will be mixed with the fibers and binder before mixed using an electric mixer for a homogenous blend of the composite as it sets in the mold.

The vermiculite will also be shaken using a gyratory sieve shaker to dislodge any unwanted particles of sand which might impede the function of the small pores within the vermiculite. The ratio of mixture of vermiculite to coconut coir fiber will be varied experimentally to determine the general trend of improvement or deterioration of acoustic absorption coefficient. This proposed test matrix is outlined in Section 3.3.

FIGURE 4. Close up of vermiculite particles

To form the composite, the mold was constructed from wood - 300mm x 300 mm in area and 60 mm in height. The final product will be shaped as a square mat and two circular cut outs of diameters 100 mm and 29 mm will be made from it. The cut-out size is to co-incide with the method of testing which is the standing wave impedance tube testing. The inner surfaces of the mold in contact with the mixture was spray painted to close the pores of the wood and sprayed with releasing agent to aid demolding process after the binder has cured with the composite. The releasing agent being used is spray grease commonly used for baking cakes. After the mixing process is finished, the whole mixture is transferred to the mold and compressed by using two wooden planks and tightened by using G-clamps. The clamp will be tightened to meet the required thickness and left to cure at ambient temperature. FIGURE 5 shows the mold under construction and FIGURE 6 shows the completed wooden mold.

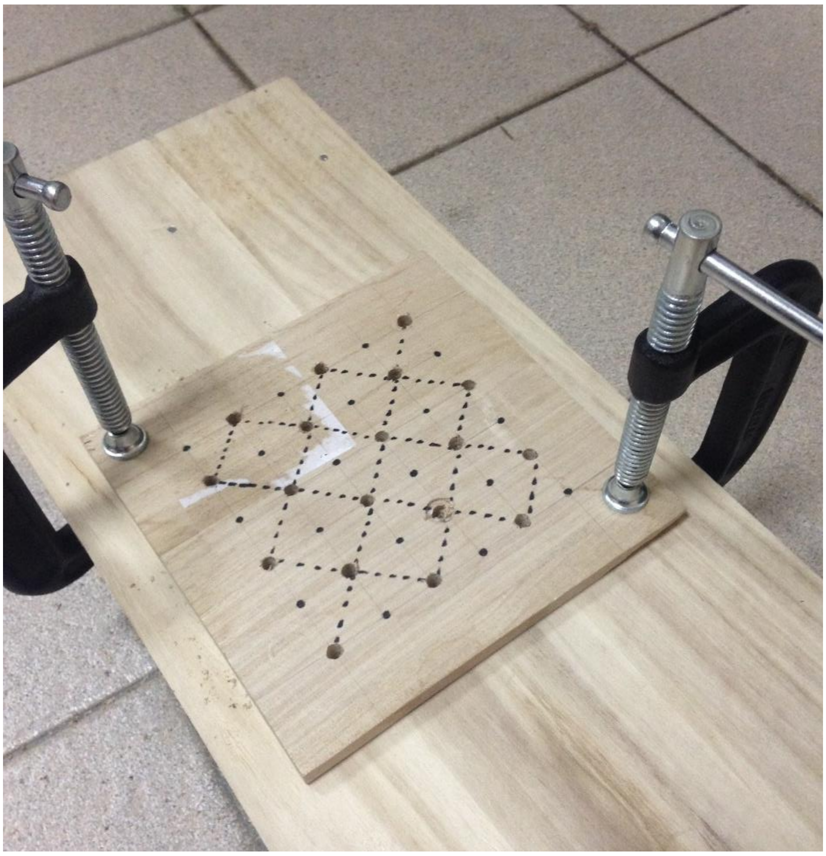

FIGURE 5. Part of the wooden mold under construction.

FIGURE 6. The finished wooden mold painted black and clear coated.

However, after the first bench testing, it was realized that the mixture bonds too strongly with the mold. The demolding process causes the final product to deform and the most likely cause is the uneven surface of the wood, even after sanding it. To overcome this issue, a cake mold is chosen as the substitute. The material of the mold is aluminium and is more costly than the wooden mold but the bench test shows that demolding is significantly easier. Nonetheless, additional clamps were need to ensure proper compression of the sample during the curing process. The dimensions of the aluminum mold is 270mm by 270 mm and 50 mm in height. The inner surface of the mold was lined with aluminum foil to easily remove the sample as it dries and to prevent from excessive deformation of the sample during demolding.

Based on small scale bench tests, the material must be mixed homogenously and then transferred as one piece into the mold. If the material is built layer by layer, the compression and demolding will create a clear 'boundary' between the layers which results in a weakened matrix and more binder must be added to retain the shape. The goal of the sample is use as less binder as possible to further reduce material wastage.

3.2 IMPEDANCE TUBE TESTING

To determine the sound absorption coefficient of the coconut coir-vermiculite composite, the material will be tested in accordance to ISO 10534-2 which is comparable to the ASTM E1050 standards in the literature [19]. However, due to material and equipment issues, the test will be done using standing wave ratio in impedance tube and it measures the sound absorption coefficient against the various sound frequencies in discrete measurements. This is in accordance with another standards, which is the ASTM C384 or ISO 10534-1 highlighted in the literature. The principle behind the test is, a sound emitting source – the speaker, will create a sound wave which travels along an impedance tube at a test frequency. The length of the tube is also carefully calculated so that the frequency of the sound will create a standing wave within the tube as a guide for finding the tube's 1st harmonic (shortest length). At the end of the tube, the specimen will be held against a back plate, which is has a very high value of acoustic impedance and thus, assumed to perfectly reflect the incident sound wave. The reflected wave will then be picked up by the movable microphones and the reduction of intensity will be registered as the reflected intensity. Since sound in the tube can only be reflected or absorbed, Equation (2.6) can be used to indirectly determine the acoustic absorption coefficient of the composite sample. FIGURE 7 shows the schematic of the impedance tube setup and how the sound waves travels within the tube.

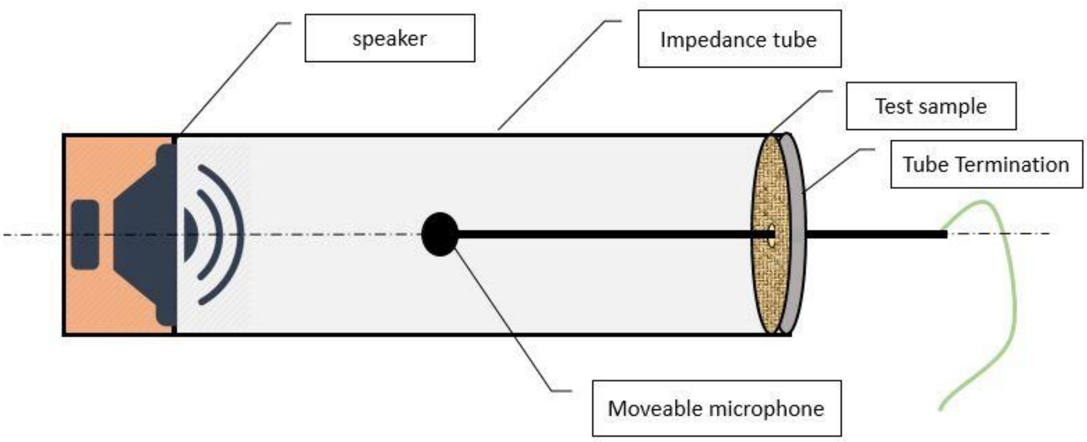

FIGURE 7. Schematic of the standing wave impedance tube setup.

The proposed test will be done using tubes of two different size as shown in FIGURE 8 which is 100 mm in diameter and 29 mm in diameter. The 100 mm specimen will be used to test frequencies from 500 Hz to 1200 Hz whilst the 29 mm specimen will be used to test frequencies from 1200 Hz to 6000 Hz. A third party inspection company can carry out this test in accordance to the standards, with the proper equipment and setup.

