ANALYSIS OF SOUND INSULATION OF TRIM MATERIALS IN CAR USING KENAF FIBRES WITH SEA

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A report submitted
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DECLARATION

I declare that this project report entitled "Analysis of Sound Insulation of Trim Materials In Car Using Kenaf Fibres With SEA" is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....

Supervisor's Name : ....

Date : ....

DEDICATION

الله الرحمن الرحيم

To my beloved mother and father

ABSTRACT

Customers require a suitable car and a comfortable atmosphere of disturbing noise generated from outside the vehicle. Therefore, the automotive industry has supplied sound insulation materials using synthetic materials such as felt fibres. Materials used are substances that affect chemicals and are not environmentally friendly. The purpose of project study as the alternative to conventional synthetic materials as sound insulation. Kenaf is a fibre made up of natural fibre has been selected to replace existing materials. To prevent noise from outside the vehicle, with the advantages of kenaf fibres capable of replacing the existing fibres as a sound insulation material. Simulation tests and experiments have been made to prove kenaf fibres capable of replacing existing materials.

ABSTRAK

Pelanggan mahukan kereta yang sesuai dan suasana yang selesa daripada terganggu bunyi bising yang terhasil daripada luar kenderaan. Oleh itu, industri automotif telah membekalkan bahan penebat suara dengan menggunakan bahan sintetik iaitu serat felt. Bahan yang digunakan adalah bahan yang mempengaruhi bahan kimia dan tidak mesra alam. Tujuan tesis ini dibuat adalah untuk menggantikan serat yang sedia ada dengan serat semulajadi. Kenaf adalah serat yang terdiri daripada bahan semulajadi telah dipilih untuk menggantikan serat yang sedia ada. Bagi menghalang bunyi bising daripada luar kenderaan, dengan kelebihan yang ada pada serat kenaf mampu untuk menggantikan serat yang sedia ada sebagai bahan penebat suara. Ujian simulasi dan uji kaji telah dibuat bagi membuktikan serat kenaf mampu untuk menggantikan bahan yang sedia ada

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LIST OF ABBREVIATIONS

SEA	Statistical Energy Analysis
TPNR	Thermoplastic Natural Rubber
EPDM	Ethylene Propylene Diene Terpolymer
PLA	Poly (Lactic Acid)
PLLA	poly-L-lactic acid
CFC	Chlorofluorocarbons
CLF	Coupling loss factor
VA	Vibro-acoustic
DLF	Damping loss factor

LIST OF SYMBOL

i	=	Ability balance for a system
j	=	Subsystem
$Pinj,i$	=	The input power to the subsystem
$Pdiss,i$	=	The power dissipated through internal damping
Pi,j	=	The power transmitted from subsystem
Ei	=	Vibrational energy
Ni	=	Number of modes
ηij	=	Damping loss factor (DLF)
I	=	Intensity
Si	=	Total surface
αSi	=	Absorption area
Co	=	Speed of sound
Vi	=	Volume of cathe vity
Sp	=	Panel of surace
τd	=	Transmission coefficient
$pexc$	=	Power in cavithe ty
ρo	=	Air density
ηi	=	Modal density
S'	=	Total surface area
L'	=	Total length of all edges
V	=	Volume
w	=	Width
h	=	Height
d	=	Depth of the cubic volume
f	=	Frequency
$\Delta\omega$	=	Number of frequencies
Ei	=	Total sound energy

Er	=	Sound energy reflection
Et	=	Sound energy transmission
α	=	Ratio of absorbed sound energy

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the customer requires suitable vehicle systems with optimization intensity on vehicle noise and vibrations characteristics. Noise and vibrations of motor vehicles are progressively imperative for the automotive industry, especially for vehicle producers and component suppliers. The exterior sounds are usually controlled by sound pollution constitution, while internal noise and vibration feel highly valued by customers themselves (Dejan and Vladimir, 2016).

Noise is characterized as any repulsive or startling sound created by a vibrating object and has increasing importance to vehicle users and situations. Vibration is characterized as any frightful repetitive motion of an object, back-and-forth or up-and-down and represents an imperative issue closely related to reliability and quality of the vehicle (Dejan and Vladimir, 2016).

For existing materials inside the car's cabin is called felt which is the material that composed of wool that is mixed with synthetic. The combinations of the fibre for felt include wool and polyester or wool and nylon. Synthetics cannot be turned into felt by themselves but can be felted if they combine with wool (Giollo and Ann, 1981; McDowell and Colin, 1993). Felt material is represented as a synthetic fibre and becomes excellent sound insulator because of having a superb vibration damping. It is made of chemical resistant and cannot be recycled.

The objective of this project is to study the feasibility of kenaf fibres as sound insulation materials in the car, an alternative to the conventional trim materials which is felt. In another word, kenaf is called 'Hibiscus Cannabinus'. Hassan et al. (2017) mention that the plant of the kenaf fibre native to East-central Africa. It is existence for nearly 4000 years ago. The potential of kenaf is easy to grow and high photosynthesis rate. Moreover, kenaf has been used as a building material for board production. In the year 2000, kenaf was first introduced to Malaysia with the name 'National Kenaf and Tobacco Board (NKTB)'. The current policy is to plant kenaf to replace tobacco at tobacco farms. The purpose of the replacement is to control and regulate tobacco. Kenaf has a very high potential to grow where it can reach 3.7 – 4.7 meters in 4 weeks. Basri et al. (2014) mention that tangkai kenaf plant consists of two types of fibres that are very useful. For outer part is called kenaf bast fibre and the inner part is called kenaf core fibre. Besides that, Mansor et al. (2013) mention that kenaf represents as one of the natural fibre and have good potential in several advantages and also known as environmentally friendly.

