THE APPLICATION ON THE USAGE OF NATURAL FIBERS AS NOISE ABSORBERS

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ABSTRAK

Sistem Penyejukan Udara dan Pengaliran Haba (HVAC) adalah salah satu sistem penyaluran yang biasa ditemui untuk membuat penghuni bangunan selesa dengan mengawal aliran suhu dan udara. Walau bagaimanapun, bunyi bising yang dihasilkan di dalam sistem dan mencapai penghuni di dalam bangunan, sekaligus menyebabkan gangguan, ketidakselesaan dan keresahan. Terdapat penyenyap bunyi di pasaran, namun bahan penyerap bunyi yang digunakan adalah jenis *mineral wool*. Kajian ini memberi tumpuan kepada penyenyap saluran dengan bahan menyerap bunyi yang dibuat dari sabut Kelapa, Arenga Pinnata (Ijuk), Kenaf, Kapas dan Rockwool. Semua komposisi bahan ini telah diuji untuk mengenal pasti prestasinya. Objektif kajian ini adalah untuk membandingkan kehilangan sisipan di HVAC dengan menggunakan pelbagai konfigurasi bahan. Bahan-bahan telah diuji secara berasingan pada pelbagai frekuensi untuk menentukan kesan aliran udara ke hadapan dalam sistem HVAC pada kehilangan penghantaran dan untuk menganalisis kesan kehilangan sisipan pada keadaan lurus dan bengkok dalam sistem saluran HVAC. Ujikaji dijalankan mengikut standard ASTM E477. Dalam ujikaji ini, bahan menyerap bunyi sabut Kelapa dan berbeza konfigurasi telah dikaji terlebih dahulu, diikuti dengan bahan-bahan menyerap bunyi yang lain iaitu Arenga Pinnata (Ijuk), Kenaf, Kapas dan Rockwool. Secara keseluruhan dari keputusan dan perbandingan, semua bahan yang dikaji pada saluran lurus dan bengkok menunjukkan prestasi yang sama di mana pada frekuensi bawah 500 Hz, kehilangan sisipan adalah tinggi pada frekuensi yang tertentu sahaja. Kehilangan sisipan meningkat berterusan dari 500 Hz sehingga 6300 Hz dan stabil sehingga frekuensi 10000 Hz dalam lingkungan 6 dB hingga 40 dB. Kehilangan sisipan meningkat apabila bilangan bahan penyerap bunyi bertambah di dalam penyenyap bertambah tetapi konfigurasi 4 keping telah dipilih sebagai konfigurasi yang terbaik kerana aliran udara adalah lebih tinggi kira-kira 60% berbanding dengan konfigurasi 5 keping. Kehilangan sisipan 30g Rockwool yang

digabungkan dengan 30g Kapas adalah lebih tinggi berbanding dengan bahan-bahan yang lain iaitu secara puratanya 44.8% lebih tinggi daripada Rockwool sahaja, 44.1% lebih tinggi daripada Kapas sahaja, 35% lebih tinggi daripada Kenaf sahaja, 81.4% lebih tinggi daripada gabungan Arenga Pinnata dan Kenaf, 65.1% lebih tinggi daripada sabut Kelapa sahaja, dan 118.9% lebih tinggi daripada Arenga Pinnata sahaja. Kehilangan sisipan pada saluran lurus dan bengkok yang telah dianalisis menunjukkan bahawa saluran bengkok memberikan kehilangan sisipan lebih pada purata 47% berbanding saluran yang lurus.

ABSTRACT

The Heat Ventilation Air Conditioning System (HVAC) is one of the ducting systems that are commonly found to make occupants in the building comfortable by controlling the temperature and air flow. However, noise is produced in the system and reaches the occupants inside the building, thus causing distraction, discomfort and uneasiness. There are HVAC silencers in the market, however the typical sound absorbing material used is mineral wool types. This research focuses on the ducting silencer with the sound absorbing material that made from Coconut fiber, Arenga Pinnata (Ijuk), Kenaf, Cotton and Rockwool. The compositions of these materials have been tested to identify its performance. The objective of this research is to compare the insertion loss in the HVAC by using various configurations. The materials have been tested separately at various frequencies to determine the effects of the forward airflow in the HVAC system in the transmission loss and to analyse the affect of the insertion loss on the straight and bend in the HVAC duct system. The experiment that was carried out follows the standard ASTM E477. In this experiment, the sound absorbing material of Coconut fiber with different configuration has been investigated, followed by other types of sound absorptive materials such as Arenga Pinnata (Ijuk), Kenaf, Cotton and Rockwool. From the overall result and comparison, all the materials that tested on straight and bend ducting showed the same performance trends where at below frequency of 500 Hz the insertion loss was high at certain frequency only. The insertion loss increases steadily from 500 Hz until 6300 Hz and maintained until frequency 10000 Hz at around 6 dB to 40 dB. The insertion loss increase as the numbers of sound absorptive materials in the silencer increase but the 4 pieces configuration has been chosen as the best configuration because the air flow was higher around 60% compared to configuration of 5 pieces. The insertion loss of 30g Rockwool combined with 30g

Cotton was higher compared to other materials which are averagely 44.8% higher than Rockwool alone, 44.1% higher than Cotton alone, 35% higher than Kenaf alone, 81.4% higher than combination of Arenga Pinnata and Kenaf, 65.1% higher than Coconut fiber alone, and 118.9% higher than Arenga Pinnata alone. The insertion loss at straight and bend ducting that was analysed showed that the bend ducting gave more insertion loss at an average of 47% than the straight ducting.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

%	-	Percent
^{o}	-	Degree
α	-	Sound Absorption Coefficient
^{o}C	-	Degree Celsius
ASTM	-	American Society for Testings and Materials
(C6H10 O5)n	-	Cellulose Polymer
cm	-	Centimeter
c/f	-	Wavelength
CO_2	-	Carbon dioxide
GFRP	-	Glass Fiber Reinforced plastic
h	-	Height
HVAC	-	Heat Ventilation Air Conditioning
Hz	-	Hertz
IL	-	Insertion Loss
ISO	-	International Organization for Standardization
kg	-	Kilogram
KPa	-	Kilo Pascals

L	-	Length
m	-	Meter
mm	-	Millimeter
MPa	-	Mega Pascal
N	-	Newton
NaOH	-	Sodium Hydroxide
NR	-	Noise Reduction
NRC	-	Noise Reduction Coefficient
OAR	-	Open Area Ratio
PMC	-	Polymer matrix composites
PU	-	Polyurethane
PUF	-	Polyurethane foam
SEM	-	Scanning Electron Microscopy
s	-	Seconds
TL	-	Transmission Loss
TLF	-	Tea Leaf Fiber
UF	-	Urea-formaldehyde
w	-	Width

CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, comfortness has been considered as a main issue in a modern building. This issue, however can be realized by using mechanical application such as the Heat Ventilation Air Conditioning (HVAC) system. HVAC system makes the building occupants comfortable by controlling temperature and air flow based on the climate of the area building located. In spite of that, it produces noise which later could distract the occupants. In this case, fans, ducts, and diffusers are the potential source of noise. Excessive air speed, poor ductwork design, and improper diffuser selection can all contribute to this noise problem. On the other hand, HVAC systems run continuously and can provide a covering background noise that increases acoustical privacy.

