INVESTIGATION ON THE SOUND ABSORPTION PROPERTIES OF *GIGANTOCHLOA LIGULATA* BAMBOO

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by

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ABSTRAK

Penggunaan bahan penyerap bunyi boleh meminimumkan masa bergema, atau masa yang diperlukan untuk bunyi bergerak merentasi sesuatu ruang. Penggunaan sumber asli untuk mengurangkan pelepasan karbon semasa sintesis bahan baharu semakin popular termasuk penggunaan sumber asli sebagai penyerap bunyi. Dalam kajian ini, bahan semula jadi berasaskan gentian buluh, *Gigantochloa ligulata* telah diperiksa dan dikaji. Matlamat penyelidikan ini adalah untuk mengetahui sejauh mana gentian buluh tulen dan gentian buluh yang dirawat resin boleh menyerap bunyi. Sampel dihasilkan dengan menggunakan mesin penekan hidraulik dan berat bagi setiap sampel ialah 5g. Kajian ini melibatkan penggunaan tiga saiz gentian buluh yang berbeza iaitu 850μm, 2mm, dan 5mm. Sebanyak 3 sampel telah dihasilkan bagi setiap saiz gentian buluh. Pekali penyerapan bunyi (SAC) gentian buluh diukur menggunakan tiub impedans. Pengukuran diambil pada tiga jarak jurang udara yang berbeza. Hasil kajian diperhatikan bahawa nilai SAC pada jurang udara yang berbeza untuk setiap sampel hanya menghasilkan sedikit atau tiada perbezaan. Walau bagaimanapun, keputusan menunjukkan bahawa nilai SAC tertinggi diperhatikan pada jurang udara terkecil iaitu 10mm. Untuk saiz gentian buluh yang berbeza, trend yang serupa dihasilkan untuk sampel yang mengandungi resin epoksi sebagai pengikat, dengan saiz gentian terbesar mempunyai SAC tertinggi jika dibandingkan dengan saiz gentian yang lebih kecil. Keputusan menunjukkan bahawa kebanyakan puncak tertinggi pekali serapan bunyi terletak pada zon frekuensi tinggi antara 3000 hingga 4500 Hz dengan lingkungan SAC antara 0.5-0.7. Keputusan ini menunjukkan bahawa gentian buluh berkebolehan sebagai penyelesaian yang berfungsi untuk aplikasi penyerapan bunyi.

ABSTRACT

The use of sound absorbent materials may minimise reverberation time, or the time it takes for sound to travel across a space. The use of natural resources to reduce carbon emissions during the synthesis of new materials is becoming increasingly popular including the use of natural resources as a sound absorbent. In this study, a natural material based on bamboo fibre, *Gigantochloa ligulata* was examined and characterized. The goal of this research is to find out how well pure bamboo fibre and resin-treated bamboo fibre can absorb sound. The sample are produced by using hydraulic press machine and the weight for each sample is 5g. The testing involved three different sizes of bamboo fibre which are 850μm, 2mm, and 5mm. A total of 3 sample were produced for each size of bamboo fibre. The sound absorption coefficient (SAC) of bamboo fibre is measured using impedance tubes. The measurement was taken at three different air gap distance. It is observed that the SAC value at different air gap for each sample produced only little to no difference. However, the results shows that the highest SAC value is observed at the smallest air gap which is 10mm. For different sizes of bamboo fibre, similar pattern emerges for samples containing epoxy resin as the binder, with the largest fibre size having the highest SAC when compared to a smaller fibre size. The results shows that most of the highest peak of the sound absorption coefficient lies at the high frequency zone between 3000 to 4500 Hz with range of SAC between 0.5-0.7. These results implies that bamboo fibre looks to be a viable solution for sound absorption applications.

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LIST OF ABBREVIATIONS

SAC	Sound absorption coefficient
dB	Decibel
CO_2	Carbon dioxide
LCA	Life cycle assessment
SEM	Scanning Electron Microscopy
EDX	Energy Dispersive X-Ray Analysis
ISO	International Standardization for Organization
BJA	Bamboo Jungle Adventure

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Noise pollution is a serious worry since it may interfere with our everyday routines and cause physical and psychological stress. In our culture, a quiet existence free of noise has long been a fantasy. Noise is one of the most significant environmental hazards, creating a wide range of difficulties including health consequences, communication difficulty, hearing loss, changes in human behavior, and sleep disruptions. Noise-reducing materials like rock wool, glass wool, and asbestos were developed a few decades ago to reduce noise levels, especially in the workplace. The production of these materials has a harmful effect on the environment due to the release of carbon dioxide, CO_2 into the atmosphere (Yang et al., 2020). As a result, smog, air pollution, and climate change will be aggravated. Extreme weather, food shortages, and increasing wildfires are just a few of the additional repercussions of climate change induced by greenhouse gas emissions. As a result, materials that are safer and more ecologically friendly must be substituted to be used as a sound absorber.

As a sound-absorbing material, natural fibres have a lot of potential. Natural fibres such as palm, coconut coir, and many others have been thoroughly researched for their ability to absorb sound. Higher frequencies are efficiently absorbed by oil palm and coconut coir fibre, whereas lower frequencies are not very effectively absorbed (Ismail et al., 2010). Sound may be absorbed using porous materials with high sound absorption coefficients, such as those found in natural fibres. Natural fibres have a lot of potential to replace synthetic absorbers as a viable option to synthetics due to their biodegradability, minimal health concerns during processing, and abundant supply. Other benefits of natural fibres include reduced density, lighter weight, cheaper cost, and a lower CO_2 emission.