FIGURE 8. Impedance tube setup. [14]

The apparatus for the impedance tube testing method however is also not available on campus. With reference to journal papers, the impedance tube was constructed from 4-inch diameter PVC pipe with length of 0.69 meters [11]. The speaker to be used must have a minimum diameter of 4-inch concentric to annulus of the selected PVC pipe. FIGURE 8 and FIGURE 9 shows the construction of the PVC impedance tube against the 4-inch subwoofers which will provide the sound source. Using this method, only discrete points across the broad frequencies can be determined and the points will be connected using approximation instead of a continuous sampling across the spectrum. Given the restrictions of time and budget, the results would be representative enough of the sample to accurately determine the acoustic absorption coefficient until 1600Hz, which is the minimum requirement outlined by standards.

FIGURE 9. Construction of the impedance tube supporting base.

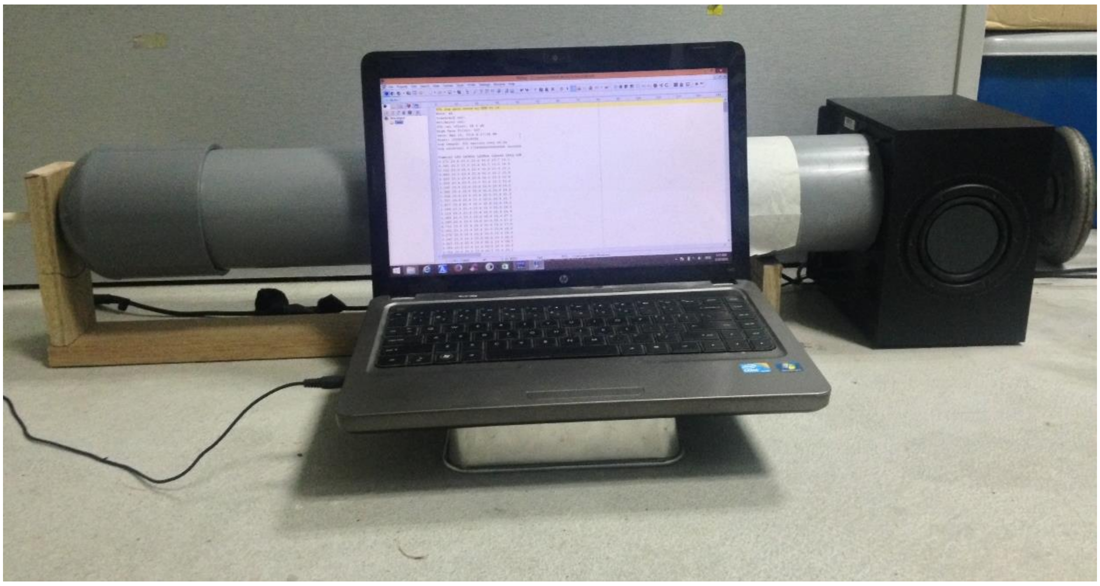

FIGURE 10. Completed PVC Impedance Tube using 4 inch pipe and subwoofer.

Since the standard indicated that the microphones need not be calibrated, it was mounted directly onto a movable rod and installed on the setup. The microphone is a normal clip-on microphone used for wireless speakers. The microphone was then tested to verify that it works using an audio software. The interface between the tube and the speakers was also sealed using silicone sealant to reduce if not eliminate the acoustic leakage of the speakers to the surroundings. Since the length of tube required for standing waves to be created inside the tube varied with ambient temperature, the tube was cut at 0.695m and instead, the harmonic frequency was varied to produce the standing wave. These waves were produced at slightly deviated frequencies typically tested such as 125Hz, 250 Hz, 500 Hz, 1000 Hz and 2000 Hz [10].

3.3 PROPOSED TEST MATRIX

The proposed test matrix consist of set ups to vary the ratio of vermiculite to coconut coir fibers and study the effects. A set of shorter fibers will also be used to check the effects of fiber length on the overall performance of the sound absorption quality. TABLE 1 shows the summary of the proposed test matrix.

TABLE 1. Proposed Test Matrix

Sample	Weight Percentages (%)	
	Coconut Coir Fibers	Vermiculite
Long Fibers		
1	90	0
2	80	10
3	70	20
Short Fibers		
1	90	0
2	80	10
3	70	20

3.4 EXPECTED RESULTS

The expected outcome from the impedance tube testing is to verify that the readings of previous researchers on the same material could be validated and to achieve at least a 10% improvement on the control samples at any given excitation frequency. As a baseline reading, researchers Lamyaa *et al.* were able to achieve 0.5 AAC using 20 mm thickness coconut coir fibers alone [20].

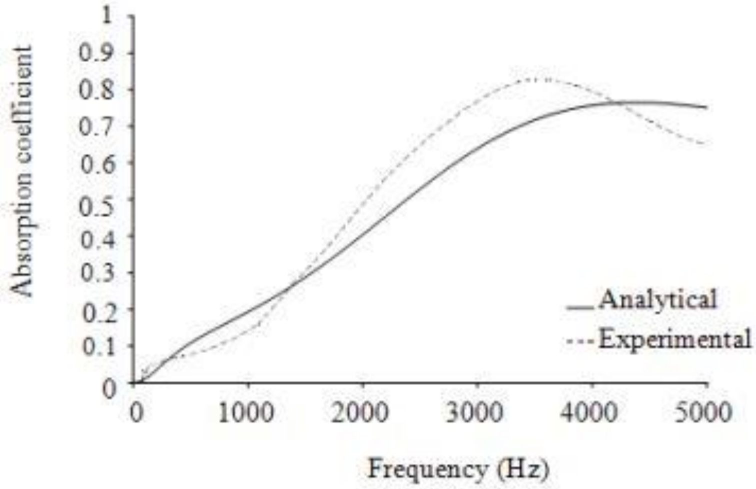

FIGURE 11. Acoustic Absorption Coefficient plot of 20mm Coconut Coir sound absorption panel [21].

FIGURE 11 shows that the peak absorption coefficient was achieved at 3800 Hz with an absorption of 0.83. Thicker composites have been found to achieve better absorption but within the scope of study, vehicular application has space limitations and as such, the data chosen for comparison is 20mm in thickness.

3.5 REQUIRED APPARATUS AND SOFTWARES

For the purpose of this project, several key equipment and apparatus has been identified to be crucial in the processing of the material as tabulated in TABLE 2 below:

TABLE 2. Summary of Apparatus and Software required for the project

No	Apparatus/Software	Purpose
1.	Apparatus: Electronic Balance	To weight the materials for the composite accurately.
2.	Apparatus: Mechanical Mixer	To mix the fibers and the vermiculite particle together with the binder until homogenous.
3.	Apparatus: Grinder	To cut the fibers into short length to be used in making the composite.
5.	Apparatus: Thermometer	To measure the ambient temperature during acoustic testing.
6.	Apparatus: Microphone/Speaker set	To produce excitation acoustic waves and record the acoustic waves being produce inside the impedance tube for determination of acoustic absorption coefficient.
7.	Software: Room EQ Wizard	To produce the acoustic signals for the excitation waves to the speaker at 1/3 Octave Bands.

3.6 PROJECT PLANNING AND FLOWCHART

The project flow consists of several key milestones and numerous project activities to be carried out over the course of 32 weeks. The first 16 weeks deals mainly up until methodology and the material fabrication and testing starts by week 17. FIGURE 12 below shows the general flow of the project.