Recently, the study of the kenaf fibres as sound insulation remains lacking. This research is about to replace the conventional trim material inside the car cabin with the natural fibre which is kenaf.

1.2 Problem Statement

The research is made to reduce the sound from the outside of the car to get into the interior compartment. To block the noise from entering the interior of the car, barriers and other treatments have been used. For the interior of the vehicle, kenaf fibre and conventional trim materials have applied to dissipate sound and thus reduce the overall sound pressure level. The thickness of the material is directly related to the effectiveness of sound insulation (Zent and Long, 2007).

More recently, issues related to global warming caused by the emission of greenhouse gases into the atmosphere by the industrial manufacture of materials may change the acoustical materials market. The production of conventional trim materials contributes to the release of carbon dioxide mostly from power plants and transport, methane, nitrous oxide and others Therefore, the amount of greenhouse gas emissions set directly and indirectly by the production of materials affects its carbon footprint, which may become increasingly important in the consideration of future world trade (Arenas and Crocker, 2010). Consumers are more in favour of eco-friendly materials, less contaminating processes, and recycling of products as they have been aware of and concern about the negative effects of pollution.

Natural fibres can be vegetables such as cotton, kenaf, hemp, flax, wood, and etc. For the animal, such as wool, fur felt or mineral such as asbestos. Conventional trim material which is synthetic fibres can be cellulose such as bamboo fibre. For mineral is fibreglass, mineral wool, glass wool, graphite, ceramic, and etc. For the polymers, such as polyester, polypropylene, Kevlar, and etc.

Obviously, sound absorbers made from natural fibres such as kenaf can be easily recycled, and their production involves low carbon footprint and no CFC release so they can be classified as ecological green building materials.

There is no research about using kenaf fibre as sound insulation in the car prior to my research. The main purpose of using kenaf fibre is to make kenaf fibre as sound insulation inside the car cabin.

1.3 Objective

1. To develop statistical energy analysis (SEA) model of 'rough' body-in-white car structure.
2. To study the feasibility of kenaf fibres as insulation materials in the car, as an alternative to the conventional trim materials.
3. To perform an experiment to take a measurement of transmission loss using impedance tube.

1.4 Scope

The scopes in this project are:

1. Only plate panel is considered.
2. In this work structural vibration and noise transmission, the interior part of the vehicle is studied.
3. The main focus is on the computation of absorption and transmission loss of the SEA panels, the approximations used and the way pass-through are included in the model.
4. The kenaf fibre is only tested on a sedan car.

CHAPTER 2

LITERATURE REVIEW

2.1 Building The SEA

Elliot et al. (1988) reported SEA can be a great tool for acoustic designs to predict the reactions and power flows between model elements.

Pinnington and White, (1981) mention that generally configured between the noise and vibration source and the rest of the complex structure, the project of the vibration isolation system is to reduce the flow of noise and vibration. Calculation of vibration transmission structures is performed as part of the calculation of sound and vibration transmission through complex structures. The vibration isolation system is a mechanism for transferring noise and vibration.

Most studied in Souli et al. (2015) said that in the SEA system method is considered to be divided into linear outlines subsystems and convert energy through resonant vibration mode. The subsystem may be a dash, floor, doors, firewall and etc. In the automotive industry with similar modes, and wherever the main variable is energy.

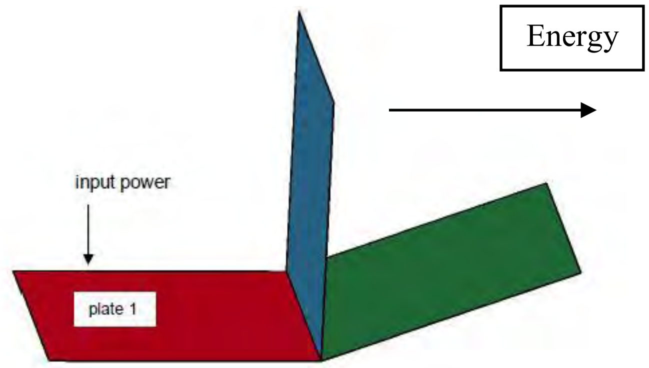


Figure 2.1: SEA subsystem (Souli et al., 2015)

Figure 2.1 shows the SEA subsystem may be a dash, floor, doors, firewall and etc. In the automotive industry with similar modes, and wherever the main variable is energy.

2.2 Model Development

The development of the Statistical Energy Analysis (SEA) model depends on energy storage in the structure and also the coupling type between the substructures. According to Lafont et al. (2016), there is no general definition of SEA subsystem. A subsystem is just outlined as a group of modes wherever the energy is equally distributed. A subsystem dissipates energy exchanges energy with the other subsystems. The equation governing the ability balance for a system i *is*

$$P_{inj,i} = P_{diss,i} + \sum_j P_{i,j} \tag{2.0}$$

Where $P_{inj,i}$ the input power to the subsystem from external sources is, $P_{diss,i}$ is the power dissipated through internal damping, $P_{i,j}$ is the power transmitted from subsystem i to a neighbouring subsystem j through the mechanical coupling. All powers are time averaged.

Power dissipation in a subsystem is given by

$$P_{diss,i} = \eta_i \omega E_i \tag{2.1}$$

The power dissipated and

$$P_{ij} = \eta_{ij} \omega N_i \left(\frac{E_i}{N_i} - \frac{E_j}{N_j}\right) \tag{2.2}$$

The power transmitted from i to another subsystem j. E_i is the mean vibrational energy, N_i is the number of modes, η_i and η_{ij} are called damping loss factor (DLF) and coupling loss factor (CLF).