Several natural fibres' sound-absorbing qualities have been studied, however *Gigantochloa ligulata's* acoustic properties have not yet been conducted. *Gigantochloa ligulata* is one of the bamboo species that can be found in Peninsular Malaysia and globally. Bamboo could be considered a renewable resource since it can be harvested year after year due to bamboo's rapid growth. Bamboo is also notable for its biodegradability, or ability to decompose without polluting the environment. Therefore, it has the potential to be a suitable sound absorbing material, whether used as an interior sound insulator or as an outdoor sound absorber.

In this research, the acoustic performance of *Gigantochloa ligulata* fibre as a sound absorber is demonstrated. Sound absorber specimens were created using three different sizes of fibre, for both bonded with resin and pure bamboo. The effects of absorber specimen fibre diameters, density, and air cavity gap on absorption coefficient and noise reduction were examined. The characterization of bamboo was done by performing SEM and EDX analysis.

1.2 Problem Statement

Controlling noise by sound absorption can be an efficient technique of lowering echo and noise within a place. Hence, sound absorbers are becoming increasingly significant in the fight against noise pollution. The problem is that the sound absorber such as glass wool, rock wool, and foam glass are examples of synthetic fibre sound absorbers that are still utilised in industry and construction which are detrimental to both human health and the environment due to their toxicity and polluting effects. It has been demonstrated that their production emits more carbon dioxide into the atmosphere than those produced from natural resources. They may be harmful to human health even though they are widely used, since their fibres may accumulate in alveolus and cause inflammation when breathed in. Therefore, a better sound absorbing materials must be used to ensure that it does not negatively impact the environment and the human health as well. Natural fibres offer a lot of potential as a sound-absorbing material since they are safer and more ecologically friendly than synthetic fibres. The acoustic qualities of bamboo fibre may contribute to lessen the negative environmental effect on the development of a better and more environmentally friendly sound absorber.

1.3 Objectives

The aim of this research mainly to investigate the potential of bamboo fibre as replacement of synthetic sound absorber. The research is carried out with a view to achieving the following two main objectives:

1. To analyze the acoustic performance of *Gigantochloa ligulata* fiber as a sound absorber.
2. To characterize the *Gigantochloa ligulata* sample.

1.4 Thesis Outline

This thesis consists of five main chapters:

Chapter 1: Introduction - Introduces the scope of the thesis, research background, problem statements, and research aims in a precise form.

Chapter 2: Literature Review **-** Review the existing literature as well as past research discoveries that are relevant to sound absorption and the use of natural sound absorbers to substitute the synthetic one.

Chapter 3: Methodology - An in-depth explanation of all the methods used in this research will be provided. The chapter presents the research's experimental elements, which contain information on the materials used, the equipment utilized, the preparation of sample, and the study's general technique flow.

Chapter 4: Results and Discussion - The findings from the previous chapter are evaluated in this chapter. In this chapter, the thesis's goals will be outlined. The data obtained regarding the sound absorption coefficient and the characterization based on SEM and EDX are discussed.

Chapter 5: Conclusion and Recommendation **-** This chapter sums up and discusses the findings, as well as making suggestions for future research and study in the use of natural fibre as sound absorber.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter 2, the literature review will discuss about the previous study that are related to the noise pollution, sound absorber, natural fibre, bamboo fibre and the sound absorption coefficient for the natural fibres as sound absorber.

2.2 Noise Pollution

Noise pollution, defined as an increase in ambient noise levels caused by human activities, may affect people and animals (Slabbekoorn, 2019). These sounds are referred to as anthropogenic noise. When it comes to annoyances like traffic or generator noise, most human noise is an unwelcome by-product. Noise, in general, is an unfavourable sound that is both loud and noisy and tends to annoy. Sound pressure level (dB and dBA) is measured in decibels (dB) and Hertz (Hz) (Wong et al., 2021). Noise pollution has a number of negative impacts on people, including psychological illnesses including anxiety and depression, hypertension, hormonal malfunction, and an increase in blood pressure that leads to cardiovascular disease (Basu et al., 2021). Hearing impairment and threshold sensitivities would shift as a result of continuous noise exposure of 85-90 dB(A).

2.3 Sound Absorber

Most of the sound energy that strikes sound-absorbing materials is absorbed, with just a little percentage reflected back. These characteristics make them effective for noise reduction inside a room or enclosure. They may be found in several places, including close to the source of the noise, on walkways, and near receivers. When a sound wave strikes a medium, it generates a variety of effects, including reflection, attenuation, and sound transmission (Zhang et al., 2018). The reflection and absorption of sound waves can provide sound isolation.

The most basic way for reducing noise is sound wave absorption. All building materials absorb, transmit, or reflect sound waves. It is possible to quantify a material's sound absorption or noise reduction efficiency by measuring its SAC or NRC (Sharma et al., 2020). The acoustical performance of a material may be assessed using its sound absorption coefficient, which indicates how much energy the material absorbs when sound waves arrive (Casas-Ledón et al., 2020). The coefficient of sound absorption ranges from zero (no absorption) to one (full absorption).

Sound absorption and sound insulation must be considered separately which they both are expressed as transmission loss factor. Density, porosity, and material thickness are all factors that determine the sound insulation and absorption values (Tudor et al., 2020). The commonly used sound absorber in the current market is called as synthetic sound absorber. However, as there are many negative effects of using the synthetic sound absorber, natural fibers are being considered as alternative to traditional synthetic absorbers.

2.3.1 Synthetic Sound Absorber

Synthetic sound absorber or also known as synthetic fibres, as opposed to natural fibres generated directly from live creatures which then manufactured through chemical synthesis. Synthetic fibres are generated wholly in the laboratory, typically from petroleum by-products, and are constructed from polymers that do not naturally exist (Saba & Jawaid, 2017). Synthetic fibre production is also extremely hazardous to the environment, since it is produced using high-temperature industrial methods such as hot extrusion, and the source of synthetic fibre is frequently derived from petrochemical sources, resulting in substantial carbon footprints (Arenas & Crocker, 2010).