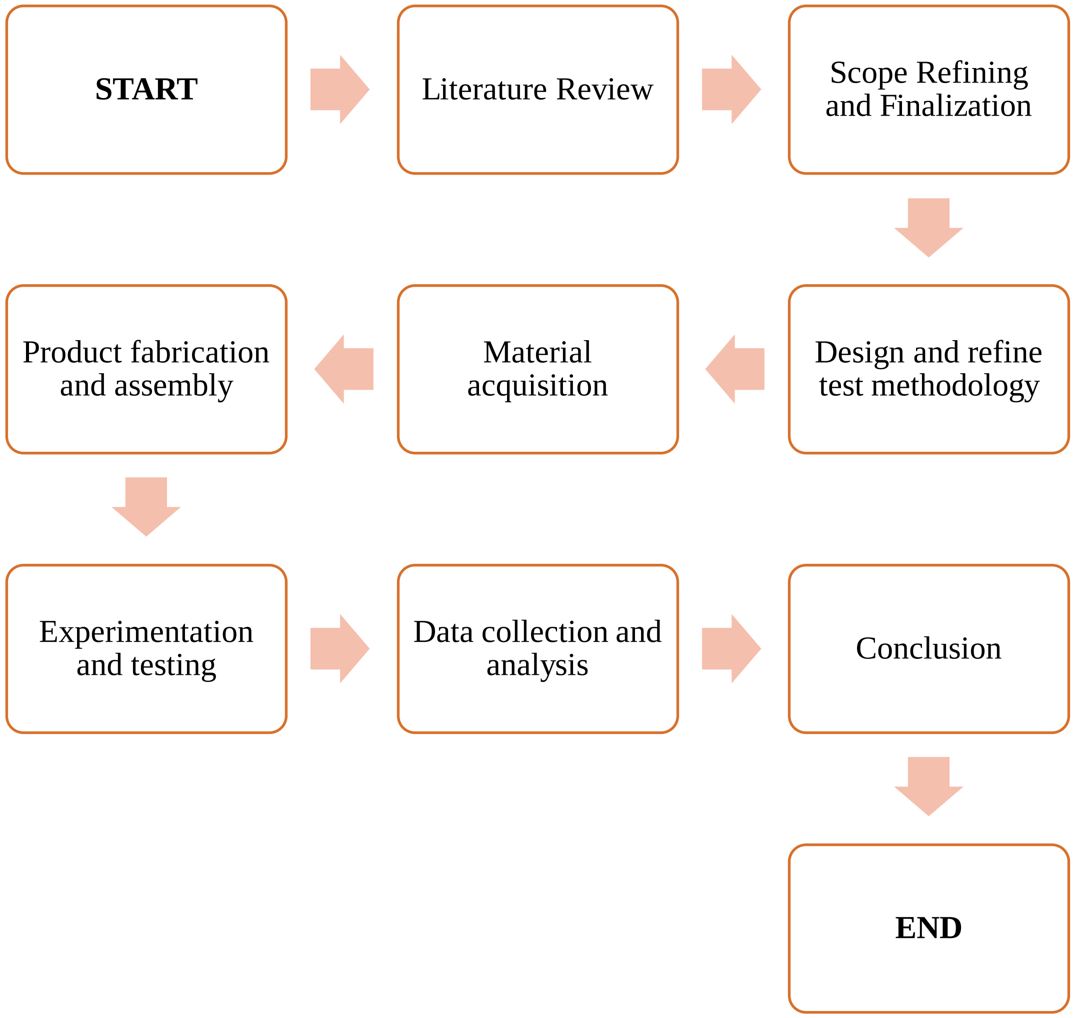

FIGURE 12. The general flow of the project.

CHAPTER 4
RESULT AND DISCUSSION

4.1 COCONUT COIR FIBER AND VERMICULITE PANELS

The panels are completed in a square mold and must then be cut into round shapes to fit into the testing equipment. The rationale behind this action is because the prepared sample tend to had more irregularities and inhomogeneity near the edges of the mold where the matrix and fiber and discontinued. As such, using a square mold and subsequently cutting a round shape will ensure better homogeneousness of the sample during testing.

As stated in the proposed test matrix, the actual panels were made according to the percentage but with only slight deviations to account for the problems faced during mixing which will be detailed in Section 4.5.3. FIGURE 12 and FIGURE 13 below shows the final product from the control set, which is made from only the coconut coir fibers and the poly(vinyl) Acetate (PVA) binder.

FIGURE 13. Physical appearance of the control sample made with only Coconut Coir Fibers (chopped fibers) and PVA Binder.

FIGURE 14. Physical appearance of the control sample made with only Coconut Coir Fibers (long fibers) and PVA Binder.

The actual weight of the materials being used during mixing of the control samples are tabulated below in TABLE 3 below. The final weight of the product has some significant loss due to the evaporated water dilution and some of the material unrecoverable from mixing (sticking to the mixer).

TABLE 3. The weight of the control samples being used during mixing.

Sample	Weight	
Control Sample (chopped fibers)	Coconut Coir Fiber	262.56g **(90%)**
	PVA Binder	28.97g **(10%)**
	Water	29.21g
	Total	291.53g
	Final (after drying)	277.56g
Control Sample (long fibers)	Coconut Coir Fiber	259.86g **(89.9%)**
	PVA Binder	29.02g **(10.1%)**
	Water	29.08g
	Total	288.86g
	Final (after drying)	281.77g

Note that for both cases in TABLE 3, water is not added in the weight calculations because it will eventually be evaporated during drying. The discrepancies between the total weight after mixing and final weight after drying is because of material loss during mixing. Some of the materials were stuck to the mechanical stirrer and could not be recovered. The first variation of coconut coir fiber to vermiculite is shown in FIGURE 15 and TABLE 4 as follows.

FIGURE 15. Physical appearance of the coconut coir fiber (chopped fibers) and vermiculite composite with 8:1:1 ratio.

TABLE 4. The weight of the control samples being used during mixing.

Sample	Weight	
Sample 1 (chopped fibers)	Coconut Coir Fiber	235.06g **(79.4%)**
	Vermiculite	30.21g **(10.2%)**
	PVA Binder	30.72g **(10.4%)**
	Water	31.55g
	Total	295.89g
	Final (after drying)	278.36g

Sample 2 (long fibers)	Coconut Coir Fiber	237.16g **(79.8%)**
	Vermiculite	30.15g **(10.1%)**
	PVA Binder	30.07g **(10.1%)**
	Water	29.45g
	Total	297.38g
	Final (after drying)	281.77g

The final variation of the mixture increases the percentage of vermiculite to 20%. During molding, much of the vermiculite were not held firmly in the matrix but only bind loosely to the surface of the material as shown in FIGURE 16. The TABLE 5 shows the actual mixture and weight of each component within the final variation of the samples.

FIGURE 16. Physical appearance of the coconut coir fiber (chopped fibers) and vermiculite composite with 7:2:1 ratio

TABLE 5. The weight of the 7:2:1 sample variation being used during mixing.

Sample	Weight	
Sample 3 (chopped fibers)	Coconut Coir Fiber	205.67g **(69.6%)**
	Vermiculite	58.12g **(19.6%)**
	PVA Binder	31.65g **(10.8%)**
	Water	31.55g
	Total	295.44g
	Final (after drying)	274.49g
Sample 4 (long fibers)	Coconut Coir Fiber	203.89g **(69.7%)**
	Vermiculite	57.15g **(19.5%)**
	PVA Binder	31.72g **(10.8%)**
	Water	30.48g
	Total	292.76g
	Final (after drying)	275.66g

It must be noted that during the molding process, the compression force is not measured but rather, the G-clamps were used as shown in FIGURE 17 and closed down until the mold are clamped to the required thickness.

FIGURE 17. The two stainless steel pans sandwiching the sample being compressed using G-Clamp.

4.2 FIBER DIAMETER MEASUREMENTS

One of the parameters to be measured is the fiber diameter and density. The fiber diameter is measured by random selection of 15 samples and the results were averaged out to get a mean. TABLE 6 below shows the results for measurement of the coconut coir fibers diameter. The density is obtained by using the buoyancy method and a digital balance.

TABLE 6. Measurement of Coconut Coir Diameter and Density

Sample	Measured Diameter (mm)	Measured Density (g/cm^3)
1	0.62	1.36
2	0.63	1.24
3	0.62	1.26
4	0.62	1.20
5	0.62	1.32
6	0.65	1.46
7	0.62	1.25
8	0.63	1.28
9	0.62	1.26
10	0.64	1.25
11	0.62	1.22
12	0.63	1.24
13	0.63	1.24
14	0.65	1.28
15	0.62	1.32
Average	0.628 mm	1.19 g/cm^3

4.3 STANDING WAVE IMPEDANCE TUBE TESTING

The method being used to obtain the measurement of Acoustic Absorption Coefficient (AAC) is the standing wave impedance tube testing. As elaborated in depth in the literature review section, the main reading to be obtained from the testing is the minimum and maximum sound pressure level (SPL). By using the SPL, the AAC can then be determined by simple calculations at each respective frequency, in a discrete manner.

Another important parameter to consider is the ambient temperature. Before running the experiment, a probe thermometer was used to measure the air temperature as shown in FIGURE 18 below. The ambient temperature is used to calculate the modified excitation frequency because the speed of sound varies as a function of temperature.