The noise that produced in HVAC system is reduced by using a silencer which works as noise absorber. The noise that generated in HVAC system is reduced by the existence of the silencer in the system and maintains the comfort of the occupant in the certain building. The typical used material as the absorbing silencer in the HVAC is Rockwool.

Three types of the method applied in noise control application. Those are noise control at source of the noise, noise control in the path of transmission and noise control at the end of the duct system (D’Alessandroa & Pispolab, 2005).

Noise control at source depends on conceptual understanding of noise that radiated from vibrating bodies. The action can be taken on this vibrating body that produce noise to eliminate or minimize the noise effects.

While in the noise control of transmission path, most of the times only minor direct control at source level is permitted. Based on the Sound Research Laboraory (1991), there are two conventional techniques available which are the dissipative and reactive techniques. Dissipative devices are untuned frictional devices which can convert acoustic energy into heat energy and they are able to filter out acoustic energy over a wide range of frequency. While the reactive devices are essentially tuned devices which rely on the tuned element for their operation. The reactive devices normally can be used only for fixed speed machinery noise consisting of pure tones.

In the noise control at receiver end using protective measures, the personal protective devices are used such as an earplug and earmuff. The exposure of noise can be controlled through shift duty.

1.2 Problem Statement

The Heat Ventilation Air Conditioning (HVAC) system is used in most buildings to regulate temperature, humidity and supply fresh air from outdoors. HVAC have a bigger responsibility in maintaining comfortable with the people inside the building but yet it has also created a negative effect to the peoples in the building through the noise created by the HVAC system.

The noise transmitted in the HVAC system through the HVAC duct and also directly from the noise source to the room or building. The noise transmitted through the HVAC duct wall will create uncomfortable for people in the room or building.

This research is focused on the effectiveness of the natural fibers in order to decrease the noise in the HVAC system and to improve the existing of the air ventilation to become more comfortable and convenient for human being.

1.3 Objectives

The objectives of this research are:

(i) To compare the insertion loss at the HVAC at various frequencies when natural fiber dissipative silencer is used.

(ii) To determine the performance of the dissipative silencer with different configurations.

(iii) To determine the performance of the dissipative silencer with different combination of natural fibers.

(iv) To compare the effect of the insertion loss and air flow after bending in the HVAC system.

1.4 Scope of Study

This research focuses on the effectiveness of the natural fibers in the dissipative silencer in order to decrease the noise in the HVAC system and to improve the existing of the air ventilation to become more comfortable and convenient for peoples. Scopes of this research are:

(i) The material used as sound absorbing material are:

- (a) Coconut fiber
- (b) Arenga Pinnata
- (c) Kenaf
- (d) Cotton
- (e) Rockwool
- (f) Arenga Pinnata combined with Kenaf
- (g) Cotton combined with Rockwool

(ii) The types of configuration for dissipative silencer used are horizontal baffle, vary and different silencer.

(iii) The noise frequency used is 1/3 octave band.

(iv) The experiment conducted by considering air flow.

(v) The HVAC duct used in the experiment is straight and ‘T’ bend type.

1.5 Potential Contribution

Dissipative silencer is widely used in industrial nowadays to eliminate the noise that produced by all the moving and vibrating bodies in the machines. Most of the time, due to the various loads that applied on the machine, the frequency of noise that produced by these machines are always varied from time to time, which means these noise that produced have wide range of frequency. So, in this case, the dissipative silencer is the best solution for the noise control method that as stated above which is noise control at the path of transmission.

The dissipative silencer consists of sound absorbing material. From previous research, the Coconut fiber, Arenga Pinnata, Kenaf, Rockwool and Cotton has the ability to absorb noise. The study of dissipative silencer that made of natural fibers can help in further utilize the use of raw material. This can help in reducing the cost of purchasing the dissipative silencer that made of other materials that are more expensive than these fibers.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Coconut Fiber

Coconut trees normally can be seen cultivated in the tropical region of the world such as Malaysia, Indonesia, Philippine and other tropical countries. The product from coconut tree is mainly applied in food and non-food products that used to sustain the livelihood of people around the world. According to Waifielate (2008), there are four main components in a coconut which are husked, skin, shell and copra.

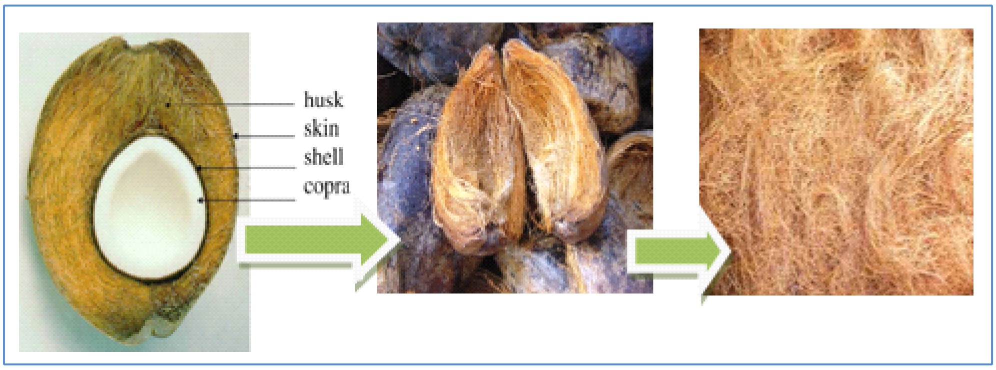

Figure 1: Cross section of coconut, component and fiber (Waifielate, 2008)

This study used the husk of the coconut to produce the fiber. The husk of the coconut comprises of 30% weight of fiber and 70% weight of pith material. Several methods such as retting, decortications, mechanical and chemical process can be used to extract the fiber from the husk.

There are several relevant and important qualities that the coconut fiber is used as one of the materials chosen in this study. The coconut fiber is a renewable resource and it is a CO_2 neutral material. The coconut fiber is abundant in our country and also very cheap. Unlike many other materials like polymer, the coconut fiber is biodegradable, low in density and it is light weight.

The main constituents of coconut fiber are cellulose, hemicelluloses, lignin and other vital substances. Compare to the other natural fiber, the coconut fiber has a high percentage of lignin by volume. The high percentage of lignin makes the coconut fiber very tough and stiffer when compared to the other natural fibers. This is because the lignin helps to provide the plant tissue and the individual cells with compressive strength and also stiffens the cell wall of the fiber where it protects the carbohydrate from chemical and physical damages. Besides that, the lignin also influences the structural properties, flexibility and hydrolysis rate. The coconut fiber looks fine and has a higher flexibility due to the high percentage of lignin (Waifielate, 2008).

2.2 Arenga Pinnata (Ijuk)

Arenga Pinnata or Ijuk is a natural fiber that obtained from the palm sugar tree (Ismail *et al.,* 2010). Arenga Pinnata is available in Southeast Asia like Malaysia and Indonesia. The products that mainly made are used in traditional application such as rope, broom, carpet and sofa cushion (Bachtiar, 2008) and is obtained directly from natural resources and it is also cheap.

Arenga Pinnata fiber is collected from the palm tree (Bachtiar, Sapuan & Hamdan, 2010) and cleaned with water then its let it dried at room temperature. The dry fiber used in the applications such as dissipative silencer (Ismail *et al.,* 2010).