2.3 Acoustic Cavity On Plate Panel

The dissipation in an acoustic cavity describes in terms of absorption coefficient α or absorption area. For a closed cavity i with a total surface S_i, the absorption area is αS_i. From the statistical energy analysis (SEA) point of view, the dissipation is represented by a damping loss factor (DLF). The power dissipated in a cavity i is given by the absorption area and the intensity, I by $P_{diss,i} = \alpha S_i . I$

Then, The DLF is

$$\eta_i = \frac{S_i C_o}{4\omega V_i} \alpha \tag{2.3}$$

where C_o is the speed of sound and V_i the volume of cavity i.

Let us look at two cavities separated by a panel. The incident wave from cavity i is transmitted via the panel of surface S_p to cavity j. The wave attenuation is characterized by the diffuse transmission coefficient τ_d.

Then, the coupling loss factor (CLF) between i and j is

$$\eta_i = \frac{S_i C_o}{4\omega V_i} \tau_d \tag{2.4}$$

In the case of a simple two cavities system, the energy in cavity j is deduced from the power balance equation,

$$E_j = \frac{p^2{}_{exc} V_j S_p}{4 \rho_o C_o{}^2 S_j} \frac{\tau_d}{\alpha_j} \tag{2.5}$$

where p_{exc} is the power in cavity i and ρ_o the air density, it is worth emphasizing how the absorption and transmission coefficients are distributed in the statistical energy analysis (SEA) Eq. (2.3) and (2.4) and the way they characterized the energy of receiving cavity. From Eq. (2.5) it is ascertained that the reduction of energy in cavity j will be obtained by a transmission coefficient τ_d diminution or by an absorption coefficient α_j augmentation.

2.4 Modal Density

Modes are an important part of statistical energy analysis (SEA) and occur once the multiple of the wavelength of a subsystem and also the dimensions of the subsystem match. When this happens the amplitude becomes larger because of constructive interference between waves travel within the subsystem. Modes also can be referred to as resonances. The modes within a subsystem receive, store and transfer energy.

The modal density η_i of a subsystem is defined as the number of modes per unit frequency. Modal density is required to calculate the symmetric matrix or the consistency relationship. If the coupling loss factors in both directions between all subsystems in a system are already known, the modal density is not required for predictions in statistical energy analysis (SEA) using general matrix form equation.

$$\begin{bmatrix} P_i \\ P_j \\ \vdots \\ P_n \end{bmatrix} = \omega \begin{bmatrix} \eta_i & \eta_{ji} & \cdots & -\eta_{ni} \\ -\eta_{ij} & \eta_j & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ -\eta_{in} & \cdots & \cdots & \eta_n \end{bmatrix} * \begin{bmatrix} E_i \\ E_j \\ \vdots \\ E_n \end{bmatrix} \tag{2.6}$$

where η_i the modal density, the general matrix and the symmetric is basically the same except that the energy is currently described as the modal energy rather than energy as in the general matrix. The modal energy is defined as the energy in the subsystem divided by the modal density. The advantage of describing the matrix in a symmetric form is that the consistency relationship may be used. The consistency relationship states the relation between two subsystems modal energies and their coupling loss factors as shown in Eq. (2.5).

$$\eta_i \eta_{ij} = \eta_j \eta_{ji} \tag{2.7}$$

To derive the modal density of a subsystem, the geometrical information about the allowed mode shapes are combined with the dispersion relation for free waves in the subsystem. For a 2-dimensional subsystem the modal density can be calculated from:

$$n\,(\omega) = \frac{s_k}{2\pi C_g} \tag{2.8}$$

For a 3-dimensional subsystem the equation to calculate the modal density will look like:

$$n\ (\omega) = \frac{1}{2\pi}\left(\frac{2\omega f V}{c^3{}_o} + \frac{\omega S\prime}{4c^2{}_o} + \frac{L\prime}{8c_o}\right) \tag{2.9}$$

S' is the total surface area, L' is the total length of all edges and V is the volume. These parameters can for a cubic volume be calculated as:

$$s' = 2(wd + dh + wh) \tag{2.10}$$

$$L' = 4(w + d + h) \tag{2.11}$$

where w is the width, h the height and d the depth of the cubic volume. An acoustic cavity behaves as a two-dimensional subsystem depending on the frequency and depth of the cavity. The frequency used to determine whether the subsystem is two or three dimensional can be found below.

$$f = \frac{c_o}{2l} \tag{2.12}$$

where C_o is the speed of sound in the fluid and l is the depth of the cavity. Below the calculated frequency, the subsystem acts sort of a two-dimensional subsystem and above as a three-dimensional subsystem.

The modal density can be used to calculate the number of modes in a specific frequency band which is used to calculate the energy per mode often referred to in statistical energy analysis (SEA) context. It is given by (Craik and Robert J.M., 1996).

$$N = n(\omega)\Delta\omega \tag{2.13}$$

where $\Delta\omega$ the number of frequencies is contained in the frequency band and η is the modal density.

2.5 Acoustic Absorber

According to Ver and Beranek (2006), the noise control system can be categorised into 3 components, which are a source of noise, noise propagation path and receiver. Thus, the noise can be controlled or reduced at the noise source, along the noise propagation path by using noise barriers or at the receiver by using active noise control. The following are types of absorber which usually used to control the noise at the noise propagation path.