FIGURE 18. The probe thermometer measuring ambient temperature.

However, prior to testing several adjustments had to be made to the impedance tube. The interface between the speakers and the tube had to be sealed tightly with silicone sealant to reduce any sound loss to the surrounding. The leaks will affect the readings obtained by the software as received by the microphones. The signal waves was generated by the signal generator software as shown in FIGURE 19 in discrete increments as tabulated in TABLE 7.

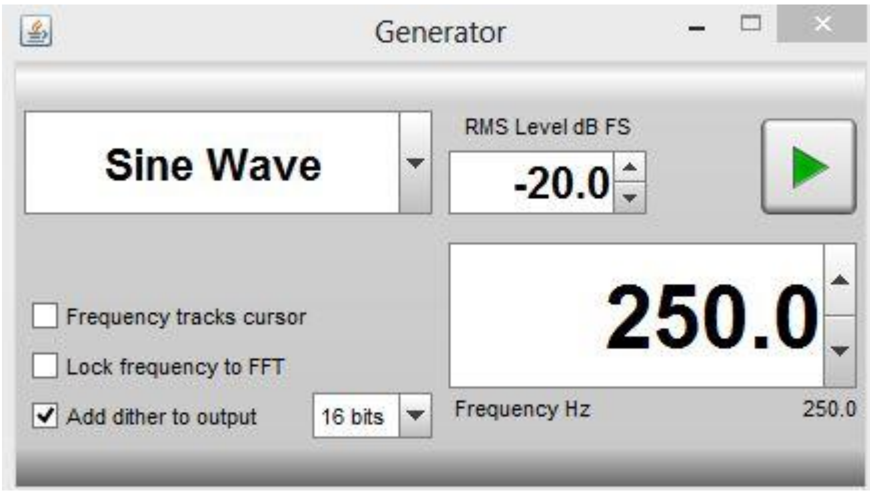

FIGURE 19. Discrete Sine Wave Signal Generator.

TABLE 7. Full Octave Signal Frequencies.

Point	Full Octave Frequency (Hz)	Corrected Frequency (Hz)
1	125.00	119.11
2	250.00	238.22
3	500.00	476.46
4	1000.00	952.91
5	2000.00	1905.82
6	4000.00	3811.64

FIGURE 20 below shows the example of the SPL logger being used for obtaining the results in graphical form. The area of interest is the minimum and maximum decibels reading.

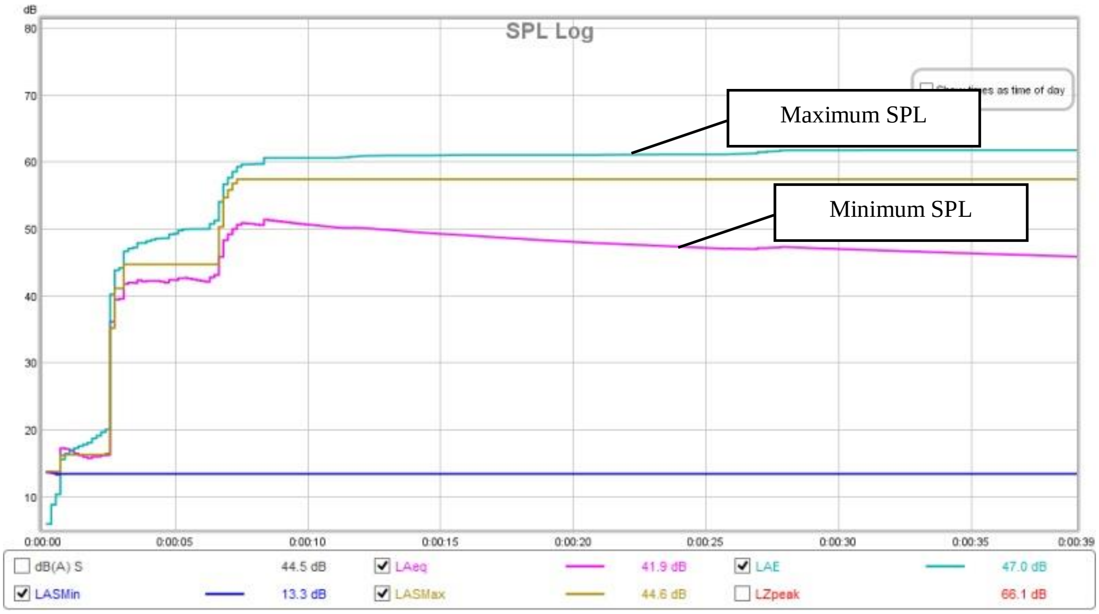

FIGURE 20. Example of graph obtained from the SPL Data Logger.

From the obtained graph, the minimum and maximum SPL levels can be determined at each frequency interval. These values can then be calculated in ratio form as in Equation 2.4 to find the reflectance ratio and subsequently the Acoustic Absorption Coefficient (AAC). The experiment was run in three different iterations with different variations of mixture of the composite material.

4.3.1 CONTROL SAMPLES (1st Iteration)

In the first iteration, the control samples were tested. As per TABLE 3, the samples consists of only the coconut coir fibers (CCF) and PVA binder. The rationale behind this iteration is to establish a baseline reading for the following two iterations at the same testing conditions. Although the same test has been done by Lamyaa et al., the control samples are still vital because the testing setup and rig are different. TABLE 8 shows the acoustic performance of the control samples at the modified excitation frequency at an ambient temperature of 32.6°C. The graph of the acoustic absorption coefficient for the control samples is shown subsequently in FIGURE 21.

TABLE 8. The acoustic performance of the control samples.

	Acoustic Absorption Coefficient (AAC)				
Frequency (Hz)	119.11	238.22	476.46	952.91	1905.82
Chopped Fibers	0.024	0.138	0.226	0.381	0.496
Long Fibers	0.027	0.124	0.189	0.342	0.424

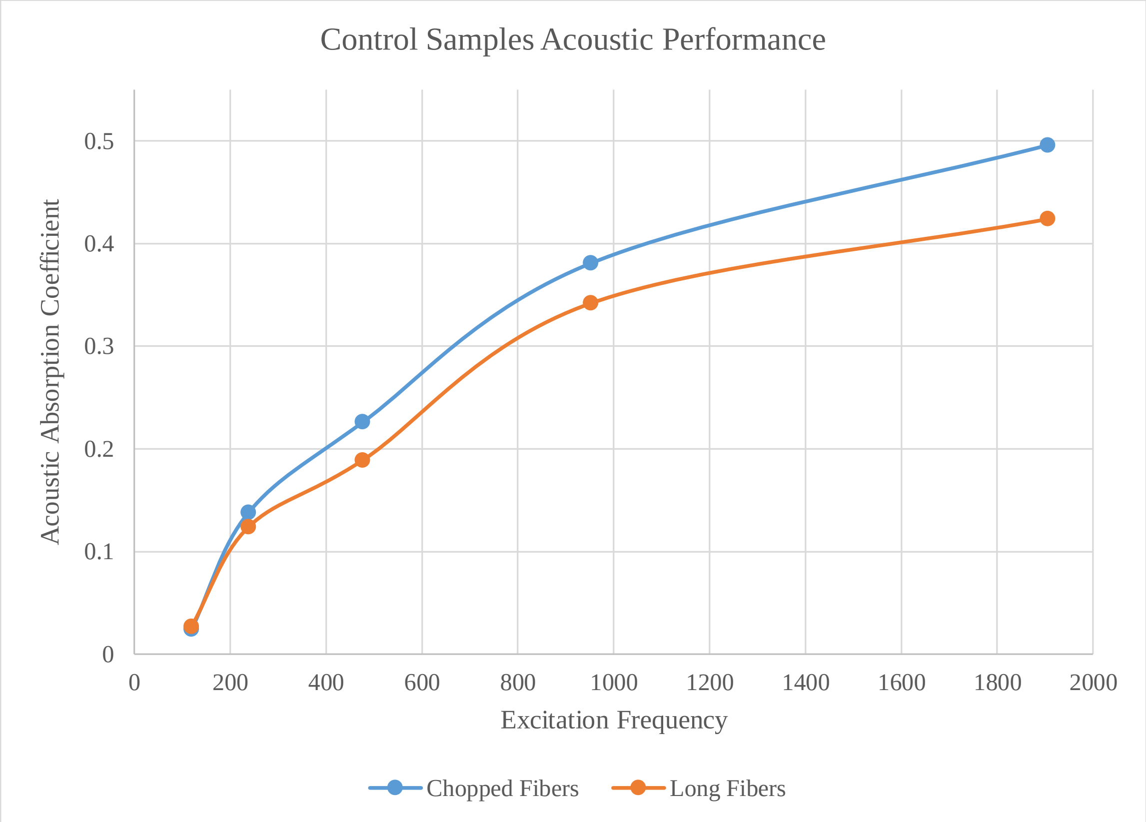

FIGURE 21. Graph of the acoustic performance of the control samples.