Figure 2.2: Arenga Pinnata (Bachtiar *et al*., 2010)

Arenga Pinnata fiber is tested for sound absorb ability where the sound absorption coefficient is studied. Impedance Tube Method is used to test the material and by referring to the test standard stated in ASTM E1050-98. The Arenga Pinnata fiber thickness has been varied and test done within the frequency of 150 Hz – 6000 Hz (Ismail *et al.,* 2010).

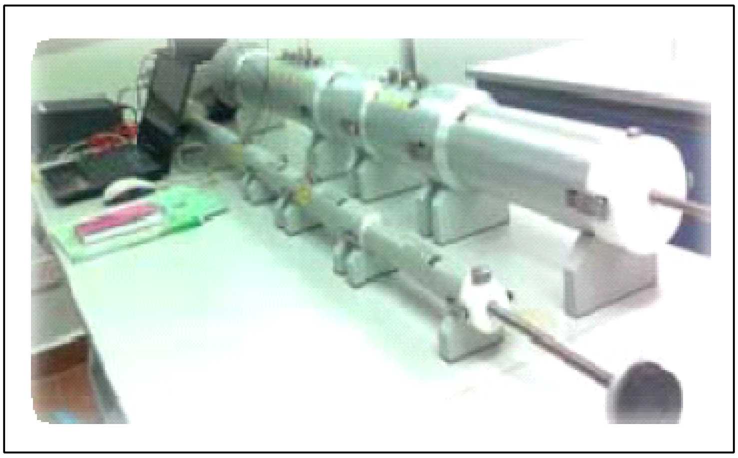

Figure 2.3: Impedance Tube Equipment

The sample that tested which is an Arenga Pinnata fiber is being cut into the cylindrical shape to fit in the impedance tube and the test conducted. Arenga Pinnata fiber has been tested sound absorption ability and it has shown ability as dissipative absorber. When the thickness of the silencer made of Arenga Pinnata fiber has increased the sound absorption coefficient also increases (Ismail *et al.,* 2010).

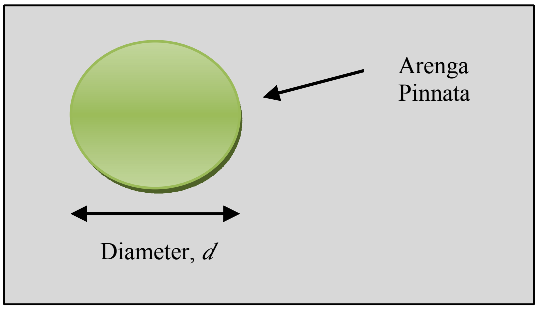

Figure 2.4: Shape of Arenga Pinnata fiber test sample for Impedance Tube Test (Ismail *et al.,* 2010)

Where:

d = 100 mm for the frequency range from 150 Hz to 1600 Hz

d = 28 mm for the frequency range from 1600 Hz to 6000 Hz

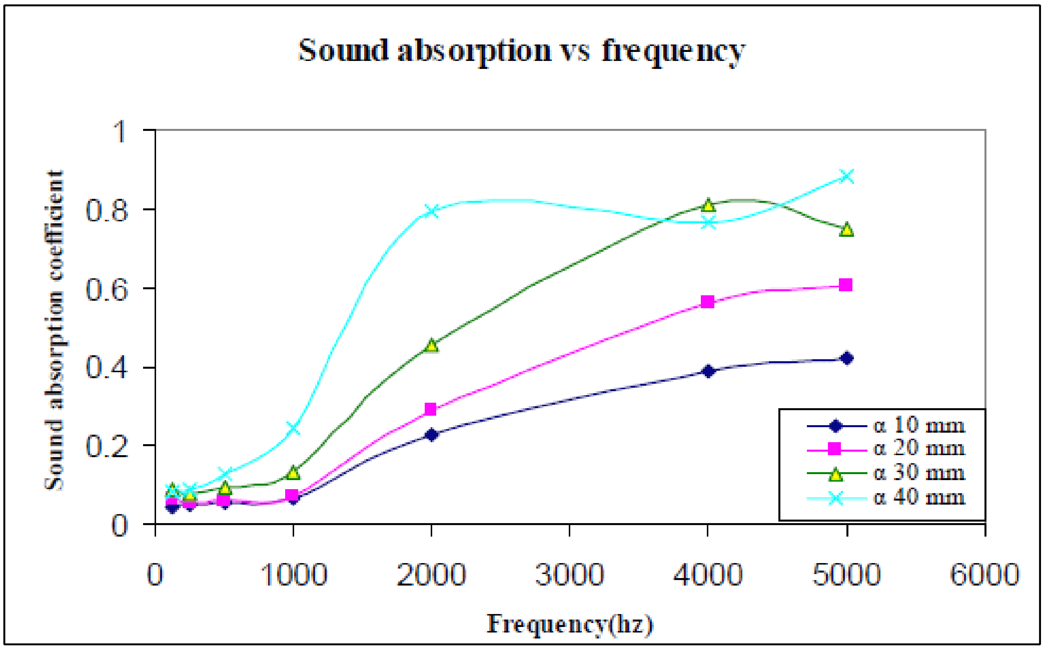

Figure 2.5: The sound absorption of Arenga Pinnata fiber (where α is the thickness of the material) (Ismail *et al.,* 2010)

From Figure 2.5, we can see that when the thickness of the sound absorbing sample increases the sound absorption coefficient also increase. The thickness increase causes the space available that is the cross section area of the material is big that makes more sound energy to be absorbed.

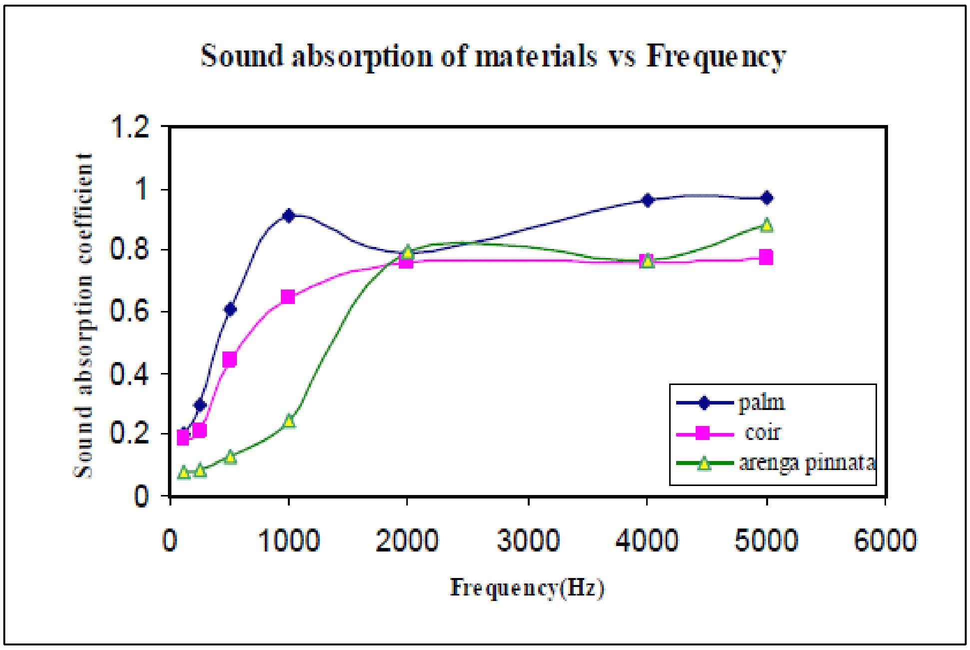

Figure 2.6: Comparison sound absorption coefficient of Arenga Pinnata fiber with Palm and Coir fibers (Ismail *et al.,* 2010)

From Figure 2.6, it shows that Arenga Pinnata fiber has a low sound absorption compare to Palm fiber and Coir fiber for frequency range 0 Hz to 2000 Hz. From frequency range from 2000 Hz to 2500 Hz Palm fiber has the highest sound absorption coefficient compare to the other two materials. Arenga Pinnata fiber has increase slightly higher sound absorption coefficient than Coir fiber from frequency range 0 Hz to 5000 Hz.