2.5.1 Porous Absorbing Materials

The porous absorbent material is a sound absorber which usually has good sound absorption properties at the centre and high frequency. The natural porous sound absorber can be found in a living room environment such as curtains, carpets, fibres, woven cloth, furniture, ceilings and unpainted brick walls (Everest, 2001; Cox and D'Antonio, 2005; Jacobsen et al., 2011). All natural porous sound absorbers show one similar characteristic, which is an open structure. Thus, Jacobsen et al. (2011) define porous material with its open structure, which allows the flow of air into and through the materials. The existence of the porous structure in the materials will create flow resistivity, which will limit the penetration of air in porous materials. The level of the flow resistivity or flow resistance will be determined by the density of the porous materials. Within the interior structure of porous materials, the surface of the porous material will act as a sound energy absorber, which is caused by the friction that occurs between the surface of the porous material and the sound waves carried by the flowing air molecules (Cox and D'Antonio, 2005). The law of conservation of energy is applied where the sound energy is converted to heat energy (Everest, 2001). Thus, the sound energy is attenuated or reduced.

Porous absorbing materials can be classified as cellular, fibrous, or granular (J. Arenas and Crocker, 2010). Fibrous porous materials can be found in the form of mats, boards or panels made of glass, mineral or natural fibres. Cellular porous materials can be found in the form of metal foam such as aluminium foam absorber, which is usually found in the automotive and aircraft industry. There is a difference between fibrous and cellular material. The fibrous sound absorbers provide a high absorption coefficient over a wider range of frequencies. On the other hand, cellular foam shows a higher stiffness, good energy absorption and fire resistance compared to the fibrous porous material. For granular materials, sound-absorbing panels are made of granular materials such as wood-chip, sand, gravel or soil mixtures with binders

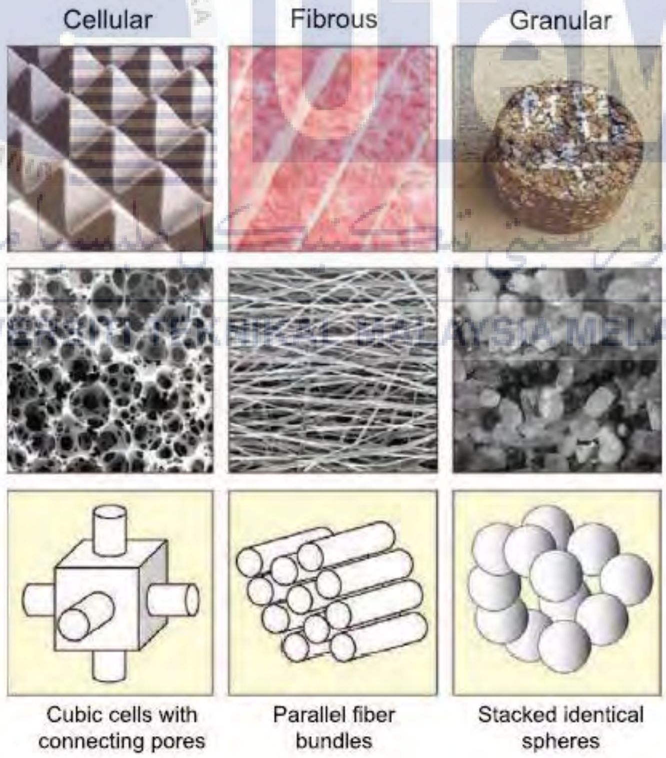


Figure 2.2: The three main types of porous absorbing materials (Arenas and Crocker, 2010)

2.5.2 Porous Fibrous Materials

Fibres can be classified as natural or synthetic. Usually, in the automotive industry, synthetic fibres will be treated as a conventional trim material. Natural fibre materials are basically completely biodegradable and the development of modern technology has made natural fibre processing more economical and environmentally friendly. Most sound absorption and thermal isolation are using synthetic fibres made of minerals and polymers. However, a significant carbon footprint is due to petrochemical sources made of high-temperature extrusion and synthetic chemical based industrial processes. The sound absorption material using kenaf fibres has received a lot of attention recently. These new methods can lead to increased use of high-quality fibres at competitive prices for industrial purposes. The absorption properties of the sound absorbing material made from this fibre can be the same as those made from minerals. These features can be modified with pre-treatment such as drying, carbon, impregnation, and mineralization. In addition, natural fibres are also safer for human health than most mineral synthetic fibres, as they do not require precautionary measures to handle.

In general, the diameter of natural fibres tends to be larger than the diameter of synthetic fibres obtained by extrusion. It is clear that natural fibres have a more irregular shape and diameters vary from synthetic fibres.

According to Arenas and Crocker, (2010), Kenaf (Hibiscus cannabinus) is a different plant that is cultivated in the U.S. and is related to cotton. Its fibres have been used to strengthen concrete and other composite materials for construction applications and for materials used in the automotive industry. Mixes such as natural kenaf fibres, polyester fibres for reinforcement, and natural fire-resistant products are materials made for thermal isolation and acoustic absorption, are now commercially available.

2.6 Absorption Coefficient, Flow Resistivity, Porosity and Tortuosity

This section describes the definitions of important terms such as absorption coefficients, flow resistivity, porosity and tortuosity. This term will be widely used in this thesis to discuss and analyse sound absorption performance behaviour.