The chopped fibers are cut into lengths which are 60mm in length on average while the long fibers are the length as received from the supplied. Both the specimens are 20mm in thickness. From the graph above, it is clear that the chopped fibers have better acoustic performance than the long fibers and the difference becomes greater at higher frequencies. At peak frequency of 1905.82 Hz, the difference of performance is chopped fibers has greater acoustic absorption frequency by 14.5% as compared to long fibers. Objectively, the readings obtained in the 1st iteration is very similar to the results acquired by the experiment done by Lamyaa *et al.* [20]. As such, the results were successfully replicated and the test setup were able to perform at par with proper impedance tube testing method, albeit only up to 1905.91 Hz.

A possible explanation for the mode of sound attenuation is the chopped fibers allow a tighter pack fiber in the composite and better homogeneity during mixing. This makes for better pore arrangement of the composite, thus allow the sound energy to travel in the material and dissipate the energy as heat. In the case of long fibers, the entanglement between the clumps is evident during mixing and it is harder to achieve a uniform mix. As such, the configuration of the fibers are more random and several thin spots in the composite may develop. These thin spots are weak spots in terms of acoustic absorption because more sound energy can pass through instead of being absorbed by the pores.

Although the peak absorption was obtained by chopped CCF, at an AAC value of 0.496 for an excitation frequency of 1905.91 Hz, the material still has some thin spots but not as advanced as the long CCF sample. The performance of the material could still be improved if a shorter fiber length were to be used or at least, in theory. As for the long CCF, the material was able to hold up better during material handling because of the entanglement of the fibers and better bonding between the fibers.

The trend of AAC shows that chopped CCF has a steadily better AAC performance as the excitation frequency climbs. However, another important parameter to be noted is the readings are taken at discrete points because of the standing wave phenomenon and the joining lines are just to fill in the blank spots and show the general trend.

4.3.2 SAMPLE VARIATION 8:1:1 (2nd Iteration)

In TABLE 9, the acoustic performance between chopped fibers and long fibers are again shown but at a variation of 80wt% coconut coir fibers, 10wt% vermiculite particles and 10wt% PVA binder. From the table, FIGURE 21 was plotted to show the difference in acoustic performance.

TABLE 9. The acoustic performance of the samples with variation of 80wt% coconut coir fibers, 10wt% vermiculite particles and 10wt% PVA binder.

	Acoustic Absorption Coefficient (AAC)				
Frequency (Hz)	119.11	238.22	476.46	952.91	1905.82
Chopped Fibers	0.023	0.141	0.232	0.417	0.512
Long Fibers	0.025	0.123	0.201	0.350	0.477

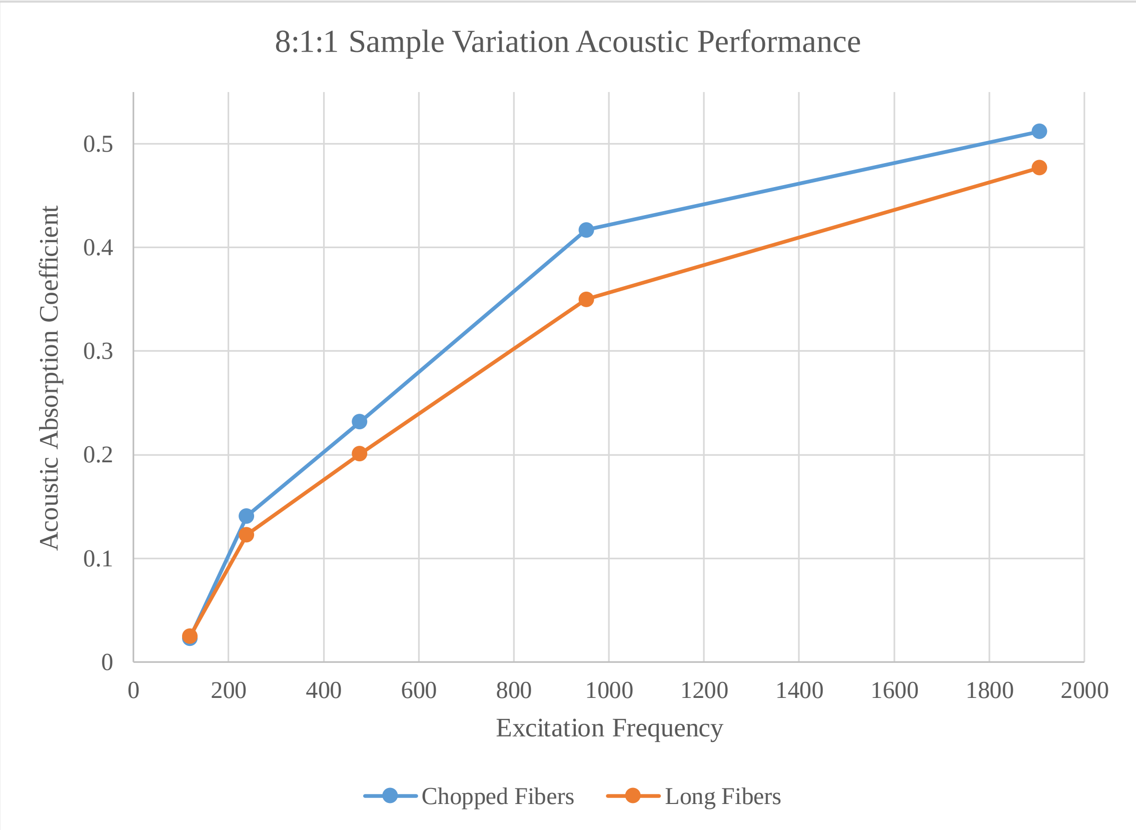

FIGURE 22. Graph of the acoustic performance of the 8:1:1 sample variation.

Based on the graph shown on the performance of the 8:1:1 sample variation, the acoustic absorption coefficient (AAC) again shows that chopped fibers outperforming long fibers across the chart. The addition of the vermiculite particles of 10wt% also improves the AAC primarily between the 250 Hz range until 1905 Hz. The largest difference being produced is around 952 Hz with the 8:1:1 variation chopped fiber sample performing 16% better than its long fiber counterpart and 8%

better than the control sample of chopped fibers. Although the long fiber sample of the 8:1:1 variation did not perform as well as the chopped fiber sample, it was still and improvement over the control sample with a maximum difference of 11% at 1905 Hz.

That being stated, the vermiculite helped to increase the AAC by an average of 8% across the graph. The reason being that some of the pores within the material are visibly being compressed and thus impeding the movement of air through the material. In order to dissipate sound energy, the pores must allow some air movement. By incorporating the vermiculite particles, the pores are able to be propped up and stay open even after compression. The 8:1:1 sample variation were also able to retain the vermiculite well in the coconut coir fiber entanglement, making the panel very stable and no significant amount of vermiculite was lost during handling the composite panel.

In comparison with the results found during the literature, the AAC peaks were also found to reach higher levels at a faster rate but near the 1905 Hz, the performance starts to plateau and climb more slowly and steadily. This is consistent with the works of Seddeq which states that porous absorbers perform better at lower if additional air gaps are being introduced or better maintained [12].

4.3.3 SAMPLE VARIATION 7:2:1 (3rd Iteration)

Finally, the 7:2:1 sample variation results were also tallied in TABLE 10 below and the graphical representation given in FIGURE 23. The 7:2:1 variation consists of 70wt% of coconut coir fibers, 20wt% of vermiculite particles and 10% of PVA binder. The same testing parameters were maintained as with the previous two iterations.