The result above shows that the Arenga Pinnata has the sound absorbing ability. The sound absorption coefficient is high where between the ranges of 0.75 to 0.90 when the frequency range is 2000 Hz to 5000 Hz.

Arenga Pinnata is suitable as a raw material to be used as dissipative silencer or sound absorbing material with a low cost, light and biodegradable.

2.3 Kenaf

Kenaf (Hibiscus Cannabinus L.) is a type of hibiscus plant and is a member of the Malvaceae family. It can grow to a height of 2.5 m to 5 m in 4 to 5 months. Kenaf mainly cultivated for its fiber. The fiber from Kenaf has best resemble fiber and suitable for jute fiber. Fiber strands are 1.5 m to 3 m long. It is usually used to make rope, canvas, sacking, carpet backing and fishing net (Gowda, 2010).

Kenaf is a natural fiber which has advantages such as renewable, environmental friendly, low cost, low density, flexibility of usage and biodegradable. Kenaf is one of the important sources of fiber in many applications. Kenaf have the ability to be a reinforced fiber in thermosets and thermoplastic composites (Mohd Yuhazri, Phongsakorn & Sihombing, 2010).

The stems of Kenaf produce two types of fiber. Those are 'bast' which is a coarser one and 'core' which is a fine one. The Kenaf comprises 35% of bast fiber and 65% core fiber. Bast fibers used to produce textile, paper and rope. Coir fiber is used as biomass or it can be reduced to particles and bonded into panels similar to particleboard (D'Alessandroa & Pispolab, 2005).

Kenaf fiber contains impurity in its fiber structure. The fiber structure of the Kenaf scanned using scanning electron microscope (SEM) machine. The impurity can be seen on the image scanned by SEM. SEM provides an excellent technique for examination of surface morphology of fiber and fracture surfaces of fiber composites. The existence of impurity can be observed in SEM micrograph of Kenaf (Mohd Yuhazri *et al.,* 2011).

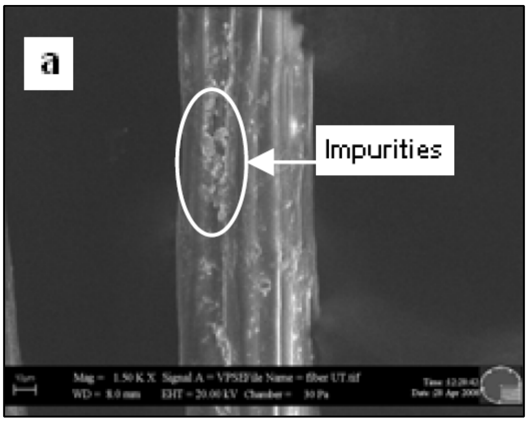

Figure 2.7: SEM micrograph of Kenaf (Mohd Yuhazri *et al.*, 2011)

Impurity can be observed in the SEM micrograph. However the impurity can be removed by treat the fiber. For example, to increase its mechanical strength, Kenaf fiber treated with sodium hydroxide (NaOH), which causes morphological changes in the Kenaf fiber (Mohd Yuhazri *et al.*, 2011).

Figure 2.8: Kenaf that planted in rows

Figure 2.9: Bast fibers (left) and Core fibers (right)

A composites reinforced with Kenaf bast fibers are having higher tensile, flexural and impact properties than Kenaf core fibers composite (Ishak *et al.*, 2010).

Table 2.1: Fiber dimension of Kenaf fibers (bast fiber and core fiber) (Ishak *et al.*, 2010)

Kenaf fibre	Length (mm)	Diameter (μm)	Lumen dia. (μm)	Cell wall thickness (μm)
Bast fibre	2.32 ± 0.21	21.9 ± 4.6	11.9 ± 3.4	4.2 ± 0.8
Core fibre	0.74 ±	22.2 ± 4.5	13.2 ± 3.6	4.3 ± 0.7

In this research, bast fiber of Kenaf is going to be used as the material for dissipative silencer because it is more suitable as a sound absorber.

A research carried out by D'Alessandro & Pispolab (2005), Kenaf show an averaged absorption coefficient 0.85 in the 500-5000 Hz range and equal to 0.55 in the 100-500 Hz range. Although Kenaf showed a slightly poor performance as a sound absorber, it can be an alternate to the traditional mineral wool blanket for thermo-acoustic application since its beneficial properties of low impact on human health and on the environment.

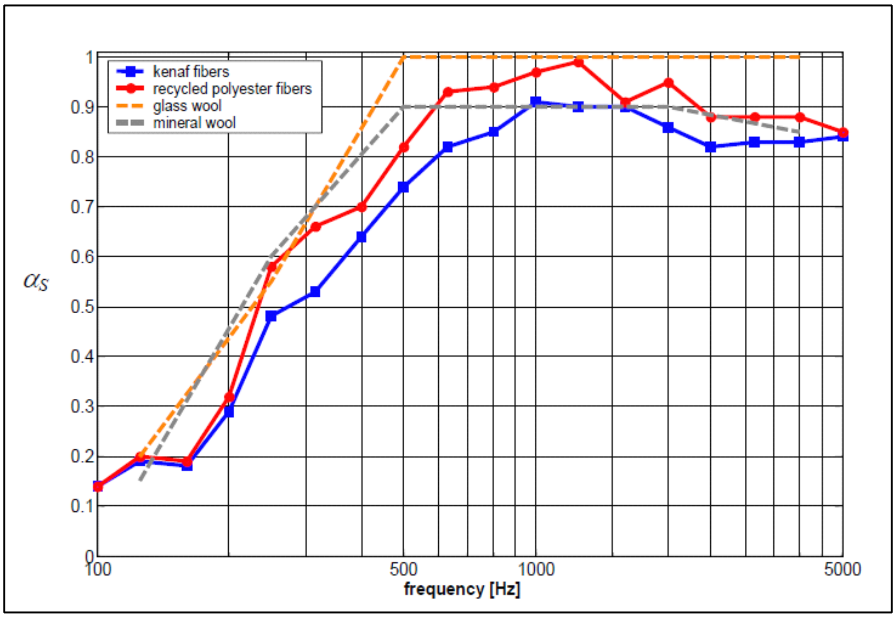

Figure 2.10: Third-octave band sound absorption coefficient α of Kenaf and recycled polyester fibrous blanket in comparison with traditional fibrous Absorber (D'Alessandro & Pispolab, 2005)

Table 2.2: Third-octave band sound coefficient of the tested samples (D'Alessandro & Pispolab, 2005)

Frequency [Hz]	100	125	160	200	250	315	400	500	630
α_S kenaf	0.14	0.19	0.18	0.29	0.48	0.53	0.64	0.74	0.82
α_S PET	0.14	0.20	0.19	0.32	0.58	0.66	0.70	0.82	0.93

Frequency [Hz]	800	1000	1250	1600	2000	2500	3150	4000	5000
α_S kenaf	0.85	0.91	0.90	0.90	0.86	0.82	0.83	0.83	0.84
α_S PET	0.94	0.97	0.99	0.91	0.95	0.88	0.88	0.88	0.85

From Table 2.2, when frequency increase the sound absorption coefficient also increase. This shows that Kenaf is a dissipative absorber type of sound absorber.