2.6.1 Absorption Coefficient

The most powerful sound absorption mechanism for porous sound absorption materials is similar to each other. When sound waves strike porous materials, three types of transformation occur for sound energy: reflection, absorption and transmission. The total sound energy can be considered as the amount of energy reflected, absorbed and transmitted (Cao et al., 2018)

$$E_i = E_r + E_a + E_t \qquad (2.14)$$

where E_i is the total incident sound energy, E_r is the sound energy of reflection, E_a is the sound energy of absorption, E_t is the sound energy of transmission. Sound absorption coefficient α is used to quantify the dissipation abilities of porous sound absorption materials, which can be tested by impedance tube or reverberation chamber. α is described as the ratio of absorbed sound energy to the total incident sound energy:

$$\alpha = 1 - \frac{E_r + E_t}{E_i} = \frac{E_a}{E_i} \tag{2.15}$$

Generally, the sound absorption coefficient is defined as the material's efficiency in absorbing sound (Everest, 2001). Sound absorbed through the conversion of acoustic energy into thermal energy due to the drag force caused by friction between the surface and the structure of porous or fibrous material and fluid, i.e. air (Ver and Beranek, 2006). Figure 2.2 illustrates the reflection, transmission and absorption of sound waves through a porous layer. To maximize sound absorption, sound reflection should be kept as low as possible. Therefore, the incident noise energy that enters the sound absorber must be attenuated or reduced before the sound wave reflects from the surface of the material absorbs the sound and the rigid backing wall, and then disseminates to the receiver (for an example microphones and human ears).

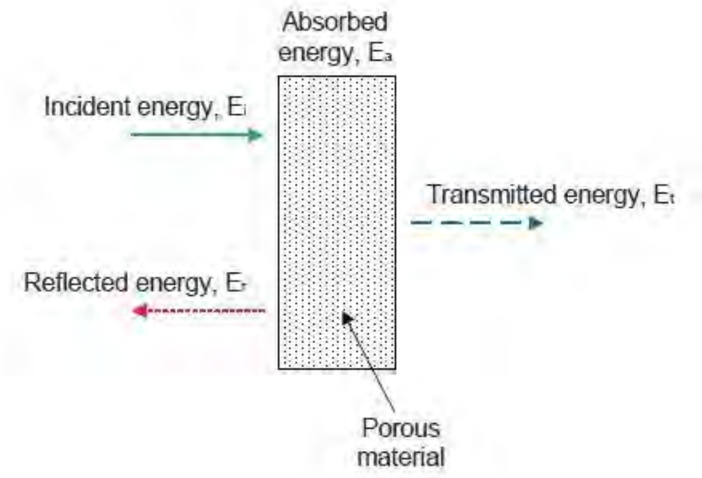


Figure 2.3: Illustration of the incident sound energy which has been reflected, transmitted and absorbed (Ver and Beranek, 2006).

2.6.2 Porosity

Porosity is the ratio of the total of the pore volume V_{pore} to the total of the sound absorber VT, given by $\emptyset = \frac{V_{pore}}{VT}$ (Fahy, 2000; Allard and Atalla, 2009; Hopkins, 2007). Good sound absorption usually has a high porosity of more than 98% (Cox and D'Antonio, 2005). In application, the tolerable values of porosity for sound absorber are at least 85% (Crocker, 2007).

2.6.3 Tortuosity

Tortuosity represents the complexity of the path in the absorber (including the pores) which also determines the effectiveness of sound absorption (Cox and D'Antonio, 2005). The value of tortuosity is usually approximate unity for fibrous materials.

2.6.4 Flow Resistivity

Materials made of fibres may be regarded as porous materials that have interconnecting or cavities (Asdrubali et al., 2015). In the porous absorber, how the sound energy is lost through the internal structure of the material because the boundary layer effect is represented by a parameter called flow resistivity. It is a measure of how easy the air can enter the absorber (Cox D'Antonio, 2005). According to Bies and Hansen, (2003), the flow resistivity and density can be approximated to have a linear relationship in a fibrous absorber.

2.7 Kenaf In Industry

According to Basri et al. (2014), the National Kenaf and Tobacco Board has taken the opportunity to replace tobacco with kenaf. Besides that, the kenaf plant suits life in a variety of climates and soil. It is capable of producing good results if it is in hot weather and wetlands. The goodness of kenaf is it has an eco-friendly nature and recyclable plants.

Kenaf plants have a variety of uses especially in opening a new sheet for the fibre industry in Malaysia. Among the yields of kenaf include gunny sack, rope, textile, craft, building material, non-woven and geotextile and etc. Kenaf has a very strong influence in the textile industry as well as in automotive. Due to its excellent features, many industries use kenaf as a sound absorption but not in sound insulation.

Figure 2.4: Kenaf Plant (Lim et al., 2018)

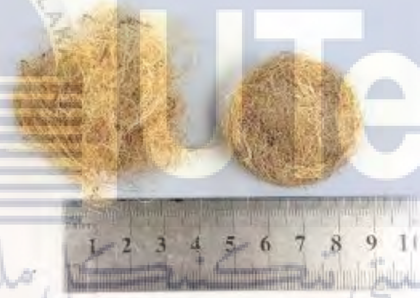


Figure 2.5: Kenaf fibres (Lim et al., 2018)

2.8 Method of Using Kenaf

Compared to other plant fibre types, kenaf fibres become more potent as both kenaf bast and kenaf core kenaf provide good mechanical performance. In contrast to certain fibres, only the outside performs well and some of the fibres are only usable internal parts. Considering this advantage, kenaf tends to grow as another natural fibre that can replace synthetic fibres in the automotive industry.

Kenaf fibre will be replacing the conventional trim material inside the car which is felt. The increased absorption of noise from lower to higher frequencies becomes a coefficient in general to the type of felt material. In addition, felt is a dense, non-woven fabric and without any warp or weft. It is generally made up of synthetic mixed fur to produce a durable, resilient felt for craft or industrial use. Some felt to be made entirely of synthetic fibres. A combination of felt includes wool and polyester or wool and nylon. Synthetics cannot be turned into felt by themselves but can be felt if they combine with wool.