Glass fibres and minerals are among the synthetic materials used. Glass fibre has been found in studies to absorb sound better than other synthetic materials. In the construction sector, glass wool commonly used as material for sound absorption. It is a silica-based mixture of limestone, quartz sand, and near to 80% recycled glass is used to create glass wool (Hassani et al., 2021). However, according to Abtahi et al. (2018), glass wool's silica-based nature should be considered since it might cause allergic reactions and cancer. Micro-perforates, polypropylene, and polyester are all synthetic sound-absorbing materials derived from petroleum-based resources, which are neither renewable nor environmentally friendly and contribute directly to anthropogenic climate change. Figure 2.1 below shows the sound absorption coefficient values for inorganic fibreglass for low and high frequencies (0 Hz-4000 Hz) of 0.700 and 1.00, respectively.

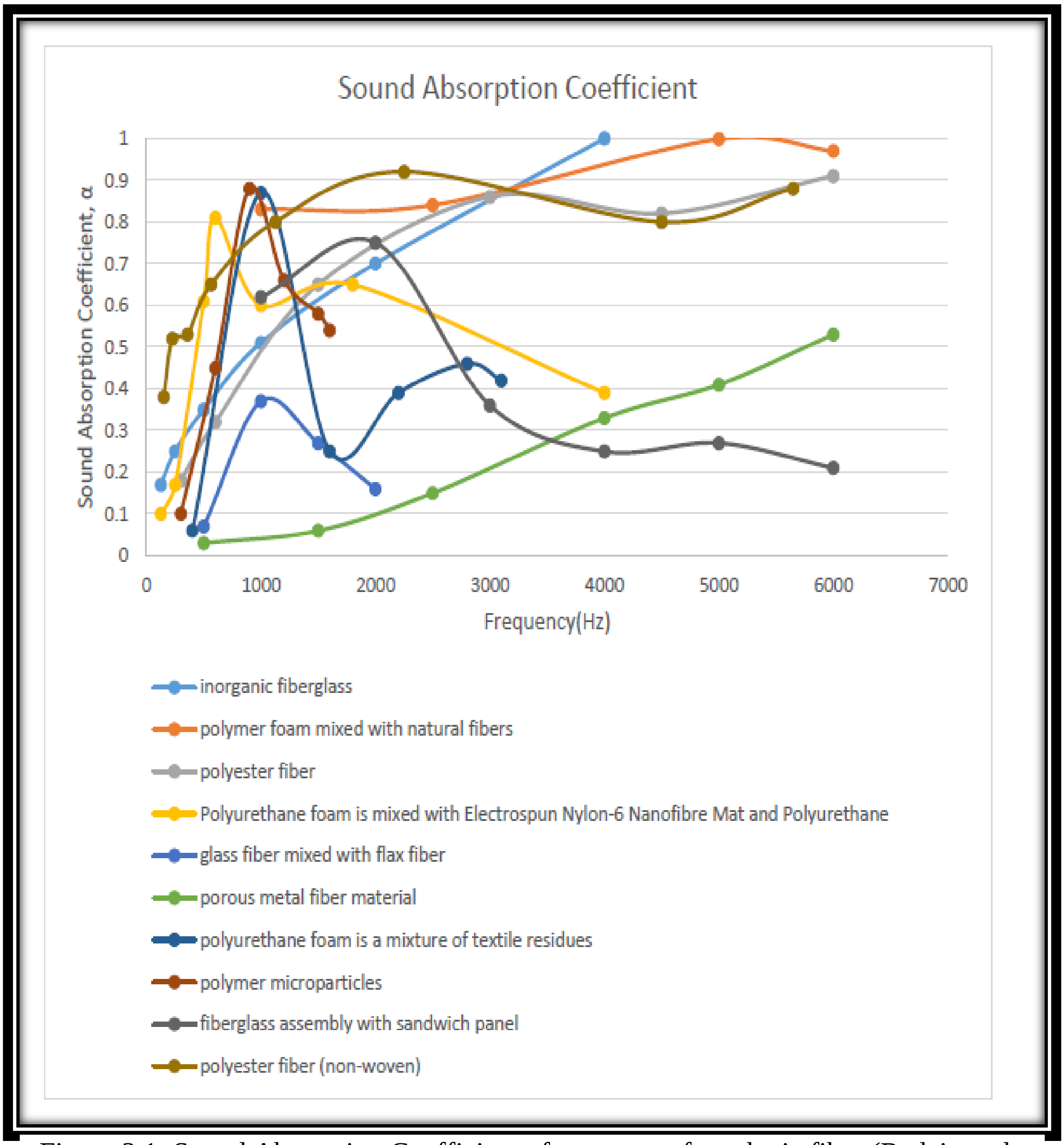

Figure 2.1: Sound Absorption Coefficient of ten types of synthetic fiber (Radzi et al., 2021)

Manufacturers are seeking for ecologically friendly and sustainable substitute for synthetic fibres that offer great sound absorption properties due to increasingly strict environmental regulations and increased public awareness of the risks of noise pollution.

2.3.2 Natural Fibre Sound Absorber

Natural materials are increasingly being considered as viable alternatives to conventional synthetic materials for sound absorption measures. Natural fibres have been deemed viable raw materials for making sound-absorbing panels at a lower cost in recent years. Additionally, these fibres frequently have strong thermal insulation capabilities, are non-toxic, and are frequently available in large numbers as a byproduct of other manufacturing processes (Berardi & Iannace, 2015). Natural fibre is also known to have a lower density than synthetic fibre, more abundant, and renewable. Additionally, natural fibre processing is more cost effective and environmentally friendly than synthetic material processing, due to the growing of current technology (Yahya & Sheng Chin, 2017). Natural fibre is much safer for our health than synthetic fibre because it does not require any special handling procedures.