2.4 Cotton

Cotton is the most widely used natural fiber which is one of the natural cellulose fibers which obtained from plants which come out from the seed. There are many species of Cotton such as Upland Cotton, Egyptian Cotton, Asian and African Cottons (Zhang, 2007).

The type of Cotton fiber that will be used in this research is type of Cotton from Kapok tree- *Ceiba Pentandra.*

Figure 2.11: Kapok tree (*Ceiba-Pentandra*) and kapok seed

From Figure 2.11, the Cotton fiber is unicellular and it develops from the epidermal cell of the ovule (seed after maturation).

2.4.1 Cotton Fiber Structure

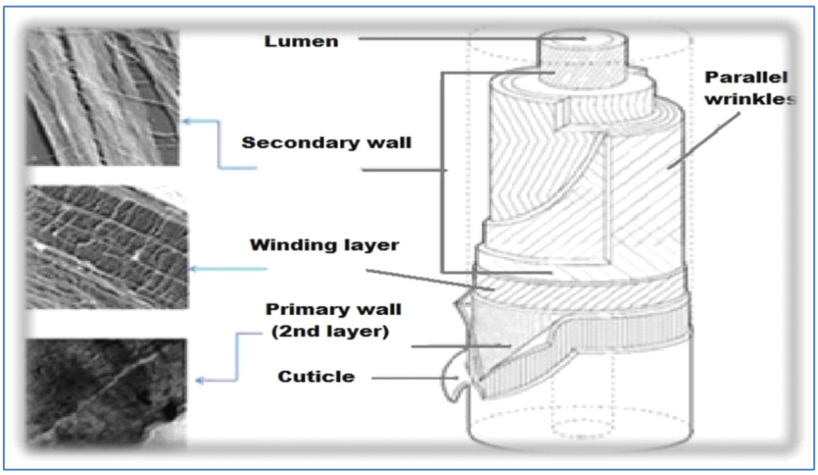

Figure 2.12: Cotton fiber structure (Seagull, 2000)

Cotton fiber is a linear polymer, cellulose polymer (C6H10 O5)n. From Figure 2.12, Cotton fiber has a hollow structure that helps increase surface area and porosity. In general, dry porous media saturated with air were capable of reducing the level of ambient noise (Jiang, Chen, & Parikh, 2009).

In order to increase the sound absorption coefficient, the textile material should be designed such that porosity will increase along the propagation direction of the sound wave (Shonshani & Yakubov, 2000).

There are several relevant and important qualities why Cotton fiber being studied in this study. The Cotton fiber has a high porosity material and high sound absorption coefficient. It is also easy to find and cheaper.

Besides that, in term of physical properties, the Cotton fiber is Hygroscopic Nature which is very absorbent and all the properties of cotton are listed in the Table 2.3 which it can be seen that the Cotton component contains the higher cellulose which consist of 80-90%.

Table 2.3: Raw Cotton Component (Russo, 2001)

80 - 90%	Cellulose
6 - 8%	Water
0.5 - 1%	Waxes and fats
0 - 1.5%	Proteins
4 - 6%	Hemicelluloses and Pectin's
1 - 1.8%	Ash

Table 2.4 is the data from previous research done by Van Rijswijk, Beukers & Brouwer (2001) which classified all the natural fiber properties. The moist absorption of the Cotton is higher among the eight natural fibers and related to the moist in the HVAC system which is the lowest degree of moisture. With an ability to absorb moisture, the Cotton also has an ability to absorb noise.

Table 2.4: Properties of natural fibers compare to the properties of glass fibers (Van Rijswijk *et al.*, 2001)

Property	Glass	Flax	Hemp	Jute	Ramie	Coir	Sisal	Cotton
Density [g/cm^3]	2.55	1.4	1.48	1.46	1.5	1.25	1.33	1.51
Tensile strength [N/mm^2]	2400	800-1500	550-900	400-800	500	220	600-700	400
Stiffness [kN/mm^2]	73	60-80	70	10-30	44	6	38	12
Elongation at break [%]	3	1.2-1.6	1.6	1.8	2	15-25	2-3	3-10
Moist absorption [%]	-	7	8	12	12-17	10	11	8-25
Price of raw fibre [$/kg]	1.3	0.5-1.5	0.6-1.8	0.35	1.5-2.5	0.25-0.5	0.6-0.7	1.5-2.2

2.5 Rockwool

Rockwool is a mineral wool bonded with Urea Extended Phenol Formaldehyde Resin. It is made from natural or synthetic minerals through the process of moulting rock at a temperature about 1600°C through steam of air.

Figure 2.13 shows the Rockwool fiber that have been widely used as thermal insulation, pipe insulation and noise insulation.

Figure 2.13: Rockwool fiber

2.5.1 Chemical and Physical properties of Rockwool

Rockwool inert vitreous silicate wool bonded with the resin and coating up to 0.2 % mineral oil as dust suppressant and water repellent. The resin content varies across the product range from 0.3 % to 3.3 % by weight. The melting point for Rockwool is in excess of 1000 °C and it insoluble in water.

Table 2.5 shows the physical properties of the Rockwool compare to the other materials which are steel and ceramic fiber (Lee & Liu, 2006). The Rockwool have density 60 kg/m^3, thermal conductivity is under 0.047 W/m°C and its melting point is under 650 °C.

Table 2.5: Properties of steel and fiber protection materials (Lee & Liu, 2006)

	Steel	Ceramic Fiber	Rock Wool
Density (kg/m^3)	7850	80	60
Thermal Conductivity (W/m°C)	52	0.047	Under 0.047
Melting Point (°C)	Over 1500	Over 1200	Under 650

In overall, from Table 2.6 shows that the materials will be carried out in this experiment has the ability to absorb noise. The absorption coefficient for Coconut fiber is 0.42 at a frequency of 500 Hz and Kenaf is 0.74. The Cellulose has a higher sound absorption coefficient which is at peak 1 at the frequency of 500 Hz. Cotton consist of 80 - 90 % of cellulose and this value can be used as a references that Cotton will have a good result for the sound absorption coefficient. The Rockwool also has a good absorption coefficient, which is 0.95 at frequency 500 Hz. The combination of Kenaf and Arenga Pinnata, also Cotton and Rockwool will produce the most efficient silencer.

