ACOUSTICAL PERFORMANCE AND PHYSICAL PROPERTIES OF SOUND ABSORBER WITH DIFFERENCE COMPOSITION OF NATURAL RUBBER

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“உட்பை, வாள், செய், உள்பையா...”
“To my mother, father, teacher and mighty god...”

To my beloved parent,

Mr. Mrs. Sambu & Praema

For their supports in whole of my life

To my supervisor “sensei”;

Prof. Madya Dr. Musli Nizam Bin Yahya

For his advice, support and patience during the completion of this project

and to all my friends,

For their encouragement, cooperation and motivation in completing this thesis.
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ABSTRACT

Natural materials are turning into a substantial alternative option for traditional synthetic ones for acoustical treatments. Natural fibres often have great mechanical properties, have no harmful effects on health, and are available in large quantities often as a waste product of other production cycles. However, great demands for composite porous material contribute to the potential application of natural fibre as sound absorption panel. To assist in that effort, the research presented here studies the feasibility of using selected four kinds of natural fibres which are Ijuk, Kenaf, Coconut coir and Palm oil frond fibre blended separately with natural rubber as sound absorptive materials. Therefore, an experimental investigation was performed to evaluate the acoustical performance characterization and physical properties under qualify applied methods to obtain it. The natural fibres were processed with a combination of natural rubber at 0%, 20%, 30% and 40% composition, respectively. The samples were produced based on diameter size required by impedance tube (ASTM E1050) and the thickness remains at 50mm. The sound absorption coefficient (α), test results indicated that samples made by 20% of natural rubber as binder content exhibit optimum acoustical properties compared other mixing percentage. Among the four kinds of natural fibre, Ijuk exposed peak result on the sound absorption coefficient of 0.96 at low frequency 1000 Hz and 0.98 at high frequency 3000 Hz. Overall, the samples made by natural fibre with natural rubber combination were giving a better acoustical performance that outcomes more than 0.6 sound absorption coefficient value after the mid to high range frequencies to and by that it is capable of using in acoustical treatment especially in low frequency. Moreover, the influences of physical elements on acoustical performance are also described in this research study.
ABSTRAK

Bahan-bahan semulajadi menjadi pilihan alternatif yang sesuai bagi bahan sintetik yang menjadi bahan tradisional untuk rawatan akustik. Kebelakangan ini, serat semulajadi telah menjadi pilihan bahan mentah untuk menghasilkan penyerap bunyi. Selain itu, serat semula jadi ini mempunyai sifat-sifat mekanikal yang hebat, tiada berbahaya terhadap kesihatan manusia, dan boleh daptat dengan kuantiti yang banyak dari sisa kitaran pengeluaran produk lain. Walau bagaimanapun, permintaan yang besar bagi bahan komposit berliang ini menyumbangkan kepada potensi penggunaan sebagai panel penyerapan bunyi. Untuk membantu usaha itu, dalam penyelidikan ini empat jenis serat semula jadi dipilih iaitu Ijuk, Kenaf, serabut kelapa dan serabut dahan kelapa sawit diadun secara bersaringan dengan susu pokok getah asli sebagai bahan kajian untuk penyerap bunyi. Oleh itu, siasatan penyelidikan telah dilaksanakan untuk mengkaji ciri-ciri akustik yang prestasi dan ciri-ciri fizikal di bawah kaedah yang ditetapkan untuk mendapatkannya. Serat semula jadi ini diproses dengan gabungan getah asli kepada peratusan 0%, 20%, 30% dan 40% pada setiap jenis serat. Bahan kajian yang dihasilkan bergantung kepada saiz diameter yang ditekendaki oleh galangan tiub, ‘Impedance Tube’ (ASTM E1050) dan ketebalan sampel dikekalkan pada 50mm. Keputusan ujian akustik menunjukkan bahawa sampel-sampel yang dibuat daripada 20% getah asli pada setiap jenis serat memperkenalkan sifat-sifat akustik yang optimum berbanding dengan sampel peratusan adunan lain. Antara empat jenis serat semulajadi, Ijuk yang mendedahkan penyerap yang tertinggi dengan mencapai penyerapan bunyi 0.96 pada antara frekuensi rendah 1000 Hz dan 0.98 pada frekuensi tinggi 3000 Hz. Keseluruhannya, sampel yang dibuat dengan serat semulajadi dan gabungan getah asli telah memberi ciri-ciri akustik lebih baik dan menghasilkan prestasi penyerap yang lebih daripada 0.6 nilai bunyi penyerapan. Oleh itu, bahawa ia mampu menggunakan untuk rawatan akustik yang diperlukan terutamanya pada frekuensi rendah.
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LIST OF SYMBOLS AND ABBREVIATIONS

α  Alpha value
σ  Air Flow Resistivity
$CO_2$  Carbon Dioxide
db  Decibels
d°C  Degree Celsius
f  Frequency
GPa  Giga Pascal
Hz  Hertz
m  Meter
m/s  Meter per second
μm  Micrometre
MPa  Mega Pascal
nm  Nanometre
v  Velocity
λ  Wave length
wt.%  Weight Percentage
Z  Surface Impedance
ASTM  American Standard of Testing Method
FKMP  Faculty of Mechanical and Manufacture Engineering
FKAAS  Faculty of Civil and Environmental Engineering
HDPE  High-density polyethylene
ITM  Impedance Tube Method
NaOH  Sodium hydroxide
NIOSH  National Occupational Health and Safety Commission
NR  Natural Rubber
NRC  Noise Reduction Coefficient
PET  Polyester
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<td>SAC</td>
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CHAPTER 1

INTRODUCTION

1.1 Research background

Acoustical control is a very important concern in civilian applications. Nowadays, the acoustical problem has become increasingly acute in social life and industrial production. With social and economic development, people's concern for the environment is becoming more significant. Noise pollution; an acoustical problem is attracting widespread attention as a critical environmental issue. Generally, the excessive acoustical problem will disrupt people's normal life and work, whereas long-term exposure to high noise environment can have serious physiological or psychological effects (Suter, 2002). Meanwhile, the highest exposure will result in sound fatigue of some industrial machinery and equipment, which could shorten their working lives and even lead to accidents.