Numerous publications have been made on acoustic materials made of natural resources. Natural fibres, such as bamboo, coir, and sugar palm were used as reinforcements with diverse polymeric matrixes (Alhijazi et al., 2020). However, many pretreatment procedures are required to create commercially viable natural fibre sound absorbers, including fibre bundle extraction, alkaline treatment, and panel or nonwoven fabric production (Yang et al., 2020). Pre-treatment are needed due to natural fibre composites' poor interfacial adhesion, low moisture resistance, and low antifungal quality (Mamtaz et al., 2016). Under unprocessed or minimally processed circumstances, natural fibre can also be used as sound absorber. Table 2.1 summarizes several studies on the acoustical qualities of raw natural sound absorbers.

Table 2.1: Summary of raw natural fibre sound absorbers Source: (Yang et al., 2020)

Researcher	Raw Materials	Key Findings
Gle et al. (2012)	Hemp particle	The acoustical properties of hemp particles can be predicted based on the characteristics and configuration of the particles. Particle size distribution has a positive effect on the sound absorption at low-frequency range.
Arenas et al. (2020)	Esparto grass	The sound absorption of raw esparto grass is comparable to traditional glass fibre materials with equivalent thickness.
Iannace et al. (2020)	Broom branch	Broom branch with small diameter has worse sound absorption performance than thicker broom branches.
Putra et al. (2015)	Bamboo	Transverse arranged bamboo showed better sound absorption then axial arranged samples.
Tang et al. (2018)	Corn husk	Corn husk has robust sound absorption because of its groove structure.
Tang et al. (2020)	Green tea residues	The waste green tea residues can be used for sound absorption as filling materials.
Zunaidi et al. (2017)	Rice straw	Rice straw fiber can absorb sound effectively. Fiber mass and diameter have a significant effect on the sound absorption coefficient.
Horoshenkov et al. (2013)	Growing plants	Leaf area density and dominant angle of leaf orientation are two key morphological characteristics for the acoustical properties.
Wong et al. (2010)	Vertical greenery systems	The vertical greenery system is one of the best sound absorbers compared with other building materials and furnishing.

2.3.2(a) Kapok Fibre

Kapok fibre has a large lumen and thin cell walls, endowing it with remarkable stuffing, buoyancy, and oil-absorbing characteristics. Additionally, the unique structure of kapok fibre would benefit sound absorption by increasing the likelihood of friction between sound waves and fibres. Xiang et al., (2013) has conducted a study on this kapok fibre to investigate the acoustical properties of natural kapok fibres and the relationship between physical and acoustical properties. They constructed and assessed kapok fibrous assemblies with varying bulk density, thickness, fibre length, and orientation.

The samples were all backed by the rigidity wall during the experimental measurement. The samples for the sound absorption measurement were made by compressing the kapok fibres into 6 and 3 cm diameter cylindrical forms, respectively. The results indicate that the kapok fibre has excellent acoustical damping properties as a result of its hollow structure. The bulk density, thickness, and arrangement of kapok fibres all have a substantial effect on the sound absorption behavior of kapok fibre assemblies, whereas the fibre length has a smaller effect. In comparison to glass wool and degrassing cotton fibre assemblies, kapok fibre assemblies with a significantly lower bulk density may exhibit comparable acoustical qualities. Table 2.2 shows the sound absorption coefficient of kapok fibrous assemblies with different bulk densities while Table 2.3 shows the sound absorption coefficient of kapok fibrous assemblies with different thickness and bulk densities.

Table 2.2: Sound absorption coefficient of kapok fibrous assemblies with different bulk densities (Xiang et al., (2013))

Bulk density (kg/m^3)	Thickness (mm)	Porosity (%)	Sound absorption coefficient 125 (Hz)	250 (Hz)	500 (Hz)	1000 (Hz)	2000 (Hz)	4000 (Hz)	Average sound absorption coefficient
8.3	60	97.7	0.117	0.164	0.57	0.948	0.964	0.999	0.627
25.0	60	93.2	0.220	0.374	0.542	0.827	0.930	0.984	0.646
42.0	60	88.7	0.238	0.298	0.636	0.662	0.861	0.965	0.610
58.0	60	84.2	0.188	0.243	0.304	0.520	0.727	0.903	0.481

Table 2.3: Sound absorption coefficients of kapok fibrous assemblies with different thickness and bulk densities

Bulk density (kg/m^3)	Thickness (mm)	Sound absorption coefficient 125 (Hz)	250 (Hz)	500 (Hz)	1000 (Hz)	2000 (Hz)	4000 (Hz)	Average sound absorption coefficient
5	20	0.059	0.078	0.105	0.17	0.344	0.674	0.238
5	40	0.078	0.107	0.186	0.411	0.764	0.883	0.405
10	20	0.067	0.082	0.127	0.297	0.619	0.918	0.352
10	40	0.081	0.126	0.308	0.714	0.977	0.963	0.528
15	20	0.065	0.090	0.160	0.413	0.785	0.996	0.418
15	40	0.107	0.143	0.397	0.864	0.984	0.959	0.576
20	20	0.071	0.094	0.185	0.549	0.893	0.997	0.465
20	40	0.109	0.204	0.443	0.905	0.946	0.979	0.598

2.3.2(b) Kenaf Fibre

The kenaf plant stem is composed of 65% inner core fibre and 35% outer bast fibre, generating pulp of low and high grade, respectively. Due to its technical and commercial potential, kenaf is expected to be the next industrial crop. Kenaf bast fibres are currently widely employed in a variety of applications, including food hygiene packaging, composites, textiles, and filters. Kenaf crop production is fast because of its rapid growth rate and low crop rotation requirements.