Table 2.6: Acoustic and thermal properties and cost of some traditional natural insulating material (Asdrubali, 2006)

	Thermal conductivity λ (W/mK)	Rel. resistance to vapour flux μ (–)	Absorption coefficient α_S at 500 Hz (-)	Index of reduct. of impact noise ΔL_W (dB)	Cost (€/m^2)
Hemp	0.04	2	0.6 (30 cm)	-	5
Kenaf	0.044	2	0.74 (5 cm)	-	-
Coco fiber	0.043	18	0.42	23	-
Sheep wool	0.044	3	0.38 (6 cm)	18	-
Wood wool	0.065	5	0.32	21	12
Cork	0.039	12	0.39	17	19
Cellulose	0.037	2	1 (6 cm)	22	-
Flax	0.040	1	-	-	7
Glass wool	0.04	-	1 (5 cm)	-	12
Rock wool	0.045	-	0.9 (5 cm)	-	6
Expanded polystyrene	0.031	100	0.5	30	10

2.6 Sound Absorption Coefficient

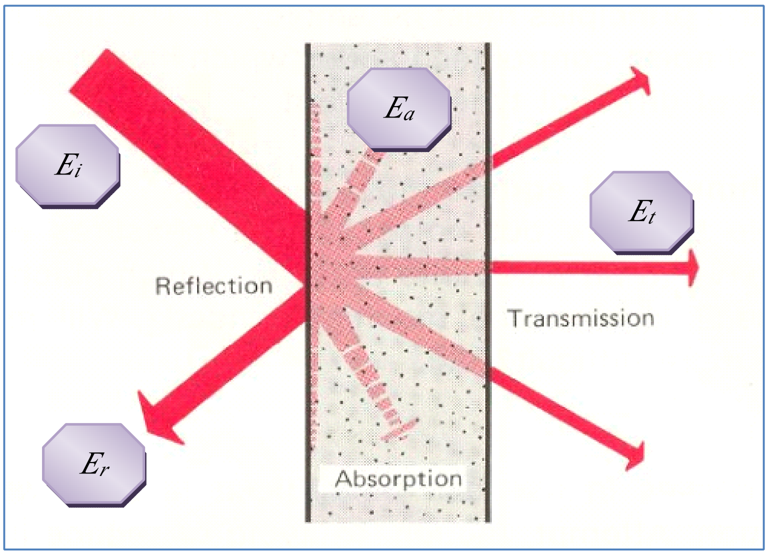

Figure 2.14: Reflection, absorption and transmission at a barrier

The sound absorption coefficient of a material is the fraction of randomly incident sound energy that is absorbed or otherwise not reflected by the material. The energy absorbed is usually being converted into another form of mechanical energy which is normally heat energy. The sound absorption coefficient is defined as the ratio of the amount of energy absorbed to the sound energy incident. It is a dimensionless quantity, expressed as a number from 0 to 1.0 (i.e. 0 % to 100 % absorption efficiency respectively). It is denoted by α. The higher the coefficient number, the better is the absorption. The absorption coefficient varies considerably with frequency. Absorption coefficients for some common materials are appended.

$$E_i = E_t + E_a + E_r \qquad (2.1)$$

Where:

E_i is energy incident

E_t is energy transmitted

E_a is energy absorbed

E_r is energy reflected

When a sound wave hit on an acoustic material, it will be absorbed and the reflected energy will be depend on the material sound absorption performance.

$$\alpha = \frac{E_i - E_r}{E_i} = \frac{E_a - E_t}{E_i} \tag{2.2}$$

For example, if the sound absorption coefficient is 0.75, it means 75% of the incident acoustic energy that strike at the material is absorbed. However, a material can have more than one sound absorption coefficients. The sound absorption coefficient of a material varies with the frequency. Normally, it is common practice to list the coefficients of a material at frequencies of 125, 250, 500, 1000, 2000 and 4000 Hz (Harris, 1994).

An analogy, if one wishes to contain water (contain sound in noise control), an imperious material would be the more suitable material to use for the container (enclosure in noise control) like shown in Figure 2.15 (a). But if one wishes to absorb excess water (absorb excess sound in noise control), the porous material would be the more suitable sponge to use in mopping up water (absorbing the sound in noise control) as shown in Figure 2.15 (b).

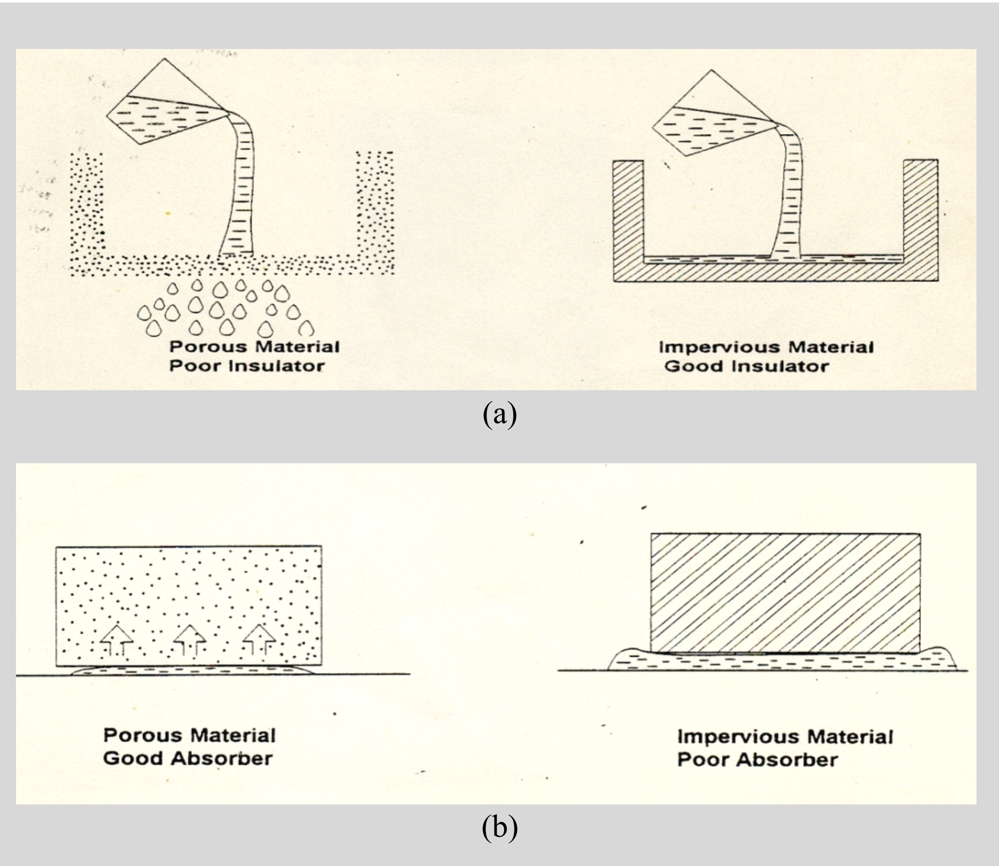

Figure 2.15: (a) Insulator (b) Absorber

In sound absorbing materials according to Singal (2005), there are three types of sound absorber that are commonly known, which are dissipative or porous absorber, membrane or panel absorber, and a cavity or Helmholtz resonator absorber.

(i) Dissipative or porous absorbers

Examples of the dissipative absorbers are such as glass fiber or mineral wool blanket, open cell foam and acoustic tile type materials. These materials are called dissipative absorber because the sound energy is dissipated in the interstices in the fiber. The maximum efficiency of the dissipative absorber at high frequencies where the wavelengths of sound are comparable with a typical thickness of these materials that used in practice.

(ii) Membrane or panel absorbers

The membrane absorbers convert sound energy into heat. Due to the rise of temperature, it result the bending deformation associated with the vibrations of the panel which are excited by the incident sound. The effectiveness of the membrane absorbers is higher at lower frequency.