2.9 Automobile Industries

According to John and Thomas, (2008), natural fibre polymer composites have become the attractive centres for the research community since the past few decades. The kenaf natural fibre material is proposed to replace the conventional composite material based on synthetic fibres due to several advantages such as renewal. Kenaf fibres have lower thermal resistance compared to synthetic fibres, similar to other natural fibres. Part of the work reported on the kenaf fibres as a reinforcement and filler in the various composites are tabulated in Table 2.1.

Among natural fibres, kenaf receives greater attention from automotive scientists and industries as all parts can be used perfectly by forming composites with various resins or polymer matrices. Figure 2.3 shows pathways using kenaf components but low mechanical strength and their hydrophilic properties restrict their submission mainly to locally related locomotive components such as interior accessories, floor pans, and dashboard. Davoodi et al. (2010); Kumar et al. (2010); Rao et al. (2011) stated kenaf fibre recorded the highest priority value of 0.129 or 12.9%, followed by pineapple leaf fibre (0.114), palm fruit bunches (EFB) (0.097), and many types of natural fibres based on overall design analysis (Mansor et al., 2013). Hence analytical hierarchical process (AHP) method and sensitivity analysis suggest kenaf fibres as the most effective and selective materials for applicators to provide hybrid glass fibre polymer composites for automotive components.

Reinforcement	Matrix	Reference
Kenaf fibre	HDPE	Salleh et al. (2014)
Treated and untreated kenaf	Epoxy	Yousif et al. (2012)
Kenaf fibre	Poly(furfuryl alcohol) bioresin	Dekaa et al. (2013)
Kenaf/fiberglass	Polyester	Ghani et al. (2012)
Short fibres nonwoven kenaf	Polypropylene	Asumani et al. (2012)
Long kenaf/woven glass	Unsaturated polyester	Salleh et al. (2012)
Kenaf bast fibres	Polypropylene (PP) blended with (TPNR) and (PP/EPDM).	Anuar and Zuraida, 2011
Kenaf fibres	Polyurethane	Batouli et al. (2014)
Kenaf fibres in polylactide	Polylactide	Lee et al. (2009)
Kenaf–polypropylene	Kenaf–polypropylene	Johna et al. (2010)
Kenaf	PLA	Ochi, 2008
Kenaf-glass	Unsaturated polyester	Atiqah et al. (2014)
Kenaf fibres and corn husk flour	Poly(lactic acid)	Kwon et al. (2014)
Nonwoven kenaf	Polypropylene	Hao et al. (2013)
Kenaf fibres	Polypropylene	Shibata et al. (2006)
Kenaf fibers	Cassava starch	Zainuddin et al. (2013)
Kenaf/glass	Epoxy	Davoodi et al. (2012)
Kenaf/glass	Epoxy	Davoodi et al. (2010)
Kenaf sheets	PLLA	Nishino et al. (2003)
Kenaf fibres	Polyurethane	El-Shekeil et al. (2012)
Kenaf fiber	Polypropylene	John et al. (2010)

Table 2.1: Reported work on kenaf fibre as reinforcement in composites (Hakeem et al., 2015)

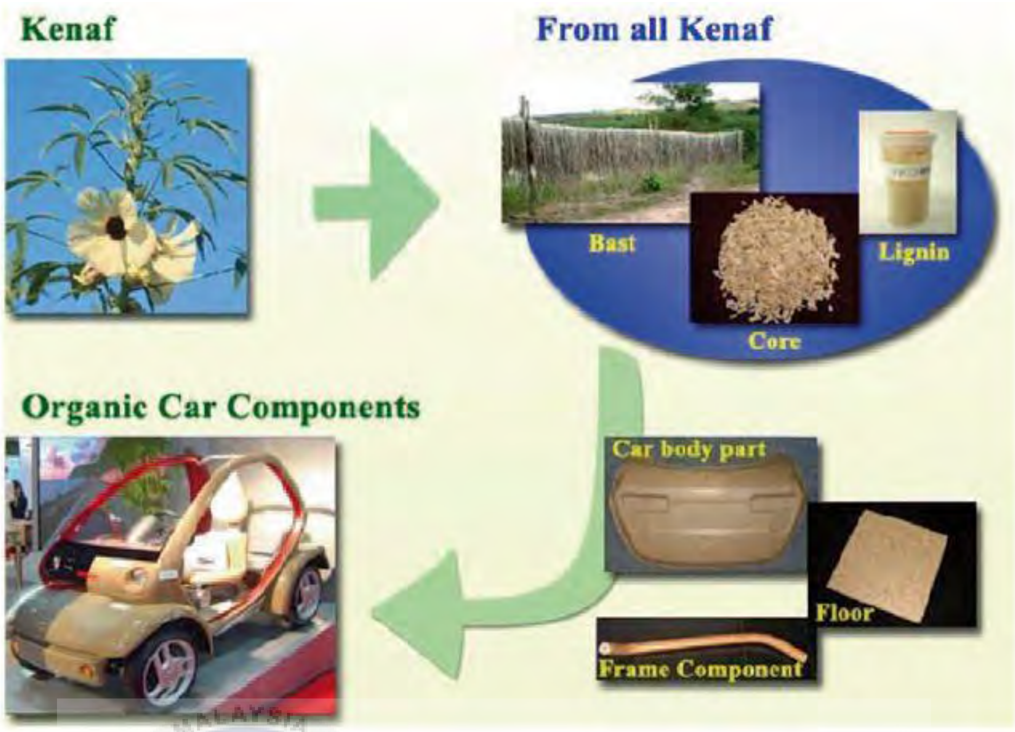


Figure 2.6: Toyota’s organic car (Hakeem et al., 2015)