TABLE 10. The acoustic performance of the samples with variation of 70wt% coconut coir fibers, 20 wt% vermiculite particles and 10 wt% PVA binder.

	Acoustic Absorption Coefficient (AAC)				
Frequency (Hz)	119.11	238.22	476.46	952.91	1905.82
Chopped Fibers	0.023	0.181	0.266	0.444	0.522
Long Fibers	0.026	0.177	0.249	0.361	0.489

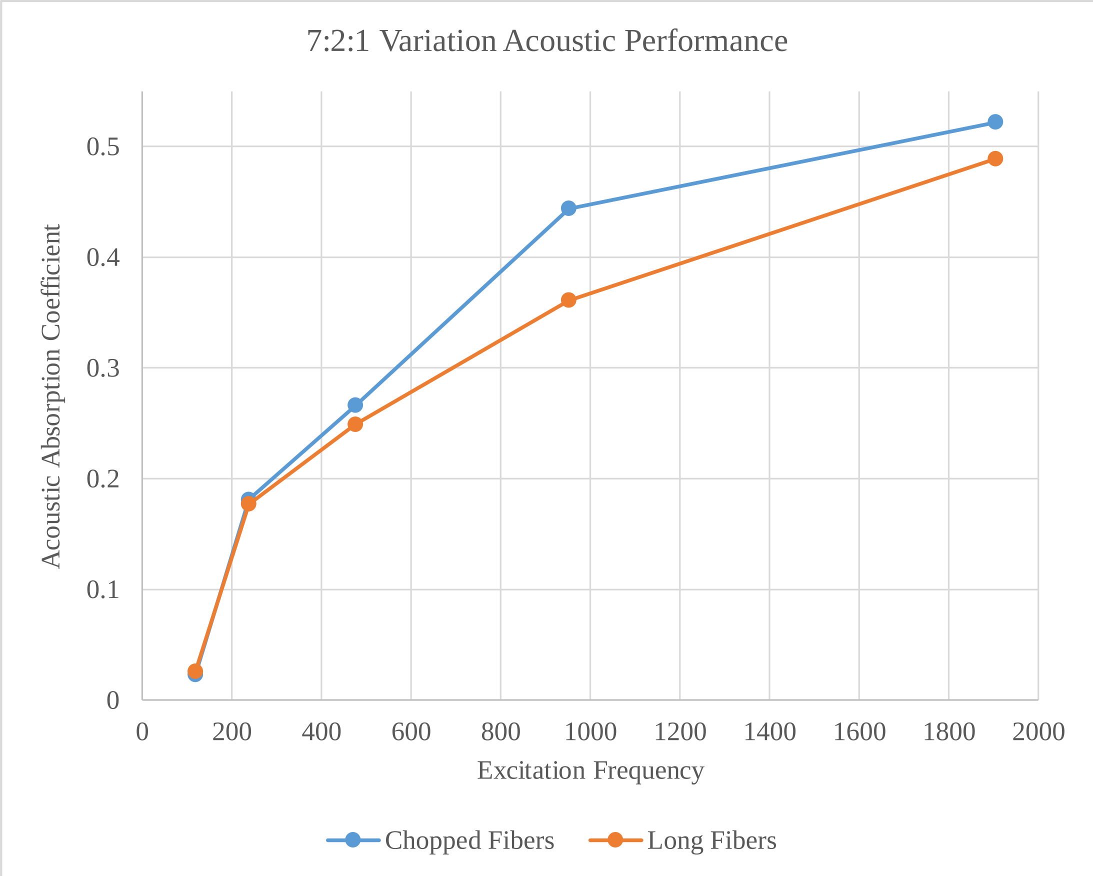

FIGURE 23. Graph of the acoustic performance of the 7:2:1 sample variation.

In the final iteration of the impedance tube testing using the 7:2:1 sample variation, the same trend could be observed between the chopped fibers and the long fibers. The maximum difference between the two fibers occurs at 952.9 Hz with chopped fibers leading by 18.7% in terms of AAC. Overall, the 7:2:1 sample variation performs the best between all the iterations but in terms of material integrity, it performs the worst. Since the sample is consists of less weight percentage of coconut coir fibers, the sample as shown in FIGURE 16 becomes very weak. The vermiculite particles are also very weakly binded and significant quantity was dislodged during handling as compare to the second iteration.

The peak performance at 1905 Hz for the chopped fibers in the 7:2:1 variation is only marginally better with 1.9% of improvement. As such, the best balance between performance and material integrity would be around 80wt% of coconut coir fiber, 10% of vermiculite particles and 10% PVA binder.

4.3.4 OVERALL ACOUSTIC ABSORPTION COEFFICIENT PERFORMANCE

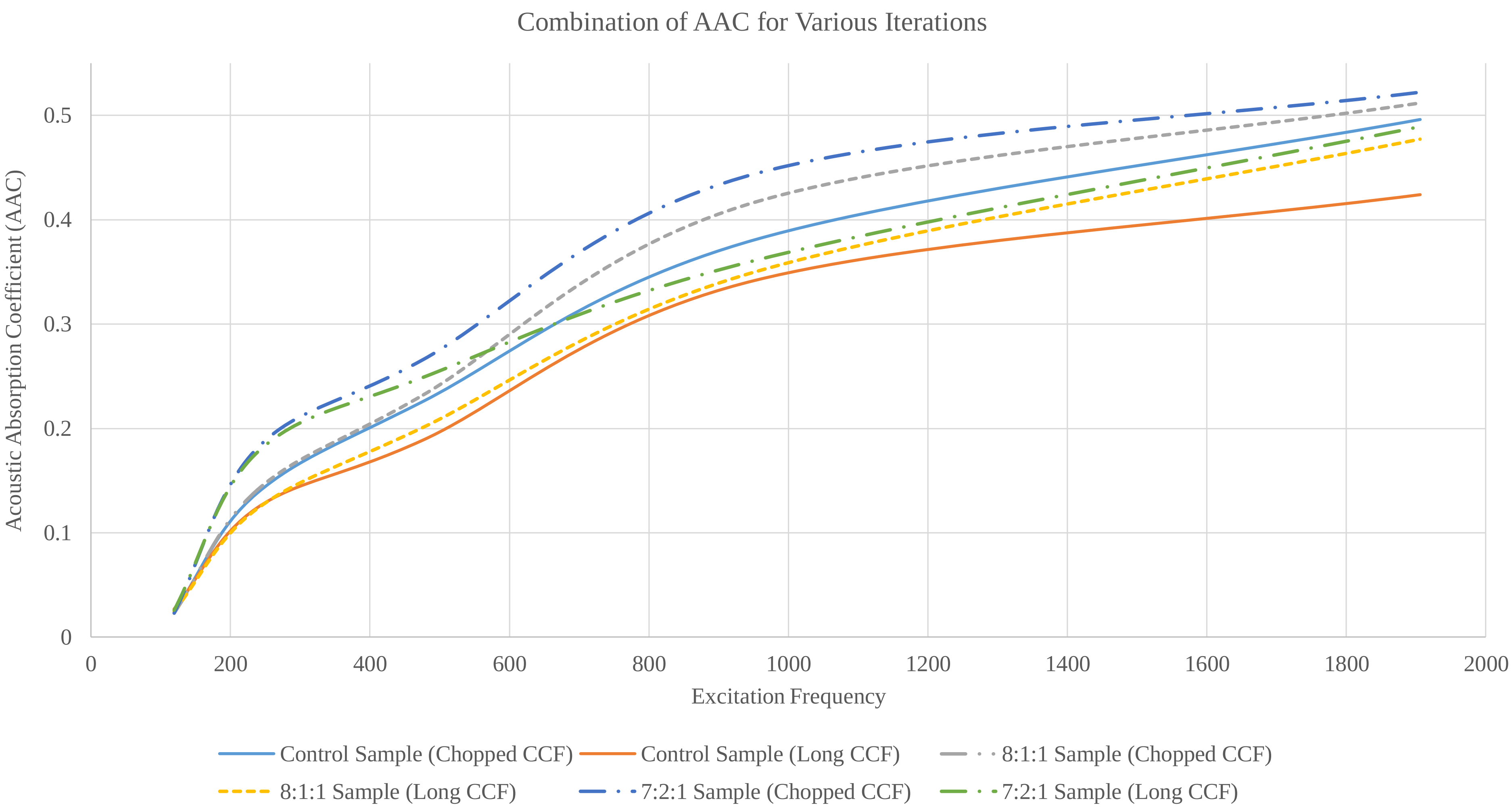

FIGURE 24. The combination of all the iteration results.