The common acoustical problem nowadays, as experienced by room/indoor users include challenging verbal communication in classrooms and conference rooms, inefficient learning and teacher's unclear voice in classrooms, hearing hazards in the industrial workshop and inadequate speech privacy in open-plan offices. A room's sound fields contain both "signals" (required or needed sounds, such as speech) and detrimental "noise". In order to modify a room's sound fields and improve the acoustical condition, the acoustician must understand the relationship between the room users and activity, the sound sources, the room and its contents, and the characteristics of a room's sound fields. One of the most frequent problems faced by acoustical control engineers is how to design sound absorbers that provide the desirable sound absorption coefficient as a function of frequency in a
manner that minimizes the size and cost, especially without posing any environmental hazards, and withstand high temperatures, high-speed turbulent flow, and contamination. The designer of sound absorbers must know how to choose the proper sound absorbing material, the geometry of the absorbers and the protective facing. The theory of sound absorbing materials or sound absorbers has progressed considerably during past decades (Biot, 1962; Ingard & Dear, 1985; Zhu et al., 2014).

Much of these are by a century ago, since the acoustical elements were studied by architectural by Sabine (Allard & Daigle, 1994). There have been extensive attempts dedicated to studies especially on surface of absorption. The past decade has seen the development of a considerable database of absorption coefficient has been tabulated based on accepted standards of measurements and the design of sound absorber was accomplished. Then, the ways to expected and measured sound absorption coefficient of the material also has been found (Delany & Bazley, 1970; Komatsu, 2008). Invariance, significant scientific awareness about the role of absorption surfaces has only been developed much more lately. Past 20 to 30 years, researchers in certain fields involved to increasing form of scientific knowledge and understanding the sound absorption.

However, researchers have consistently attained an adequate understanding of sound and its absorption. The sound is an organised superposition of particle motion on the random thermal motion of the molecules. The travelling speed of the particles in air is naturally organised into six orders of range smaller than that of the thermal motion. Instead, all the sound absorbers expedite the conversion of the energy earned by the organised particle motion into random motion. All forces other than those that compress and accelerate the fluid, caused by the oscillation particle flow in the presence of solid material result in the loss of acoustical travelled energies. The most vital contribution to the conversion is linked with the drag forces caused by friction between the interface of the rigid or versatile wall or the skeleton of the sound absorption material and the fluid within the thin acoustic boundary layer.

Therefore, a sound absorption material will absorb solely that part. The incident sound energy is not reflected on its surface. Thus, it is significant to keep the reflection at the surface as low as attainable. Primarily, the part of the incident acoustic energy that enters the absorbent material ought to be dissipated before it returns to the surface once traversing the absorbent material and reflective from a
rigid backing. Otherwise, the absorbent material provides an acoustical energy to the fluid, on the receiver face which is additional to the initial reflection. This needs an adequate thickness. Figure 1.1 explains the incident in illustration.

![Diagram of sound absorption](image)

**Figure 1.1:** Sound absorption incidents (Rossing *et al.*, 2009)

The reduction of this acoustical problem is a major requirement for performance, sound quality and customer satisfaction. To prevent it, acoustic absorbers or soundproofing panels are applied in various fields of sound control. There are many uses in the fields of building and room acoustics, transportation or the automobile industry, heavy industrial and environmental acoustic control. Optimum potential and versatile solutions are needed as key to sensible, geometrical and financial constraints.

Acoustic absorbers are effective in reducing acoustical problem within space by transforming sound wave frequency into heat. Different types of sound absorbing materials with a variety of colours, shapes, and sizes are already in the global market. They are not only providing the desired acoustic properties, but also some durability in performance. Most of the sound absorbing materials are porous materials. Conservatively, synthetic fibres such as glass wool, rock wool and fibreglass are chosen as common raw materials for acoustic manufacturing. These materials offer
good acoustical performance; however they are not sustainable (Al-Rahman et al., 2012). The environmental apprehensive over the use of synthetic fibre for acoustical material have enhanced the demands for a substitute material.

1.2 Problem statement

Currently, most of the buildings and living space construction use soundproofing panels made of synthetic fibre as a solution to the acoustical problems. There are synthetic fibres such as glass wool, rock wool and fibreglass. Synthetic acoustic panels provide a good performance sound absorption, but they create major health problem. This extensively used sound absorption material made of synthetic fibres are indeed injurious to human health (Asdrubali et al., 2012). If these fibres were ever inhaled, they can lay down in the lung alveoli, and cause skin irritation. Since it is a threat to human health, National Occupational Health and Safety Commission (NIOSH) also discovered the awareness of the synthetic materials and some concern in the community regarding the health effects associated with exposure to synthetic materials (National Occupational Health and Safety Commission, 2006). Production of these synthetics materials has been known to release a significant amount of CO₂ into the atmosphere compared to sound insulators made from natural materials. The characteristics of synthetic material also create another problem indisposition which is harmful to the global environment (Schmidt et al., 2004).