(iii) Cavity or Helmholtz resonator absorber

The Cavity or Helmholtz resonator absorber can provide a very high absorption coefficient. However, it works at a very narrow band of frequencies. These types of absorbers are not widely used. They are well used in the industrial applications where it is necessary to reduce the effect of pure tones.

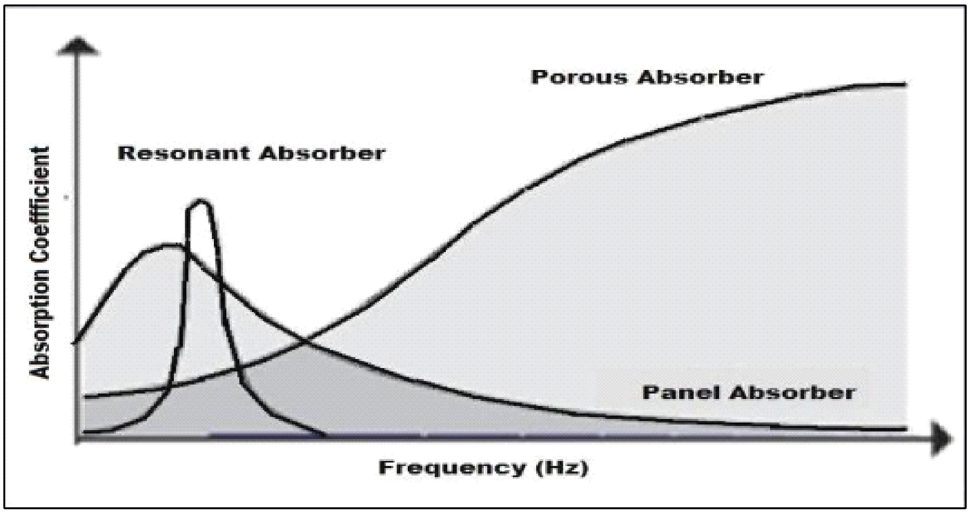

Figure 2.16: Absorber curve from resonant, porous and panel absorber (Amstrong World Industries, 1999)

Three types of sound absorbers which have a different sound absorption characteristics graph as shown in Figure 2.16. The porous or dissipative absorber has its maximum efficiency at high frequency, while the cavity or resonant absorber has very high absorption coefficient but only effective at a very narrow band of frequencies. The membrane or panel absorber has an effective noise absorption at lower noise frequencies.

2.6.1 Factors Influence Sound Absorption Coefficient

Some factors that may affect the sound absorption coefficient of the material such as thickness of the material, air gap and perforated panel have holes drilled in the material surface panel.

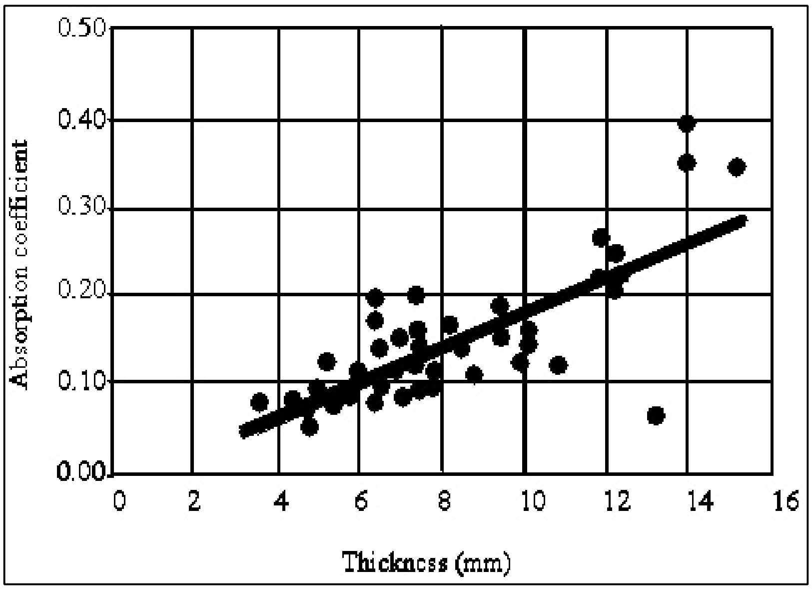

Figure 2.17: Relationship between the thickness and sound absorption coefficient (Seddeq, 2009)

From Figure 2.17, it shows that at the thickness of 14 mm, the highest value of sound absorption coefficient is 0.40 peaks. The effect of the thickness of the material proved that the thicker material would give the better sound absorption coefficient values.

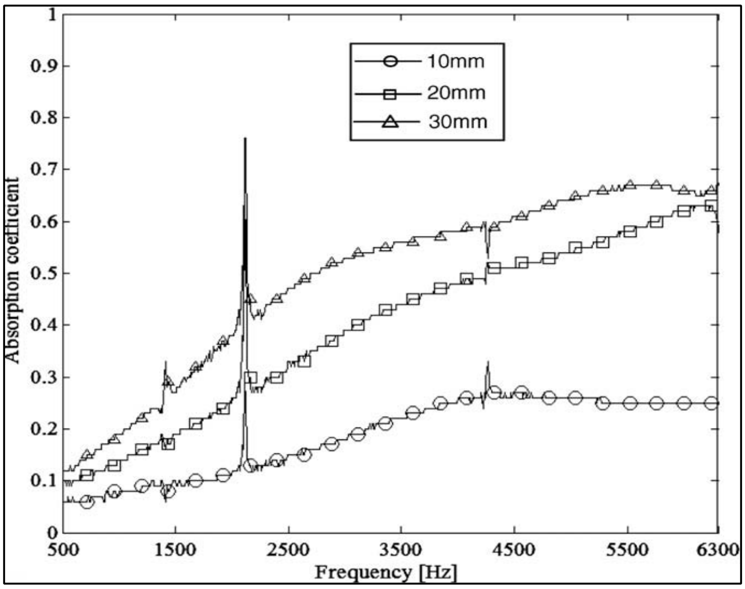

Figure 2.18: Sound absorption coefficient of the Tea Leaf (Sezkin & Haluck, 2009)

Figure 2.18 shows that the TLF sample of 10 mm thickness exhibits a maximum sound absorption coefficient of 0.26 in the frequency range from 4000 to 6300 Hz. At 20 mm thickness at the frequency of 6300 Hz, the sound absorption coefficient was at peak 0.6. At 30 mm thickness, the sound absorption coefficient is reaching peak 0.7 at frequency 6300 Hz. This shows that when increase the thickness the sound absorption coefficient also increased.