Overall, the introduction of vermiculite particles in the coconut coir fiber matrix has a general trend of shifting the AAC peaks of lower frequency excitation waves to a higher value. This indicates that the overall experiment was a success. During the final iteration, only two samples performed better than the chopped CCF control sample which are the 8:1:1 variation chopped fiber CCF and 7:2:1 variation chopped fiber CCF. In both cases, the performance are greater at the lower frequencies but tapers to only 8% improvement at 1905 Hz with a maximum improvement of 18.7% by the 7:2:1 variation chopped CCF sample.

4.4 CHALLENGES AND LIMITATIONS

During the execution phase of the project, several setbacks were encountered along the way from the material sourcing, material preparation, sample preparation, and also sample testing. These challenges were able to be successfully rectified but some are in need of more attention especially for future research.

4.4.1 MATERIAL SOURCING

Two main raw material for this project were coconut coir fibers and also the vermiculite particles. The coconut coir fibers are abundantly available but often is not processed as it is a byproduct of agricultural waste. The fibers are clumped together with bit of coconut husk and also other infiltrates such as sawdust, pebbles and dried soil. The coconut coir fibers are also of random length but averaging around approximately 200 mm – 240mm. This is the main type of coconut coir fibers being sold by several supplier from around Seri Iskandar, Perak and Subang Jaya, Selangor. However, processed coconut coir were also sold with the same specification but with shorter average fiber length of approximately 30-40mm. While the latter is easier to handle, the effects of different fiber length is also in need to be scrutinized and as such, the former type is chosen to be the raw material.

As received, the fibers were tested by bonding them using PVA. However, the immediate problem was the lack of adhesion between the fibers. Upon further bench testing, it was determined that the cause of this poor adhesion is the dust which accumulates on the surface of the fibers. Another type of bench testing being done is water absorption test. These bench testing are not proper tests but just to determine the parameters to be controlled during the mixing process which will follow after. For the absorption test, a predetermined weight of coconut coir was submerged in a small bucket water with approximately 150 ml of water.

According to the literature, the coconut coir should be able to absorb at least 104% of its weight in water. This can be verified to be true. Although it has good absorption, coconut coir does not retain this water well. This might be due to the nature of the fibers itself which is very porous and thus, unable to hold large quantities of water and retain it. The significance of this bench testing is to determine the quantity of water to be mixed with the PVA to ensure that the binder covers most of the fibers and provide a strong bond as a bulk material. Without water, the binder will be too viscous to cover the large surface area of each individual fibers in the sample.

Another material to be sourced is the vermiculite particles. This material is typically found in gardening shops to be used as in soil mulching or top soil mix as it can retain a lot of the moisture from the ground. The material is also very porous and light weight making it very suitable in use for this project. However, its porosity also gives very negligible strength. As it is, the material comes in a mixture of sizes and not uniform as shown in FIGURE 24 below.

FIGURE 25. The actual vermiculite particles as received from supplier.

The material was filtered through a 0.5 mm sieve to allow only the larger particles to be used as shown in FIGURE 25. The smaller particles were discarded because it is easily pulverized and does not create significant propping effect for the bulk panel. However, since the material comes in a mixture of particle sizes, only about 40% in volume is left after the sieving process because the majority of the vermiculite is less than 0.5 mm in diameter.

FIGURE 26. The vermiculite particles being filtered through 0.5mm sieve.

4.4.2 MATERIAL PREPARATION

Before the coconut coir and vermiculite particle are mixed, some issues were encountered during bench testing. During bench test, it was found that the bonding between the fibers are weak due to poor adhesion of the binder to the surface of the fibers as described previously. In order to counter this, the fibers were soaked in water and a small amount of detergent to clean the surface from dust, grease and sand. The fibers were soaked overnight and repeated for three cycles to ensure thorough cleaning. Any residual coconut husk were also removed from the bulk material to help with sample homogeneity.

After the coconut coir has been washed, the detergent was rinsed and the material was dried under the sun for 5 hours. Every 30 minutes, the material was turned to ensure even drying throughout the fibers. Since the fibers are entangled, it takes longer time for the bulk material to dry even after turning every half an hour. Since it was still moist after 5 hours under the sun, an additional 5 more hour of drying was added the next day. The volume of the material becomes visibly larger when it is completely dried and the fibers are smoother to the touch.

In preparation for mixing, another bench test was done on the fibers to examine the adhesion properties and as expected, the fibers were bonded more strongly after cleaning. Its adhesion with the vermiculite particles were also excellent, making it very entangled in panel form, also providing structural support in the overal composite.

4.4.3 SAMPLE PREPARATION

The sample was prepared in two stages namely the mixing and the molding. During the first batch of mixing, exact amounts of material were weighed and mixed using a kitchen mixer. However, the viscous binder did not fully cover the fibers but only some patches were covered in thick layer. The first mix was transferred into the mold in stages, layer by layer but the end result was delamination of these layers during demolding process. Hence, the mixture must be transferred after mixing in a single transfer and not in a stagger manner.

During the second mix, water was added into the mix but in quantity which is equal to half that binder. The binder coverage was slightly better but it still does not cover the overall coconut coir and vermiculite particles. After it is being transferred to the mold in a single move, the mixture was left overnight to dry. During demolding, the structure of the sample disintegrated because it bonded to the walls of the mold even after the mold was greased. FIGURE 26 shows some of the coconut coir fibers stuck to the mold after demolding.

FIGURE 27. Some of the Coconut Coir Fiber stuck to the wooden mold.

After considering the options, two stainless steel baking pan was bought to be used as the mold. The mixture will be transferred into the mold lined with aluminium foil as shown in FIGURE 27 and it will be sandwiched against another baking pan. G-Clamps were also used to compress the mixture according the required thickness. This time, the sample formed perfectly with the acquired thickness but it retained most of the moisture of the added water and thus making it very flimsy and soft. The vermiculite particles were also not retained within the coconut coir fiber entanglement.

FIGURE 28. Aluminium foil used to line the mold.

Finally, a solution was met to prepare the sample according to the required thickness, ratio and shape. First, the mixture for coconut coir fiber must account for an additional 5-6 wt% (approximately 15g) and for the vermiculite, an additional 8wt% (approximately 5g) for residual material left in the mixture which are unrecoverable. After mixing, the mixture must be transferred to an aluminium foil lined mold and left out to semi-dry under the sun for 15 minutes (PVA total drying time is 30 minutes). During this semi-drying phase, the water is evaporated from the mix and only leaving the thin coating of binder on the fibers. After semi-drying, the material is then sandwiched between the second baking pan and compressed according to the desired thickness. However, during compression, an additional 2mm must be added to account for the spring-back effect of the material. Finally, the sample is left to cure before demolding and removing it out from the aluminium foil lining.

It is a good practice to check for dimensional tolerances but some fluctuations are expected since natural fibers are not uniform and unpredictable in behaviour because it is arranged in a random manner.

4.4.4 SAMPLE TESTING

Using the proper equipment, the material must be tested using two different impedance tubes because it will produce a very accurate result. The ambient temperature must also be controlled and relative humidity be monitored. However, given the limited time and budget, only a single size impedance tube could be constructed and a small wattage speaker being used gives a limited frequency response range. The test being done is also only until 1905 Hz which is not enough to give the peak AAC performance of the samples because the trend shows that it is still climbing.

The main issue with the constructed impedance tube is the microphone readings. During measurement, the microphone must be moved along the tube via a drilled hole near the end cap to find the node and anti-node of the produced standing wave. However, the absence of a sleeve bearing results in some form of interference. The sample is also displaced slightly without a proper sample holder in the tube which might produce affect the accuracy of the readings.