Thus, outcomes with alternative nature materials have not only comparable capability as sound absorbers and abundance as well as less health. Recently, a great attention has been focused on “green” materials, especially in the building sector. Many research centres have developed new sustainable materials, in many cases with interesting features on acoustical properties. The cheaper, profused, weightless, and biodegradable natural fibres are an attractive material to be considered for sound absorbers (Zulkifli et al., 2008). Several researchers and investigations on natural fibres for sound absorbing material development have been reported. It includes various types of natural fibres such as bamboo fibre (Tsuijiuchi et al., 2002), paddy straw (Putra, 2011), jute fibre (Fatima et al., 2011), kapok / cotton (Veerakumar & Selvakumar, 2012), tea-leaf waste (Ekici et al., 2012), sugar cane (Putra et al., 2013) and many more that are involved in acoustic researchers. The main imperative
findings with these natural fibres are greater than synthetics fibre due to its better acoustical properties and in mechanical properties.

In this study, four types of fibres will be used to identify its characterises of acoustic and physical properties on it. There are Ijuk fibre (*Arenga Pinnata*), Kenaf fibre (*Hibiscus Cannabinus*), palm oil frond fibre (*Elaeis guineensis*) and the coconut fibre known as coir. These types of fibres are commonly available in East Asian countries and usually they become abundant and waste after the industrial process. According to Van Dam (2009), over 1.5 million metric tons of natural crops are left over per average year over the recent years. The previous investigation confirmed that some of the natural fibres that will be applied in this study are applicable to composite material component (Benyahia *et al.*, 2014; Shah *et al.*, 2013). So, reliable evidence on these natural fibres are clearly to be used in engineering applications. Unfortunately, there is a scarcity of knowledge on the acoustical and physical properties of these four fibres by making it natural composite material. With that in thought, additional analysis and discoveries on the acoustic and physical properties of these selected fibres should be known and identified. In another word, it provides sustainability; including long term maintenance, which has environmental, the economic and social benefits (Fangueiro. R, 2011).

1.3 Research questions

Based on the explanation above, some important research questions are found in this research:

1) Are these natural fibres; Ijuk, Kenaf, Coir and Palm oil frond feasible to be applied for acoustical panels?
2) What are their physical properties and how much do they help influence the acoustical performance?
3) How durable is the natural fibre composite material when exposed to typical environmental conditions, including water and high-temperature exposure?
1.4 Research objectives

The aim of this research is to evaluate and validate the suitability of Ijuk fibre (*Arenga Pinnata*), Kenaf fibre (*Hibiscus Cannabinus*), Palm oil frond fibre (*Elaeis guineensis*) and the Coconut fibre to be utilised as acoustical absorber materials. To achieve this tenacity, several objectives have been defined as follows:

1) To realise the performance of sound absorber's on acoustic characteristics made from natural fibres; Ijuk, Kenaf, Coir and Palm oil frond which binds together with natural rubber and to validate the acoustical performances by using round-robin test in inter-laboratories.

2) To identify the physical properties and influence the acoustical performance of selected natural fibres.

3) To determine the durability of natural fibres composite material when exposed to typical environmental conditions, including water and high-temperature exposure.

1.5 Scope of research

The scope of the study is concentrated to:

1) Pre-treatment of the selected natural fibres to remove unwanted dirt and depolymerises cellulose that covers the fibre.

2) Natural Rubber (latex) which is less in chemical composites used in the binding process together with chopped fibres by following the weight percentages of 40%, 30%, 20% and also 0% that indicates no natural rubber mix.

3) Use three laboratory's Impedance Tube (ASTM E1050) to obtain normal incidence of Sound absorption coefficient (SAC) and Noise reduction coefficient (NRC) for each sample of natural fibres mixed with natural rubber.

4) Physical properties related to acoustical parameters are obtained, such as bulk density, porosity, tortuosity and airflow resistivity.
5) Durability properties which are water absorption (ASTM C1140) and flammability (UL 94 Standard) are tested to identify the capabilities of the samples.

1.6 Thesis outline

This section gives a brief summary of the thesis layout. This thesis is divided into five chapters with the following scopes and objectives. Chapter 1 presents the research topics which include background, objectives and scope of the research.

Chapter 2 belongs to comprehensive literature review about the acoustical research area and properties. The definition, theory and related work outcomes from previous researchers similar to this research are explained in Chapter 2. Research methodology includes material preparation, sample production and experimental work procedure as presented in Chapter 3. Measurement techniques to evaluate acoustical properties of the specimens are also included.

The experimental outcome of four fibres in terms of physical, acoustical and durability properties are reported in Chapter 4. The influence of density, porosity, tortuosity and airflow resistivity on the acoustical performance of samples are discussed in this chapter. Acoustical absorption obtained by different laboratories are presented to validate the acoustical performance of selected natural fibres. The properties of samples, including water absorption and flammability, are also detailed. The summary of experimental results is also presented at the end of this chapter.

Chapter 5 will point out the conclusions of the research. Some further works and recommendations are also included in this chapter.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Acoustics is best defined as a scientific study of sound, which revolves around the generation, transmission and effect of sounds. The sound is created by a vibrating surface, causing pressure variations in an elastic medium, called a wave (Bies & Hansen, 2009). The more elastic an element, the better it conducts sound waves.