Lim et al. (2018) conducted a study on the sound absorption performance of kenaf fibres. The impedance tube method was used to get the normal-incidence sound absorption coefficient. The impacts of thickness were discussed using complete fibre and air-fibre specimens, as well as the effect of bulk density.

The results indicate that at bulk densities of 140–150 kg/m3 and thickness of 25–30 mm, the absorption coefficient begins to exceed 0.5 at 500 Hz and averages 0.85 above 1.5 kHz. When bulk density and thickness are increased, the frequency bandwidth of absorption and the degree of absorption coefficient improve substantially. Additionally, the additional air gap improves absorption at lower frequencies. Figure 2-2 below shows the graph of the absorption coefficient of kenaf fibre of varied thickness with constant bulk density of 93.5 kg/m^3.

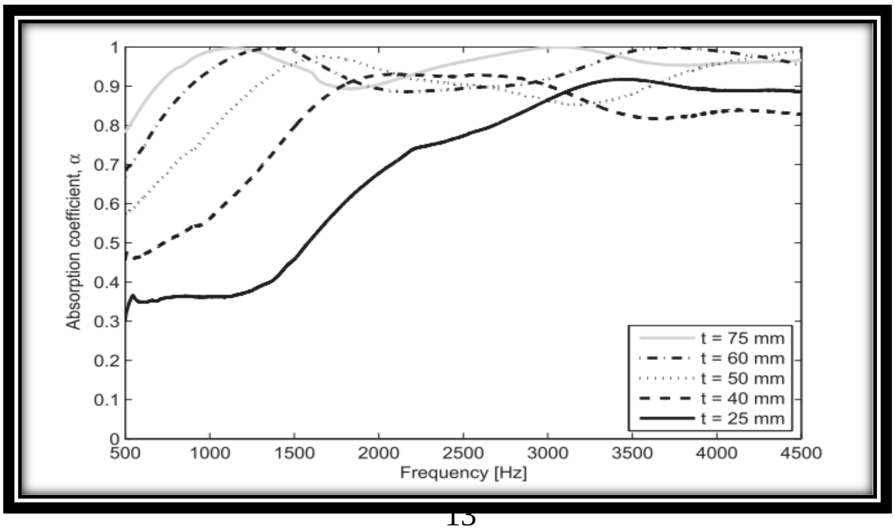

Figure 2.2: Absorption coefficient of kenaf fibre of varied thickness with constant bulk density (Lim et al. (2018))

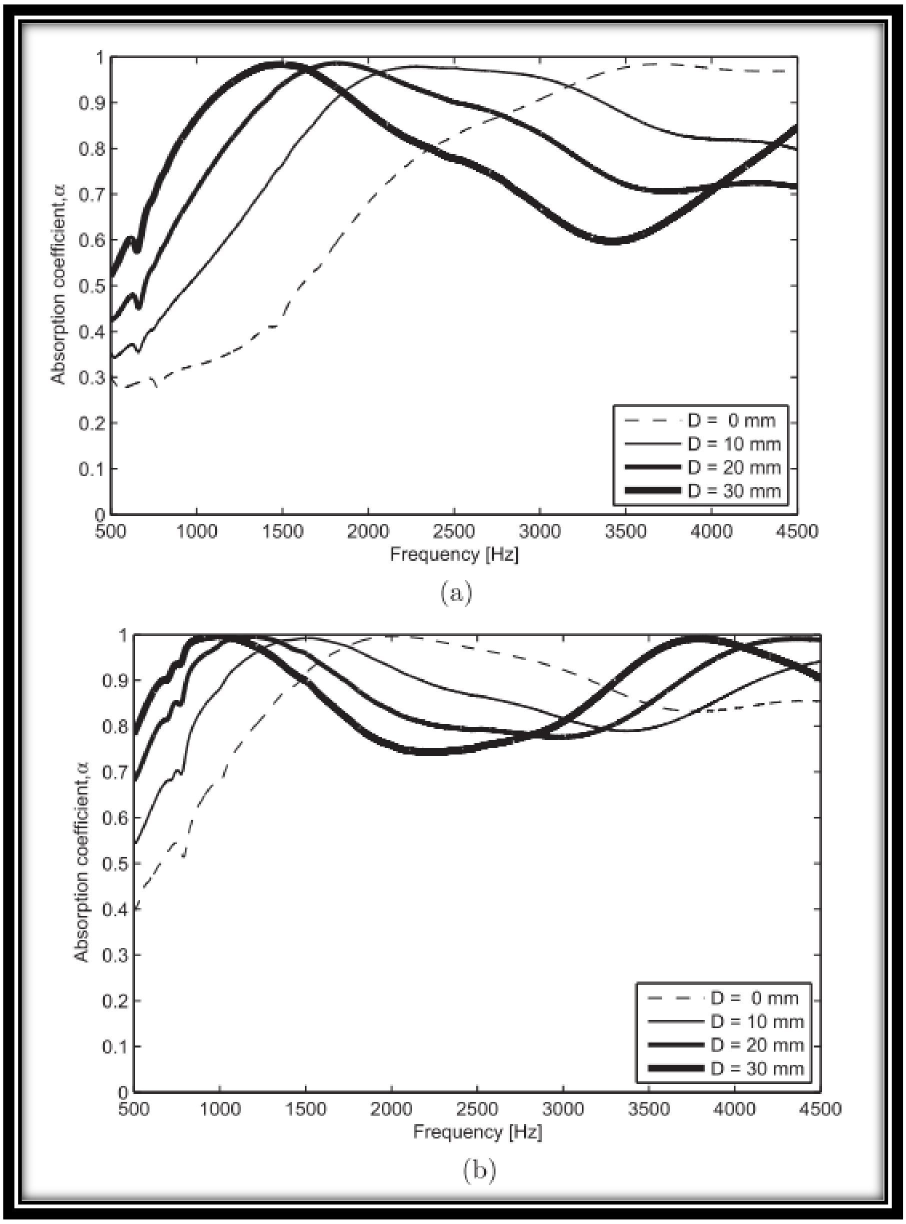

Figure 2.3: Absorption coefficient from kenaf fibre specimen of thickness: (a) 20mm and (b) 30mm backed with varying air gap depth, D (Lim et al. (2018))