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

This chapter explains the methodology in conducting this project. A literature review is the first task to be done once the research started, this leads to the knowledge of the reciprocity modelling of this project. In order to allow comparison with the modelling, an analysis has to be conducted, namely model development and acoustic cavity. From the analysis, noise and vibration can be analysed and therefore enable the comparison with the established modelling. Validation for statistical energy analysis (SEA) of motor vehicle structure of noise and vibration results is made by VA-One software. Determining the difference results, it can help to identify the major contributor in the overall energy of the system. On the other hand, as the research progresses, a literature study on conventional trim material and natural fibre sound insulation. The study starts with natural fibre such as kenaf fibre for sound absorption characteristic of acoustic material. For invalid result from the comparison, the data will be taken again, whereas, for a valid result, it can then discussed in the thesis.

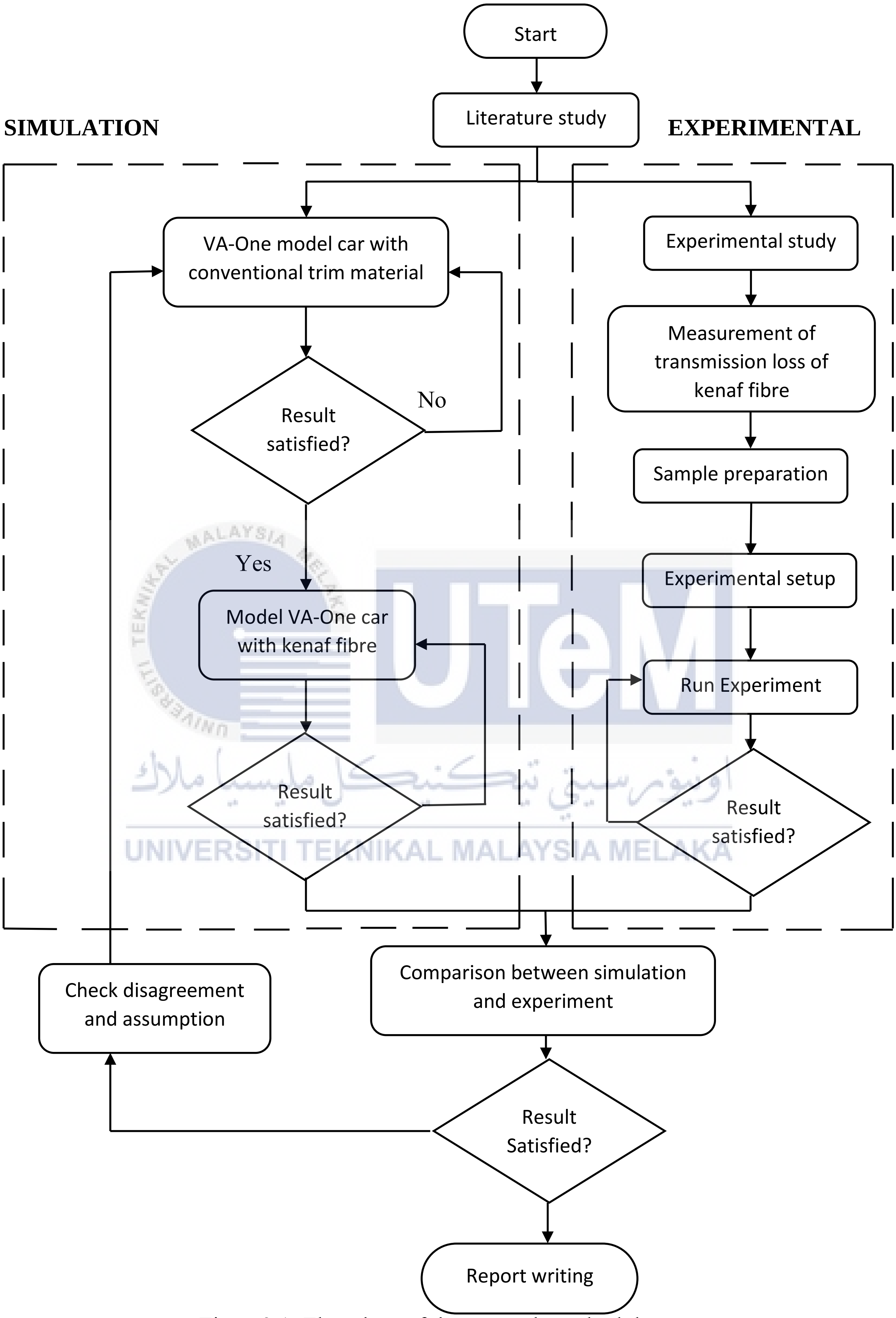


Figure3.1: Flowchart of the research methodology

Next, modelling a car with sound insulation for conventional trim material inside the car has been made using VA-One software to obtain the shape and results of sound pressure level which are setting the boundary condition to make sure the diffuse of acoustical field is pointed on the right place to make a simulation so that other parts are not affected.

Once it succeeds, proceed with modelling a car with sound insulation of trim materials inside the car using kenaf fibre. Material that needs to be simulated inside the car by using conventional trim material that had in the software such as synthetic fibre which is felt, and natural fibre which is kenaf. So, the results have been obtained which material is more superior. Simulation is made by using VA-One with SEA.

Comparison of result analysis shows a different scale which material has a good performance as sound insulation. With the simulation results, measurement of transmission loss performance of kenaf has proven and the results are validated.