The purpose of this chapter is to give basic information on acoustics and it is fundamental to control. The facts and information for this chapter have been gathered from various reference books and research papers.

2.2 Acoustics

The expression "sound" and "acoustics" are comparable; however there is a distinction in their practicality interference representation. Acoustic is characterised as the experimental investigation of sound which incorporates the impact of reflection, refraction, absorption, diffraction and impedance. Sound waves can be considered as a phenomenon. It is a longitudinal wave where the particles of the medium are incidentally dislodged in a heading parallel to energy going and after their arrival to the original position. The vibration in a medium produces alternative waves of moderately dense and meagre particles which are termed as compression and rarefaction individually. The resultant variation in normal ambient pressure is received by the ear and recognised as sound. A simple sound wave is shown in
Figure 2.1. This wave can be described in terms of Amplitude, Frequency, Wavelength, Period and Intensity.

![Diagram of a wave](#)

Figure 2.1: Simple waves of sound

Amplitude refers to the difference between the maximum and minimum pressure. Frequency ($f$) of a wave is measured as the quantity of complete forward and backward vibration of a particle on the medium per unit of time. A measurement unit for frequency is Hertz (Hz). The wavelength ($\lambda$) of a wave is the separation when an unsettling impact goes through the medium in one complete cycle of the wave. As the wave repeats the pattern for each wave cycle, the length of one repetition is called as wavelength and the time required for the completion of one cycle of wave motion is called periodically. The normal rate at which the sound energy is transmitted through a unit area is known as the power of sound wave (Cox & D’Antonio, 2009).

Frequency has a converse relationship to wavelength. Both are related to each other by the velocity of sound, $v$, which points out the direction and time of sound travelling to reach listeners. Wavelength is enlarged as frequency is reduced, and conversely as shown in Eq. (2.1) (Cox & D’Antonio, 2009).

$$\lambda = \frac{v}{f}$$

(2.1)
Where,

\[ \lambda \text{ wavelength } (m) \]
\[ f \text{ frequency } (Hz) \]
\[ v \text{ velocity of sound } (m/s) \]

Sound propagates in the air, water or building material with a certain velocity, where it is normally 344 m/s in the air (Parkinson, 1999). These two measures express the nature of pressure variation in a medium that are experienced as sound in the brain. The human ear can detect sound ranging from approximately 20 to 20,000 Hz, but the most sensitive in the frequency range of 500 Hz to 4000 Hz. This upper limit tends to decrease with age. Sounds with frequencies below 500 Hz and above 4000 Hz cannot be acknowledged as sound by the ear, but can be felt as a vibration in human bodies (Cox & D’Antonio, 2009).

Besides, amplitude properties is also involved in the sound wave, which is determining how far the wave travel beyond and below the static pressure of an elastic medium travelling through it, measured in decibel (dB). The higher the decibel level, the higher the sound volume or loudness produced. For example, an F-35 fighter jet has an amplitude of 150dB, while a human whisper is nearly 20dB. For a typical office environment, the amplitude usually drops in the range of 40 and 60dB. When sound level goes beyond 65dB, the human ears take it as unwanted sounds and perceive it as noise (Arenas & Crocker, 2010).

The undesirable or painful sound is termed as noise. The high generation machine in all the mechanical segments, industrial areas and fast vehicles produces massive noise. The three elements of noise systems are noise source, noise path and noise receiver:

- The Noise Source - the medium of emission.
- The Noise Path – the passage of acoustical propagation.
- The Noise Receiver – the hearing elements.

The three elements above are crucial factors to be considered for acoustical control (Randall, 1952; Bruneau, 2013).
2.3 Sound absorption

Sound absorption is defined as the ratio between the acoustic energy that is not reflected by the surface to the sound energy in the incident wave (Cox & D’Antonio, 2009). This phenomenon occurs when the wavelength of sound waves that hit a surface is smaller than the dimension of the material’s surface. Sound energy dissolves into a small amount of heat as waves bounce around within the material (Cox & D’Antonio, 2009).

In a larger closed indoor hall, the reverberation created when gathering people in zones close to the stage can be ideally diminished by including sound absorption material at the rear wall or back divider. Figure 2.2 shows an example of a classroom condition with and without sound absorbing treatment by using sound absorption panel. The teacher’s voice is the sound source while students hear the sound of the teacher’s voice directly. Aside from that, students also hear reflected sound from plaster wall, floor, and dividers.

At the point when absorptive panels are fixed in the room, the students hear a less reflected voice; sound because the level of reflected sound is diminished in the entire part of the room. Sound absorption reduces the sound energy in the reverberant field. In numerous open spots like transportation terminals and department stores, the sound absorption treatment are not done with the aim of reducing unwanted sounds but to guarantee fitting intelligibility of speech. Figure 2.3 gives another illustration on the impact of sound absorbing material expansion inside a sound reflected area.