From this study, it can be concluded that the normal-incidence sound absorption coefficient of kenaf fibre is found to be more than 0.8 at 1.5 kHz for specimens having a thickness of 40 mm and a bulk density of 93.5 kg/m3. By increasing the bulk density, the sound absorption coefficient can be further enhanced.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the approach used to accomplish the research's goal, as mentioned in Chapter 1. This chapter will go through the process of preparing the sample step by step. The testing technique will next be reviewed in relation to relevant guidelines ISO 10534-1 (standing wave ratio method), ISO 10534-2, ASTM E 1050 (two microphone transfer function method for measurement of acoustic factor, sound absorption coefficient, specific acoustic impedance ratio, and specific acoustic admittance).

3.2 The Flow of The Experimental Work

Figure 3.1 below shows the flow chart diagram for the process flow of the research methodology. The overall stages of the research work are described in the flow chart below.

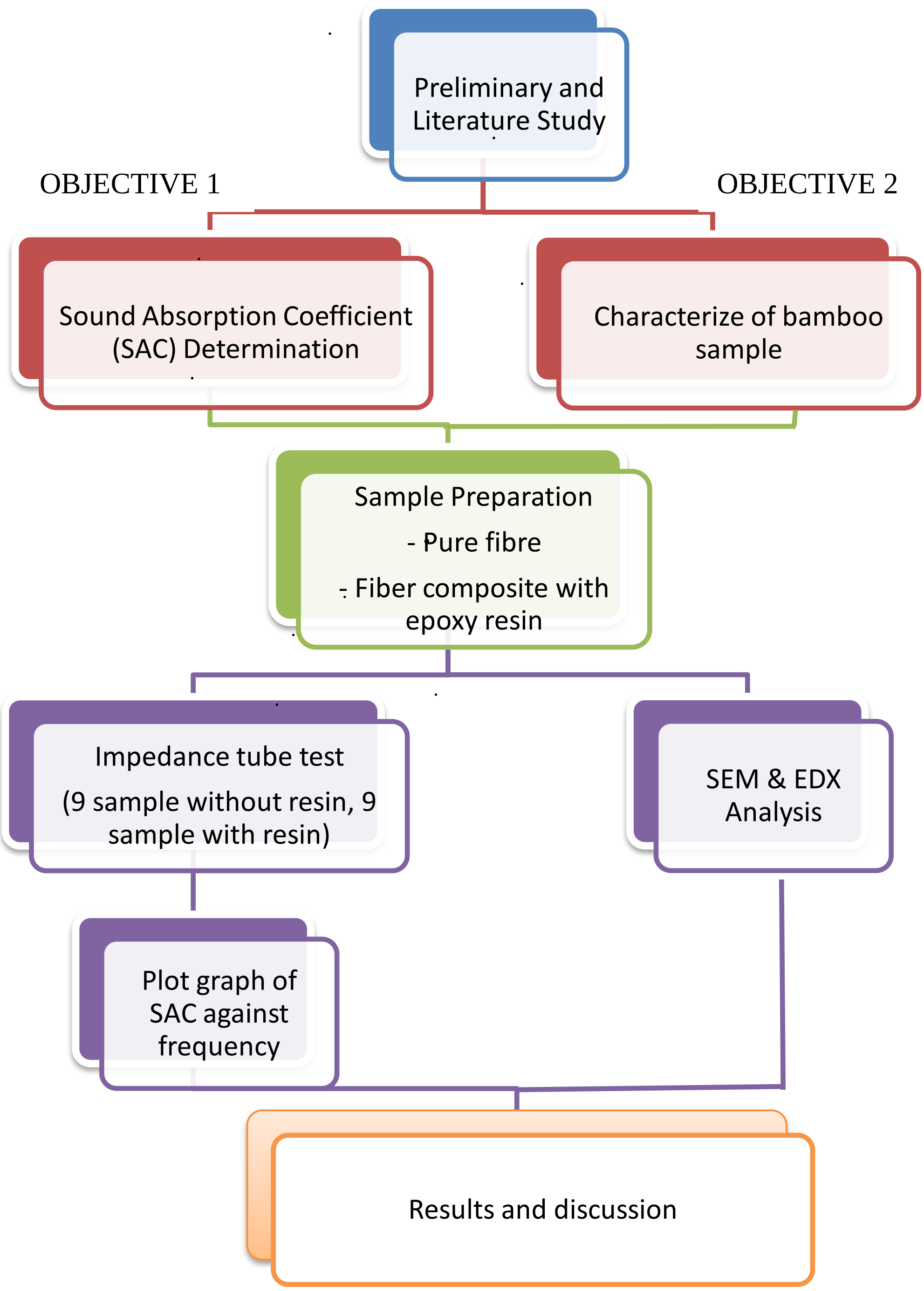

Figure 3.1: Flow chart of the research project

3.3 Materials

The study uses the bamboo species *Gigantochloa ligulata* as the main materials and epoxy resin (EpoxAmite^{TM}100) as the binder for sample. The bamboo species for this research project are provided by the Bamboo Jungle Adventure (BJA) organisation. The bamboo culms were up to 2 metres in length and had at least three nodal parts.