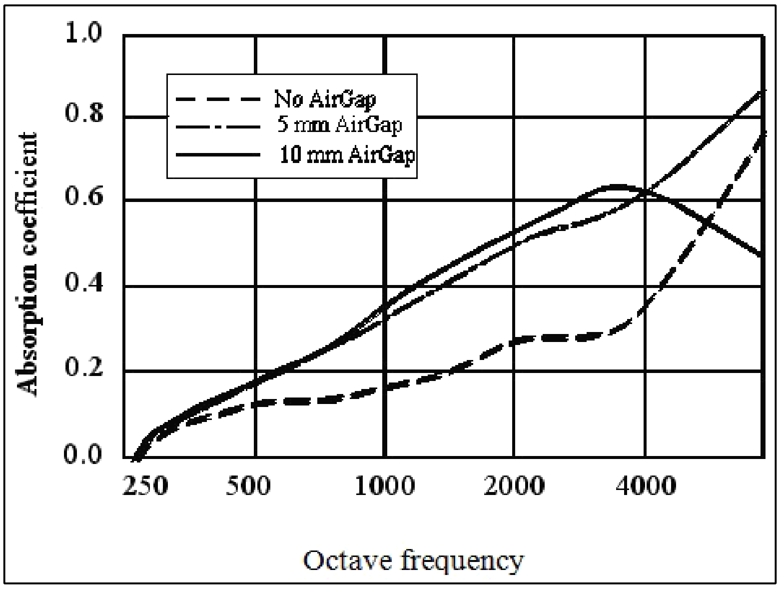

Figure 2.19: Influence of the air gap (Seddeq, 2009)

Seddeq (2009) also found out that the use of air gap give better values for sound absorption coefficient in the impedance tube testing. From Figure 2.19, the creation of the air gap increases the sound absorption coefficient value in the middle and higher frequencies, in spite of showing minima at certain frequencies. There are not many differences between 5 mm air gap sample and 10 mm air gap sample.

Moreover, maximum peak for differences air gap is different (higher the air gap, the maxima the peak shift toward lower frequency). This indicates an optimum value for an air gap beyond which there is not much influence seen in sound absorption properties.

The 10 mm air thickness at octave frequency more than 3000 Hz the sound absorption coefficient was decrease and can conclude that the air gap give good sound absorption coefficient for some material at certain frequencies.

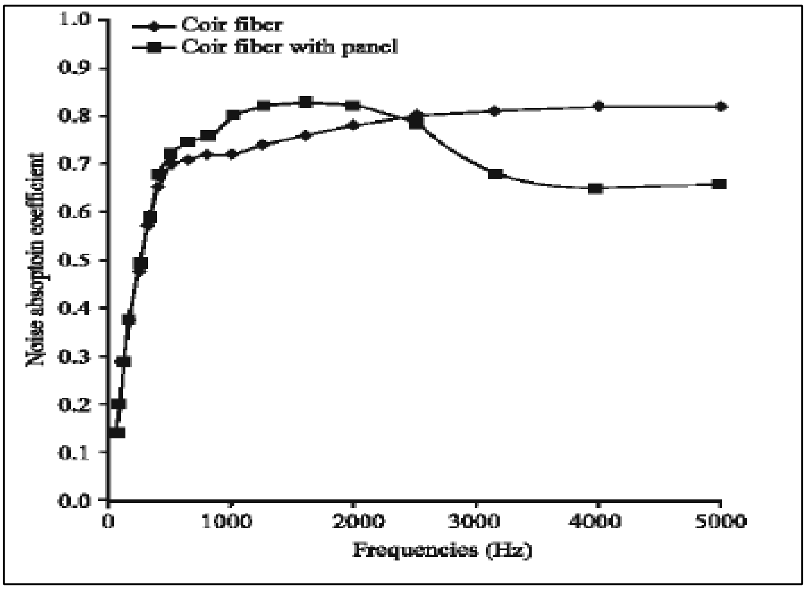

Figure 2.20: Comparison of Coir fiber with and without perforated panel (Zulkifli *et al.,* 2008)

Figure 2.20 shows that the Coir fiber perforated panel shows higher sound absorption coefficient compared to the plain Coir fiber for the range 500 Hz to 2500 Hz. For the frequencies more than 2500 Hz, the Coir fiber without panel give higher coefficient index.

The highest coefficient index for Coir fiber with perforated panel is in the range 0.7 to 0.85 for the frequency of 500 Hz to 2500 Hz. While the Coir fiber without panel is around 0.8 for the range 2500 Hz to 5000 Hz. Perforated panel design requires holes to be drilled on the panel surface.

2.7 Noise Reduction Coefficient

Another term employed to describe the absorption properties of a material is the Noise Reduction Coefficient (NRC). The NRC of a material is the average value sound absorption coefficients (α) of the material at the frequencies of 250, 500, 1000, 2000 Hz. To prepare specifications for a material that used for noise control in the building, it is normally used as a convenience (and must be used with caution as it averages out information on absorption efficiency at different frequencies).

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \tag{2.3}$$

2.8 Sound Insulation

When sound is propagated inside a room (or enclosure) some amount of the sound energy incident to the boundary will be transmitted through the boundary element (i.e. a partition, wall, or appropriate building element) to the adjacent spaces. The transmitted sound will result in a new sound field which may (or may not) cause noise problems. The ability of a partition to limit the flow of sound energy through it is termed its sound insulation, and this is largely determined by its weight (or more specifically, its mass).

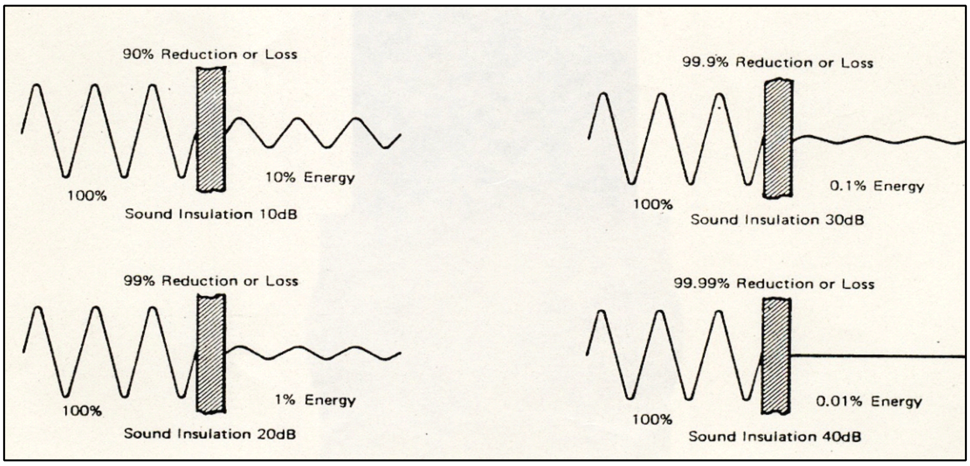

Figure 2.21: Sound insulation efficiency and resulting sound insulation

The sound insulation will be simply represented by the difference in the average sound pressure levels in the two rooms (or enclosure) at any given frequency.

$$\textit{Sound Insulation} = (L_1 - L_2)dB \qquad (2.4)$$

Where:

L1 = SPL in the sound source room

L2 = SPL in the adjacent receiving room

The effectiveness of any structure as an insulator is determined by the following four parameters:

(i) Weight
(ii) Homogeneity and uniformity
(iii) Stiffness
(iv) Discontinuity or isolation

Difference between sound absorption and sound insulation are shown in Table 2.7. A good sound insulating material is usually a poor sound absorber.

Table 2.7: Difference between sound absorption and sound insulation

NO.	SOUND ABSORPTION	SOUND INSULATION
1	Ability to absorb acoustic energy (sound).	Ability to minimize the transmission of acoustic energy through the material.
2	Absorbent materials are relatively light-weight and porous.	Sound insulating materials are of reasonable to heavy mass and impervious.

2.9 Dissipative Silencer

The dissipative silencer is also known as a muffler or dissipative attenuator. The silencer is an engineering device that's designed to attenuate sound waves propagating in a flowing medium. A silencer is for reduction of the sound power level of a fan, an airflow noise, or other sound source transmitted along a duct-borne path or airborne path. The dissipative silencer is a straight-through device with the passageway lined with acoustical absorbing material.

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