As found in Figure 2.3, the expansion of sound absorption to the ceiling of a room (<500 ft²) can decrease the 10dB reverberant noise. The sound level in the reverberant fields can be dropped an extra 6dB while all dividers; walls and roof are treated with sound absorbing material. Every multiplying sound absorption material inside the room lowers one half reverberation times. Then again, there is no impact for sound level close to the sound source. Absorption treatment close to the sound source will only diminish 3dB of noise. Dividers secured with sound absorbing materials have not been able to reduce noise from a source. The most extreme impact conceivable in covering dividers; walls with absorbing materials is to maintain and avoid from reflecting the noise (Bies & Hansen, 2009).
Figure 2.2: Classrooms with and without Sound Absorptive Panel
Figure 2.3: Effects of sound absorbers' addition (Rossing et al., 2009)

2.4 Surface absorption and reflection

The ability of a surface to absorb incident sound energy is described by the energy of absorption coefficient $\alpha$. At a point when a sound wave interfaces with real materials, the energy contained in the incident wave is reflected, transmitted through the material, and absorbed within the material. Hence, the inverse of sound absorption is the sound reflection. For a geometrical or specular reflection to happen, it is necessary that the reflecting surface is substantially in contrast with the wavelength of the incident energy. From the work led by (Leonard, 1964), it was determined that in order for a specular reflection to happen, least panel measurement needed is 30 x $\lambda$. When the board measurement is around 10 x $\lambda$ slight diffraction will occur and when the board measurement is under 5 x $\lambda$, the incident energy is diffracted.

Additionally, the point of reflection is one with the same incident angle, a flat and hard surface, and bears a homogeneous physicality. Practically, as a result of limited absorber's size, surface uneveness, and as well physical or impedance discontinuities, the energy is scattered or diffused (reflects a range of angle). Such diffuse reflection normally brings about a quicker decay of sound and lower resonance times in the room.
At the point when a sound wave hits a wall, its energy is partitioned into three sections. In the event, the sound incidence on a wall has an energy wave $E_i$, a part of the sound energy $E_r$ is reflected back while some part of energy $E_a$ is absorbed by the walls. Whatever remains of the energy, $E_t$ is transmitted to the opposite side of the wall as indicated in Figure 2.4. These phenomena can be written as (Maekawa & Lord, 2004).

\[ E_i = E_r + E_t + E_a \]

![Figure 2.4: Interactions of Sound Waves with a Surface](image)

### 2.5 Type of sound absorptive materials

Materials that decrease the acoustic energy of a sound wave as the wave goes through it by the absorption phenomenon are called sound absorptive materials or sound absorbents (Vér & Beranek, 2006). They are normally used to mollify the acoustic environment of a closed volume by reducing the sufficiency of the reflected waves. Absorptive materials are most resistive in nature, either fibrous, porous or in rather uncommon cases; responsive resonators (Vér & Beranek, 2006). Classic examples of resistive material are nonwovens, fibrous glass, mineral wools, felt and
foams. Resonators include hollow core masonry blocks, sintered metals and so on. The majority of these products give some level of absorption at about all frequencies and performances at low frequencies commonly increments with an expanding material thickness (Vér & Beranek, 2006; Oliva & Hongisto, 2013).

Sound absorbing materials are an inactive medium where rate sound is changed into heat. It is broadly used to reduce the noise level in any mechanical operation or in places with acoustical problems (Sagartzazu et al., 2008). There are three basic types of sound absorbing material utilised as a part of to overcome the acoustical problem. They are membrane resonator, Helmholtz resonator and porous absorber.

i. **Porous Absorbers** are extensively utilised as a part of acoustical engineering (Wang & Torngr, 2001). Fibrous media are the most accessible porous absorbers. Fibrous material considered as a composite medium in which the fibres are suspended in air under certain binding forces (Putra et al., 2012; Cox & D’Antonio, 2009). Foams, fabrics, carpets and cushions are examples of these absorbers. They are ordinarily made out of cellulose or mineral fibres that ensured high acoustics absorption and flame resistant.

ii. **Membrane Resonators** are consistently strong, impermeable and non-inflexible or cavity behind them. Material like thin wood panelling over framing, lightweight, strong roofs and floors and other massive surfaces are qualified of reverberating because of sound. Frequently used in a room designed for special low-frequency noise problem such as for audio to balance the natural high-frequency absorption (Kuttruff, 2009).

iii. **Helmholtz Resonators** are ordinarily characterised as a special kind of air spring oscillator is an enclosed volume having a slight neck and an opening toward another side (Xiang et al., 2013). It is known as a Helmholtz resonator, named to pay tribute to the man who first figured it is resonant frequency. Helmholtz resonators are utilised as a part of bass-reflex or ported loudspeaker cupboards to develop the bass response of loudspeakers by tuning the box so that the port emanates the energy at low frequencies. The box-cone combination is not a basic Helmholtz resonator but acts rather like a high-pass filter. To go about as a true Helmholtz resonator, they must have a volume, a neck, and an opening, which measurements are slightly contrasted
with the wavelength of sound with being absorbed (Cox & D’Antonio, 2009; Kuttruff, 2009).

Different absorbers have different sound absorption, physical characteristics for different frequencies. Figure 2.5 demonstrates the sound absorption characteristics of each type of absorbers. Membrane resonators effectively absorb at lower to mid frequency range. Helmholtz resonators are compelling at a lower frequency; however, this type concentrates on an extremely narrow band of frequencies. Porous absorbers are adequately absorbed in a high-frequency range (Cox & D’Antonio, 2009). In this way, when sound absorption treatment is needed as an answer to acoustical issues inside a room, the material selected must be suitable for the required frequency range and dependable on a place to fix. The combination of porous materials and resonators can give the uniform or flat sound absorption with the frequency which needed in recording or radio/TV studio. The performance of absorptive materials is influenced by many parameters, which are explained in the latter part of this chapter.