3.3.1 Epoxy Resin (EpoxAmite^{TM}100)

The type of binder that was used in this research was EpoxAmite^{TM}100 Resin with 102 medium hardener. This sort of resin is a simple to use liquid epoxy system that may be used for a range of manufacturing projects. EpoxAmite^{TM}100 resin is an unfilled, low viscosity, odorless laminating system that cures at room temperature. The physical and performance attributes of cured epoxy are remarkable. This epoxy was cured with 102 Medium Hardener (Smooth-on).

3.4 Composite Preparation

3.4.1 Preparation of Bamboo Fibres

The bamboo obtained from the BJA was up to two meters long and had to be cut into smaller pieces (1cm x 1cm). This procedure was to guarantee that the bamboo could be readily ground to get the required particle sizes for this study. The bamboo culm was cut using a Universal Radial Crosscut Saw such as in Figure 3.2 below.

Figure 3.2: Radial cross-cut saw

The bamboo must be oven-dried for 24 hours after being cut into 1cm x 1cm pieces such as in Figure 2.3 before the grinding procedure can begin to ensure there were no moisture in the bamboo samples. The moisture level of bamboo before grinding is very essential since it influences the physical qualities of the material as well as the powder properties, such as flowability after grinding. Because the energy expenditure needed to form new surfaces vary, the moisture content of bamboo is often connected to its energy needs for grinding. Hence, in this study, dry grinding is being used as to implement the particle-on-particle impacts to reduce size.

The bamboo that has been dried were grind using mini crusher machine (Figure 3.4). To get the different sizes of bamboo fibres, there were various sizes of sieve mesh that can be inserted at the mini crusher depending on the outcomes of the sample that were needed in this research. After the grinding process, the bamboo fibres were sieve using laboratory sieve shaker (Figure 3.5) to obtain the bamboo fibre size of 850μm, 2mm and 5mm.

Figure 3.3: Oven-dry process

Figure 3.4: Mini crusher

Figure 3.5: Laboratory sieve shaker

Figure 3.6 shows the result from the sieve analysis that has been conducted. The bamboo fibres would be stored in a zip lock plastic to prevent from any moisture and can easily be stored for preparation of sample.

Figure 3.6: Bamboo fibres with different sizes (850 μm, 2mm, 5mm)

3.4.2 Preparation of Bamboo Fibre Specimen

Preparation of bamboo fibre specimen for sound absorption testing was done by measuring the weight of bamboo fibre. The total weight of the bamboo sample is 5g for each specimen which contains 80% of bamboo fibre and 20% mixture of resin and hardener. The resin and the hardener were manually mixed before added into the cup that contains bamboo fibres (Figure 3.7). After mixing the bamboo fibres with epoxy resin mixture, the composite compound was inserted into a cylindrical mold with diameter size of 34.8mm such as in Figure 3.8. Next, the composite was pressed using a hydraulic press machine for 1 hour to ensure adequate curing time of the epoxy resin to bind the bamboo fibres. Figure 3.9 show the hydraulic press machine that was used in this research.

Figure 3.7: Manually mix of specimens

Figure 3.8: Cylindrical mold

Figure 3.9: Hydraulic press machine

For the sample with pure 100% bamboo fibre, the same steps were followed such as above except that there were no addition of epoxy resin and binder. The fibres were straight away weight for 5g for each sample and then manually pressed in the same manner as before.

3.5 Sound absorption coefficient measurement

The Sound Absorption Coefficient of each sample was measured by using of the impedance tube, LMS Scadas Mobile, LMS Software (LMS Sound Absorption Coefficient) and two Microphone units (Grass 46AE) as displayed in Figure 3.10. The plunger at the back of the impedance tube is functioned to adjust the air cavity gap. The air cavity gap was changed between 10mm and 30mm for this experiment. The impedance tube had one end loaded with a sample and the other end linked to a loudspeaker that fed white noise into the tube (Lim et al., 2018). Sound waves are generated by the loudspeaker when plane waves impact the sample and are partly absorbed before being reflected back. The acoustical properties of the test sample were tested in the frequency range of 50-5000 Hz. Figure 3.11 shows the test specimens with different sizes of bamboo fibre.