Finally, without an integrated data logger and source, two laptops must be used to run the program simultaneously - one as a source and the other as a data logger. This presents a problem because the source and the reading is hard to control simultaneously.

CHAPTER 5
RECOMMENDATION AND FUTURE RESEARCH

The constructed PVC impedance tube testing method being used to run the test were based of a research paper which is not meant to be a perfect replacement but only to serve educational purposes [11]. For accurate measurements, the industry standards take into account better speakers with accurate frequency response along with an oscilloscope to measure the signal output from the speakers. As a recommendation, the Brüel & Kjær Standing Wave type 4002 is typically used in acoustic studies to measure the Acoustic Absorption Coefficient (AAC) from 200 Hz until 6000 Hz. The large range of the sound spectrum will provide a better picture of the acoustic absorption performance of the specimen and a peak value can be identified. Often, the value will reach a peak value between the 2000 Hz to 4000 Hz ranges.

Another possible improvement to the system was to run the test in an anechoic chamber which is a chamber void of any echoes and acoustic interference. In the best case scenario, the chamber will also be climate controlled so that the ambient temperature and the speed of sound remains constant. Interference during the testing phase will result in accuracy issues and the inability to run the test as per industry standards. In terms of materials, coconut coir fibers and vermiculite has a lot of untapped potential because of its stability and shapability as a sound absorption panel. More study has to be done on a more suitable binder because although poly(vinyl) acetate is adequate to hold the specimen's shape, it did not hold well with the final iteration which is the 7:2:1 sample variation. The use of other polymers such as polyurethane would have been a better choice but comes with the added challenge of material handling.

Finally, vermiculite could also be replaced with another waste material with a more uniform structure. Part of the challenge during fabrication was the different particle sizes of the vermiculite although it has been sieved through. One of the viable alternative to vermiculite is recycled rubber which is commonly used as recreational pathways in gardens and parks. The rubbers are grinded into small 2-3mm particles which are uniform and thus, suitable for the purpose of propping up pores in the coconut coir fiber during compression.

CHAPTER 6
CONCLUSION

In conclusion, the acoustic performance of coconut coir fiber and vermiculite composite as noise insulation material is promising to replace synthetic fibers such as glass wool, rock wool and asbestos. The results show that chopped fibers are better than long fibers as it improves the AAC performance by an average of 9% across three different iterations. Both the 7:2:1 variations chopped CCF and 8:1:1 variations chopped CCF were able to improve the AAC by an astonishing 18.7% and 16%, respectively in relation to their long fiber counterpart. Both the mentioned samples were also able to perform at least 8% better than the control samples.

Although several challenges were met along the way, both the objectives underlined by this study were able to be met. The constructed standing wave impedance tube were able to recreate measurements obtained by other researchers. Several path of improvement still exist for the study of the coconut coir fiber and vermiculite composite especially pertaining to the optimization of the mix between the vermiculite particles and the matrix fibers. In terms of durability of the material, it is excellent for use as porous absorbers and at the thickness of only 20mm, it is very suitable for use in vehicular applications.

REFERENCES

[1] S. C. Devar and N. Singh, "Noise Pollution - Sources, Effects and Control," *Journal of Humanities and Energy,* vol. 16, no. 3, pp. 181-187, 2004.

[2] *Occupational Noise Exposure,* Cincinnati, Ohio: Centers for Disease Control and Prevention, NIOSH, 1998.

[3] T. Koizumi, N. Tsujiuchi and A. Adachi, "The Development of Sound Absorbing Material Using Natural Bamboo Fibers," *High Performance Structures and Composites,* vol. 59, pp. 157-166, 2002.

[4] K. H. Or, A. Putra and M. Z. Selamat, "Oil Palm Empty Fruit Bunch as sustainable acoustic material," in *Proceedings of Mechanicla Engineering Research Day 2015,* Melaka, Malaysia, 2015.

[5] L. Yusriah, S. M. Sapuan, E. S. Zainudin and M. Mariatti, "Underutilized Malaysian Agro-wastes fibers as reinforcement in polymer composites: Potential and Challenges," *Journal of Polymer and Materials,* vol. 29, no. 2, pp. 21-36, 2012.

[6] M. J. Mohd Nor, N. Jamaludin and F. Mohd Tamiri, "A preliminary study of sound absorption using multi-layer coconut coir fibers," *Electronic Journal,* 2004.

[7] X. Zhu, B.-J. Kim, Q. Wang and Q. Wu, "Recent Advances in the Sound Insulation Properties of Bio-Based Materials," *BioResources,* vol. 9, no. 1, pp. 1764-1786, 2014.

[8] R. Wilson, A. M. Langer and R. P. Nolan, "A Risk Assessment for Exposure to Glass Wool," *Regulatory Toxicology and Pharmacology,* vol. 30, pp. 96-109, 1999.

[9] M. J. Antunano and J. P. Spanyers, "Hearing and Noise in Aviation".*Federal Aviation Administration.*

[10] "Sound Attenuation," 2002. [Online]. Available: http://www.silex.com/pdfs/sound_attenuation.pdf. [Accessed 18 October 2015].

[11] "Engineering Acoustics/Sound Absorbing Structures and Materials," [Online]. Available: https://en.wikibooks.org/wiki/Engineering_Acoustics/Sound_Absorbing_Structures_and_Materials. [Accessed 26 October 2015].

[12] H. S. Seddeq, "Factors Influencing Acoustic Performance of Sound Absoptive Materials," *Australian Journal of Basic and Applied Sciences,* vol. 3, no. 4, pp. 4610-4617, 2009.

[13] M. E. Delany and E. N. Bazley, "Acoustical Properties of Fibrous Absorbent Materials," *Applied Acoustics,* vol. 3, no. 2, pp. 105-116, 1970.

[14] R. T. Muehleisen, "Measurement of the Acoustic Properties of Acoustic Absorbers," 2005. [Online]. Available: http://www.inceusa.org/nc07/links/Muehleisen_planery_acoustic_properties_materials.pdf. [Accessed 26 October 2015].

[15] M. H. Fouladi, M. H. Nassir, M. Ghassem, M. Shamel, Y. P. Sim, Y. W. Sin, Z. X. Pang and M. J. Mohd Nor, "Utilizing Malaysian Natural Fibers as Sound Absorbers," *Modelling and Measurement for Acoustic Waves and Acoustic Microdevices,* 2013.

[16] M. J. Mohd Nor, Md Ayub, R. Zulkifli, N. Amin and M. H. Fouladi, "Effect of Compression on the Acoustic Absorption of Coir Fiber," *American Journal of Applied Sciences,* vol. 7, no. 9, pp. 1285-1290, 2010.

[17] B. Castagnede, A. Aknine, B. Brouard and V. Tarnow, "Effects of Compression on the Sound Absorption of Fibrous Materials," *Applied Acoustics,* vol. 61, pp. 173-182, 2000.

[18] G. Kathiravan, *Pre Fabricated Concrete Structure using Coir Mesh,* 2015.

[19] *Determination of sound absorption coefficient and impedance in impedance tubes - part 1.,* International Organization for Standardization, 1998.

[20] M. Suhanek, K. Jambrosic and H. Domitrovic, "Student Project of Building an Impedance Tube," in *Acoustics 08 - Paris*, Paris, 2008.

[21] R. Zulkifli, Zulkarnain and M. J. Mohd Nor, "Noise Control Using Coconut Coir Absorbers with Porous Layer Backing and Perforated Panel," *American Journal of Applied Sciences,* vol. 7, pp. 206-264, 2010.

[22] "Speed of Sound," NASA, 2014. [Online]. Available: https://www.grc.nasa.gov/www/BGH/sound.html. [Accessed 18 October 2015].

[23] Z. Ibrahim , A. Abdul Aziz, A. Ramli and R. Mamat, "Determination of Sound Absorption for Absorptive Material using a two-microphone impedance measurement tube type 4206 (B&K)," *MPOB Information Series,* 2009.

[24] A. Putra, Y. Abdullah, H. Efendy, W. F. Mohamad and N. L. Salleh, "Biomass from Paddy Waste Fibers and Sustainable Acoustic Materials," *Advances in Acoustics and Vibration,* 2013.