![Absorption Coefficient, $a$ vs Frequency, Hz](image)

Figure 2.5: Sound Absorption Characteristics of Absorber (Bruneau, 2013)
In the midst of those, the most renowned sound absorbers are of porous materials. Foam and fibrous materials are the well-known porous sound absorbers which normally used (Wang & Torng, 2001). Both are intended to situate continuous fibre that trap and keep air between them. Synthetic fibres, which are defined as man-made fibres, are the most applied sound absorption materials. They are prepared by high-temperature extrusion from synthetic chemicals and regularly from petrochemical sources. Despite the fact that these commercially manufactured fibres fulfil sound absorption performance, they are more expensive and are not biodegradable composites (Zhu et al., 2014). However, recycled acoustic products can work as well as commercial acoustics products, energy efficiency in the production process must be taken into account for sustainable design. Environmental awareness on sustainable material development has driven the researchers and manufacturers to look for natural fibres (Van Dam, 2009).

2.6 Applications of sound absorptive materials

Sound absorbers are known as soundproof panels that are consumed as a part of numerous uses of acoustical control. They can be used to control the sound field in theatres, in walls or partition dividers or roofs/ceiling of living, structures to build sound protection, to control reverberant sounds in workplaces and indoors, as sound attenuators in pipes, in vehicle’s engine or mechanical compartments. Sound absorption materials are mostly resistive in nature, being fibrous, porous, in rather extraordinary cases, the receptive resonators. Porous materials are convenient as mats, sheets, or preformed elements made of glass, mineral or natural fibres, wood chips, coconut fibres or felted textile or open-cell froth (Vér & Beranek, 2006). These materials can be separated into two groups regarding the relation between their thickness and wavelength of the sound wave. They act as bulk material if the wavelength of the sound wave is in the order of, or shorter than the thickness of the material, or as a sheet if the sound wavelength is long compared to the thickness of the material (Bies & Hansen, 2009).

Viscous effects and area density control the conduct of a sheet while the solid material density, viscous and thermal effects manage the performance of a bulk material. Sheet absorbers can be made of fibres (bonded or reinforced, felted, woven,
contained) or comprised of punctured plates with little openings (holes). The bulk materials are made out of fibres or foams and are available as unbounded fibres, cover blankets or sheets. During the procedure of sound absorption, the composed motion of sound is transformed over into the muddled motion of heat (Fahy, 2000), and there is an exchange between aerodynamic and thermodynamic energy (Cox & D’Antonio, 2009). The extension and rarefaction of air inside the porous materials prompt adiabatic and thermal heat transfer.

In fibrous materials, the stroke of the sound pressure forces the fibres to move, and the fibre twisting and fibre-to-fibre erosion persuades a temperature to expand (Barron, 2002). The majority of the energy losses at high frequencies are because of friction brought about by the oscillation of air molecules and their loss of momentum in the direction of wave propagation, due to changes in flow direction and extension of contraction of the flow through unequal pores (Vér & Beranek, 2006).

A few tests performed by Fangueiro (2011) demonstrated that fibre assemblies that have no air space behind them display different sound absorption characteristics. The viscosity resistance type has the absorption characteristics of porous materials with exceptionally slight sound absorption at low frequencies, however truly significant absorption at higher ones. The fibrous resonance kind of odd fibres, and its absorption qualities at low frequencies (having a peak) while the higher frequency ones extend the conduct similar to the viscosity resistance type. The in-between or mixed type shows characteristics common to the other two types, presenting resonance absorption but no peak. While an air cavity is placed behind the sample, the material has the similar resonance absorption as in the fibrous resonance type, but its absorption does not increase in the higher-frequency range.

2.7 Mechanism of sound absorption in fibrous absorbers

For the past decades, the sound absorption of fibrous material has been discovered. In an investigation by Voronina (1994), it is explained that sound absorption is a result of dissipating incident sound into heat energy. The fibrous absorber is a disruptive media and described as a transducer, changing sound incident wave into thermal form energy as the after-effects of a specific process that identifies with
consistency, viscosity, thermal conductivity, and molecular relaxation (Arenas & Crocker, 2010).

Some sound wave would be in motion inside of being absorbed when a sound wave strikes the surface of the absorbers. This motion of sound waves sets the fibres into vibration. The fibre's vibrations permit air to stream in the spaces between fibre and particles. Some energy loss are impacts of the air motions through limited constraint (Yu et al., 2006). The losses of sound energy demonstrate some sound energy is absorbed into the material through the dissipation process. Dissipation is represented by friction because of the relative velocity between the air and fibres as outcomes of viscous boundary layer impacts. This impact takes to represent the high-frequency losses. The velocity of sound in porous absorbers is lower than in the air. A lower sound velocity within porous material provides the absorption.

The same goes to viscosity; additionally, energy is absorbed by thermal losses as sound transmits through these little openings in fibrous material. Since thermal equilibrium is gained faster, instability in pressure and density are isothermal. The expanding temperature in the gas has transported heat absent from interaction site to disperse. In air-filled sound absorbing materials, the frequency reliance of the compressibility shifts from isothermal at low frequencies to adiabatic in the high-frequency regime (Blackstock & Atchley, 2001). At lower frequency, the absorption effects are brought on by fibres, which are moderately efficient conductors of heat. Furthermore, dissipation can be a consequence of scattering and the vibration of the fibres. The fibres of the material smear up and it is affected by sound waves (Arenas & Crocker, 2010). On the other hand, dissipation because of scattering is ignored; hence, it must be expected that the wavelength is relatively large to the pore size (Biot, 1962; Cox & D’Antonio, 2009).