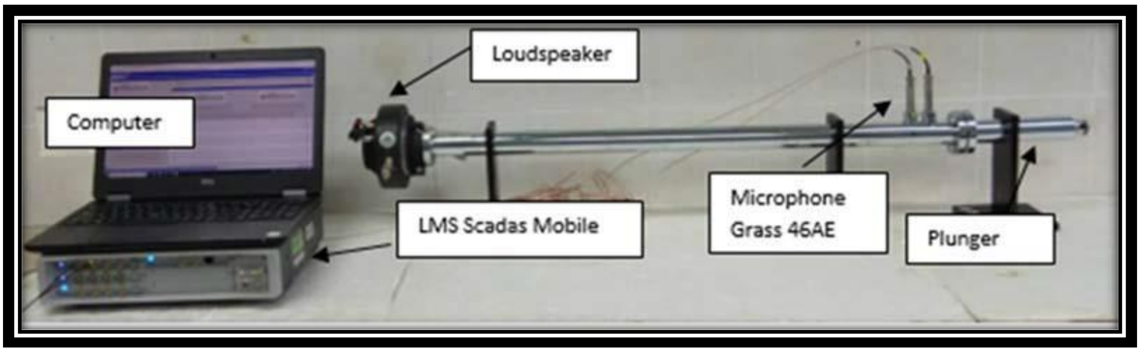

Figure 3.10: The experimental setup of the sound absorption coefficient

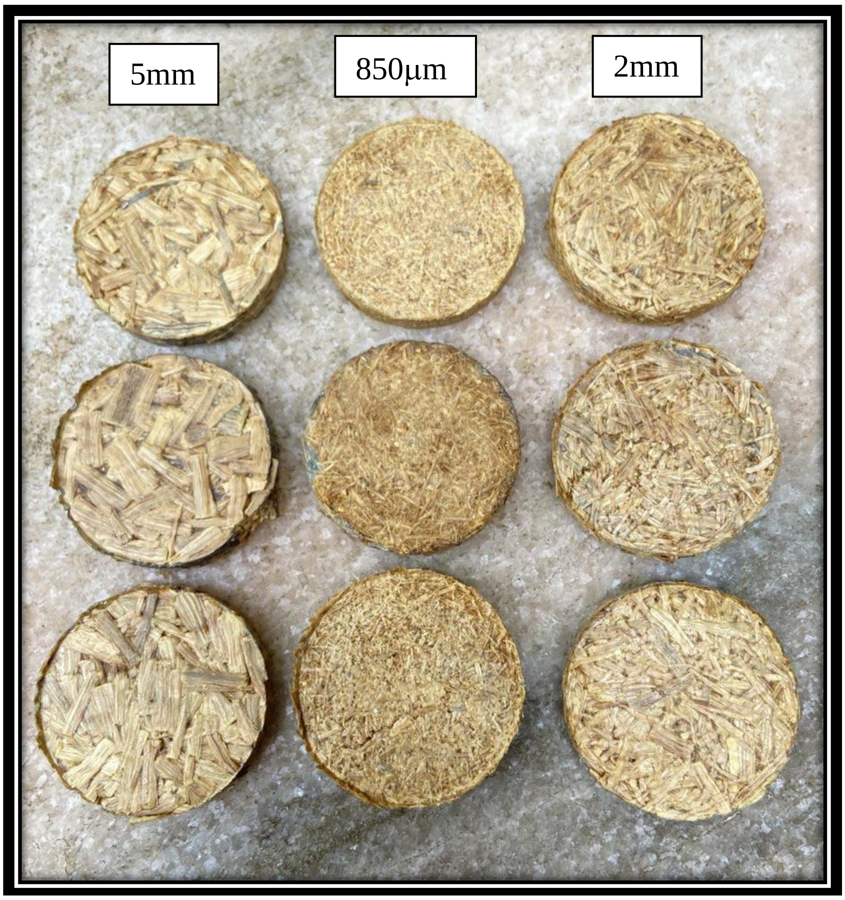

Figure 3.11: Sound absorption coefficient test specimens

3.6 Scanning Electron Microscopy (SEM) and EDX analyses

In order to provide more detailed information, SEM and EDX analysis were performed on the same test specimen. A Scanning Electron Microscope (SEM) is a spectacular magnification device that collects data by using focused electron beams. SEMs are a useful tool for both academic and industrial research because they give morphological, topographical, and compositional data in the form of high-resolution, three-dimensional pictures. A Scanning Electron Microscope (SEM) could provide a variety of information about a solid's surface. It collects and concentrates stray electrons on a sample (Choudhary & ka, 2017). EDX, often known as EDS or EDAX, is an x-ray method used to identify the elemental composition of materials. It is typically used in conjunction with a scanning electron microscope (SEM). Figure 3.12 shows the scanning electronic microscope (SEM) that was used for specimens' microstructure observation.

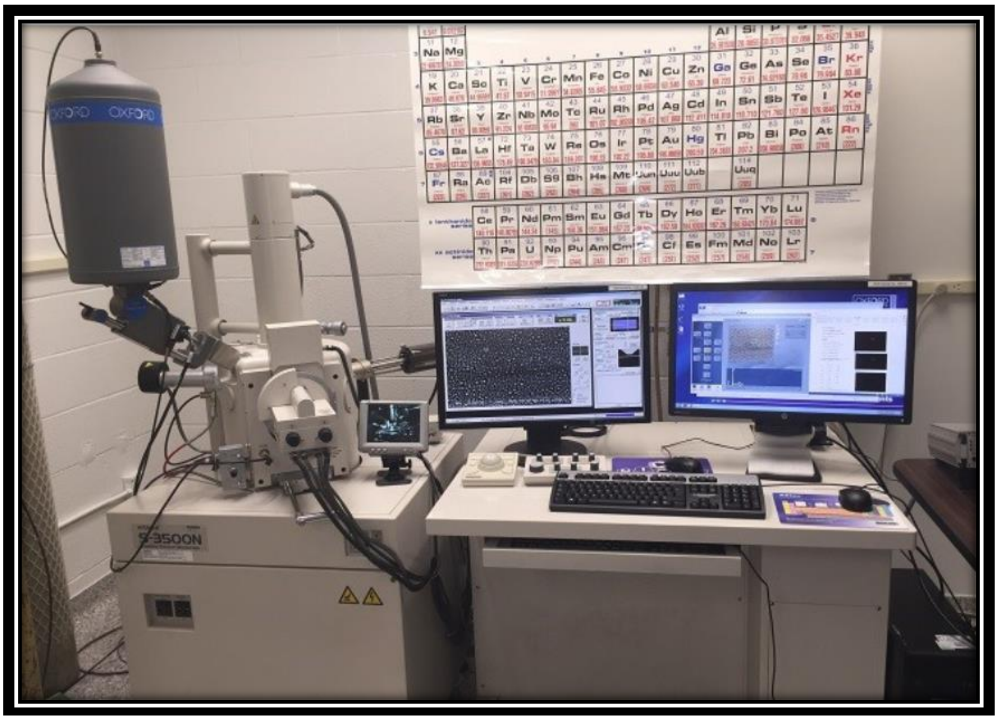

Figure 3.12: Scanning electronic microscope (SEM)