2.8 Porous Absorber

The absorber type under porous category is the most well-known material utilised as a part of acoustical problem treatment. These materials which could be from mineral or cellulose fibre is a fine sound absorber in the mid to high-frequency range. Usual porous absorbers include floor coverings as carpets, acoustic tiles, acoustic (open cell) foams, drapes, cushions, cotton and mineral wool. The porosity made by the
fibre interstices that can trap and dissipates the sound energy. The frictional resistance change effects, sound energy into frictional heat and viscous losses inside the pores because of fibres vibrations. Energy transformation into heat is the most critical mechanism of sound absorption for a porous material. The energy strength would diminish over the distance travelled through the material. The sound absorption by porous fibres is influenced by the density, the thickness, the air cavity behind the material and the surface treatment (Voronina, 1994; Kutttruff, 2009).

![Diagram of cellular, fibrous, and granular materials](image)

**Figure 2.6:** Three main types of porous absorbing materials (Arenas & Crocker, 2010)

Density variations are known to have a slight impact on sound absorption performance of porous materials. The thicker the porous absorbers, the higher the sound absorption at low frequencies, especially at under 500 Hz. The material thickness of $\lambda/4$ would result in higher sound absorption performance at the regarded frequency (Maekawa & Lord, 2004). This clarifies why the porous materials have
low sound absorption at lower frequency range and get to be higher at higher frequency ranges. Further sound absorption of a porous material can be accomplished at whichever point the porous material is positioned with an air-gap separation where the velocity of the sound waves is maximum, for example, at $\lambda/4$. Acoustically straightforward surface treatment such as acoustic fabric, tissue covering or water-based paint should be able to dissipate the sound absorption of the porous fibre (Xiang et al., 2013). Figure 2.6 shows example and categorises the porous type materials. This study also covers the porous type absorbers especially fibrous materials.

2.9 Natural Fibres

Natural fibres can be characterised as bio-based fibres or fibres from plant, vegetable and animal origin. This definition includes all natural cellulosic fibres (cotton, jute, sisal, coir, flax, hemp, abaca, ramie, etc.) and protein based fibres, for example, wool and silk. These complex proteins based fibres are resistant to most organic acids and certain powerful mineral acids. They constitute the fur or hair that serves as the defensive or protective epidermal covering of animals (Van Dam, 2009). Silk is an exemption to this, which is expelled by the larvae of moths and insects and is utilised to turn their cocoons. It is the only fibre that normally achieves a length of more than 1000 m (Sakthivel & Ramesh, 2013). A few silk fibres can be accumulated to create textile material and staple form is used to manufacture spin yarns.

Excluded here is a mineral fibre, like asbestos that happens naturally, yet it is not a bio-based element (Van Dam, 2009). Asbestos containing products are not considered as economical because of the health hazard which is a well-known health risk that resulted in the prohibition of its utilisation in several nations (Fangueiro, 2011). On the other hand, there are man-made cellulose fibres (e.g. viscose rayon and cellulose acetate) that are delivered with chemical processes from pulped wood or different sources (cotton, bamboo). Also, stimulated (soybean) protein, polymer fibre (bio-polyester, PHA, PLA) and Chitosan fibre are samples of semi-synthetic products that are constructed from renewable resources (Shah et al., 2013).

Normally bast kind fibres are found in the inward bark of certain plant stems; for example hemp, jute, flax, ramie, kenaf, etc. They are comprised of covering cells
of the group in which fibres are bonded together by pectin. They are larger, more lignified and stiffer (Mukhopadhyay, 2014). Banana, sisal, pineapple, abaca and etc. are fibres of leaf origin. These fibres are occurring as a piece of the fibrovascular arrangement of leaves. Bast and leaf fibres are by and large utilised in composite applications. The fibres found in fruits and seeds like that of cotton, kapok, palm oil, coir and etc. are not combined as bundles. These fibres begin as hairs born with the seeds or internal dividers of the fruit, where every fibre consists of a solitary, long, narrow cell. Every single vegetable fibre transcendentally contains cellulose, alongside variable types of substances like hemicellulose, lignin, pectin and waxes. Cellulose resists alkaline and most organic acids yet it can be pulverised by strong mineral acids (Ramadevi et al., 2012). A single fibre has a width of around 10-20 μm. From the living cell, cellulose is shaped as microfibrils of 5 nm diameters, each made out of 30 to 100 cellulose molecules in extended chain compliance and it gives mechanical strength to the fibre. A good orientation of microfibrils along with high cellulose content is an elementary for a fibre with good mechanical properties (Mukhopadhyay, 2014).

In several applications, natural fibres are being engaged primarily as light, cheap and ‘green’ reinforcement material, playing little or no structural role. Excitingly, this is dissimilar to what was visualised in the mid-twentieth century, when the potential of natural fibre as physical reinforcing agents was admitted by inventors like Ford to manufacture the first ‘green car’ with an all plastic body using 70 wt% lignocellulose fibres. Even Ford was capable of demonstrating the strength and impact resistance of their newly found material by famously taking a sledgehammer to hit onto the car’s deck lid (Shah et al., 2013). There is proof that natural fibre still can compete with synthetic fibres which have more performance in mechanical properties.

Moreover, synthetic fibres indeed are injurious to human health. If these fibres were ever inhaled, they can lay down in the lung alveoli, and can cause skin irritation (Al-rahman et al., 2012). Production of these synthetic materials has been known to release significant amounts of CO₂ into the atmosphere compared to naturally made materials (Asdrubali, 2006). Synthetic fibres also create another problem indisposition, which is by being harmful to the global environment (Schmidt et al., 2004). Upcoming Table 2.1 shows that natural fibres offer several economical,
technical and ecological advantages over synthetic fibres. This is one of the major reasons to pick up natural fibre as an alternative to synthetic fibres.

Table 2.1  Comparison between overall Natural Fibres and Synthetic Fibres

<table>
<thead>
<tr>
<th>Properties</th>
<th>Natural Fibres</th>
<th>Synthetic Fibres</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual global production (tonnes)</td>
<td>31,000,000</td>
<td>4,000,000</td>
</tr>
<tr>
<td>Distribution for global fibre reinforced plastic (tonnes)</td>
<td>Moderate (-60,000)</td>
<td>Wide (600,000)</td>
</tr>
<tr>
<td>Cost of raw fibre (RM/kg)</td>
<td>Low (3-10)</td>
<td>High (20-150)</td>
</tr>
<tr>
<td><strong>Technical</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>Low (-1.35-1.55)</td>
<td>High (2.50-2.70)</td>
</tr>
<tr>
<td>Tensile Stiffness (GPa)</td>
<td>Moderate (-30-80)</td>
<td>Moderate (70-85)</td>
</tr>
<tr>
<td>Tensile Strength (GPa)</td>
<td>Low (-0.4-1.5)</td>
<td>Moderate (2.0-3.7)</td>
</tr>
<tr>
<td>Tensile failure strain (%)</td>
<td>Low (-1.4-3.2)</td>
<td>High (2.5-5.3)</td>
</tr>
<tr>
<td>Specific Tensile Stiffness (GPa/g cm³)</td>
<td>Moderate (-20-60)</td>
<td>Low (27-34)</td>
</tr>
<tr>
<td>Specific Tensile Strength (GPa/g cm³)</td>
<td>Moderate (-0.3-1.1)</td>
<td>Moderate (0.7-1.5)</td>
</tr>
<tr>
<td>Abrasive to machines</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Ecological</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption (MJ/kg of fibre)</td>
<td>Low (4-15)</td>
<td>Moderate (30-50)</td>
</tr>
<tr>
<td>Renewable source</td>
<td>Yes</td>
<td>No</td>
</tr>
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<td>Recyclable</td>
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</tr>
<tr>
<td>Biodegradable</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Hazardous / Toxic (upon inhalation)</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2.10 Natural Fibre as Sound Absorbers

Natural fibres have been extensively used to produce environmentally-friendly composite materials. Natural fibres, such as wood, hemp, and coconut shells, hold great potential for substituting the expensive synthetic fibres in manufacturing acoustic absorption boards due to their abundance, low cost to process, and the natural cellular structure, which can effectively absorb acoustic energy (Peng et al., 2015).

In recent times, studied by Fatima & A.R. Mohanty (2011); Asdrubali et al. (2012); Peng et al. (2015) established that composite from natural fibres has a higher sound absorption than synthetic fibres. The absorption properties of sound absorbing materials made of naturally obtain fibres can be similar to those made from minerals (Yang et al., 2015). Those results show that natural fibre composites are likely to be advanced to synthetic fibre composites in most cases for the following reasons:
Natural fibre production has lower environmental impacts compared to synthetic fibre production (Joshi et al., 2004).

Natural fibre composites have higher fibre content for equivalent performance, reducing more polluting base polymer content (Venkateshwaran et al., 2011).

Natural fibre reportedly provides good thermal and acoustic insulator (Mishra & Biswas, 2013).

Despite the many advantages of using natural fibres for composites, they also have some disadvantages. Frequently, natural composites have a lower durability when exposed to the certain environmental condition. They have lower strength properties, high moisture absorption that causes fibre swelling. The detailed advantages and disadvantages of natural fibres are already discussed in Table 2.1. For this study, four kinds of natural fibres were discovered. There are Ijuk (*Arenga pinnata*), Kenaf (*Hibiscus cannabinus*), Coir (*Coco Nucifera*) and Palm oil Frond (*Elaeis guineensis*). Each selected natural fibres are explained in detail in the next section.

2.10.1 Ijuk fibre or *Arenga pinnata*

*Arenga Pinnata* fibre known as Ijuk, are fibres formed from sugar palm. Sugar palm is one of the oldest cultivated plants in Asia. Geologically, it is distributed in all of tropical South and Southeast Asia countries, from India to Guam and from Myanmar to Nusa Tenggara Timur in Indonesia. Naturally, it grows close to human settlements where *anthropochory* breeding is evident. It is a fast growing palm that reaches maturity within 10 years. It has become an enduring match throughout the world and a most economically important plant in Asia. Sugar palm is one of the most diverse multipurpose tree species in culture. Almost of all parts of the tree is daily utilised, since the last decade (Moge et al., 1991).

This multipurpose fibre can be used to make a number of products such as ropes, filters, brushes, brooms, mats, cushions and shelters for the fish breeding pond Moge et al. (1991); Ismail et al. (2010). According to Harish et al. (2009), fibre is the most important fundamental of sugar palm tree in the Philippines. Ijuk fibres are
REFERENCES