Simulation has done and it shows the differences in sound pressure level performance between kenaf and felt fibre. The discrepancies of transmission loss between the results are also analysed. The process has been repeated from the modelling a car with conventional trim material or kenaf fibre, and comparison of result analysis between two differences materials. All the results and analysis are presented in the thesis.

3.2 Simulation Works

Modelling a car with sound insulation for conventional trim material and kenaf fibre inside the car has been made using VA-One software. The simulation works started with setting the type of materials, i.e. felt and kenaf fibre in the software. Simulation of sound pressure level of trim material is made because to obtain which results show better performance and to analyse which type of material is good sound insulation.

3.2.1 Comparison of Result Analysis

Comparison of sound pressure level performance of conventional trim material and kenaf fibre has been made is to analyse the relationship between natural and synthetic fibre. All the results and analysis will present in the next chapter, i.e. chapter 4.

3.3 Kenaf Fibre Properties

According to Hassan et al. (2017), superior advantages and high ratios compared to different fibres have been known by kenaf bast fibre. It has the potential as a reinforcing fibre in thermoplastic composites. Absorbing carbon dioxide from the air at high concentrations is included in the sustainable properties of kenaf plants. It also absorbs nitrogen and phosphorus from the soil and is easily recyclable due to the weight of the kenaf fibre composite weight, fuel consumption and emissions improved especially in the automotive industry.

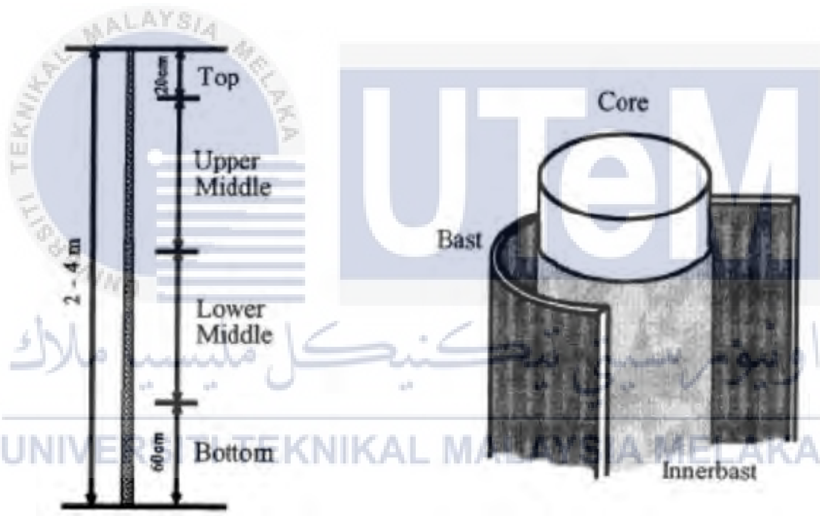


Figure 3.2: Sampling positions and parts of kenaf stems (Hassan et al., 2017)

(a) (b)

Figure 3.3: (a) Kenaf core (b) Kenaf bast (Hassan et al., 2017)

Kenaf Fibre	Length	Diameter (µm)	Lumen Diameter	Cell Wall Thickness (µm)
Bast Fibre	2.32	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

Table 3.1: Dimension of kenaf fibre for the outer part (bast fibre) and inner part (core fibre)

Hassan et al. (2017) mentioned that each element showed good mechanical properties even with a different dimension. Each element of kenaf bast and core fibre are shows good mechanical performance compared to different varieties of natural fibre. From the research that had been made, fibre length will increase with the age of kenaf, but for three different stages, increase in the initial stage of growth, decrease in the middle stage and then increase again at the tip of the stage. Kenaf bast fibres tend to be growing rather more active than kenaf core fibres (Kamal et al., 2014).

	Natural Fibres, Kenaf
Density, $(\frac{kg}{m^3})$	40
Flow Resistivity, $(\frac{Ns}{m^4})$	6215
Porosity	0.99
Tortuosity	1.05
Viscous Characteristic Length, (m)	0.000068
Thermal Characteristic Length, (m)	0.000177
Thickness, (m)	0.005

Table 3.2: Parameters for natural fibre which is kenaf (VA-One Software)

3.4 Conventional Trim Material Properties

In the automotive industry, conventional trim material which is felt is perhaps one of the most unique and versatile industrial fabrics available. It is highly resilient, retaining its strength and unique properties. Felt is produced as these fibres of fur are pressed together using heat, moisture and pressure. Besides, it is familiar with chemical resistant. Synthetic felt can be treated for flame resistance and does not ravel or fray. In addition, felt is in a position can be compressed and released thousands of times without defect. On the other hand, felt is an excellent sound insulator and has superb vibration damping. This material is being used in the automotive industry.

Figure 3.4: Felt material as sound insulation being used for sound absorption (Chinese automotive sound insulation "JAWS", 2016)

	Conventional Trim Materials, Felt
Density, $(\frac{kg}{m^3})$	50
Flow Resistivity, $(\frac{Ns}{m^4})$	40000
Porosity	0.92
Tortuosity	1.5
Viscous Characteristic Length, (m)	0.000056
Thermal Characteristic Length, (m)	0.000122
Thickness, (m)	0.005

Table 3.3: Parameters for conventional trim material which is felt (VA-One software)

3.5 Process of Modelling Simulation In Va-One Software

Figure 3.5 shows the first process of the simulation model for a plate including with cavities. In this model, the plate regarded as an acoustic source, and the generated sound is propagated to the sidewall of the plate. The plate was tested by using different acoustic properties such as kenaf fibre and conventional trim material which is felt.

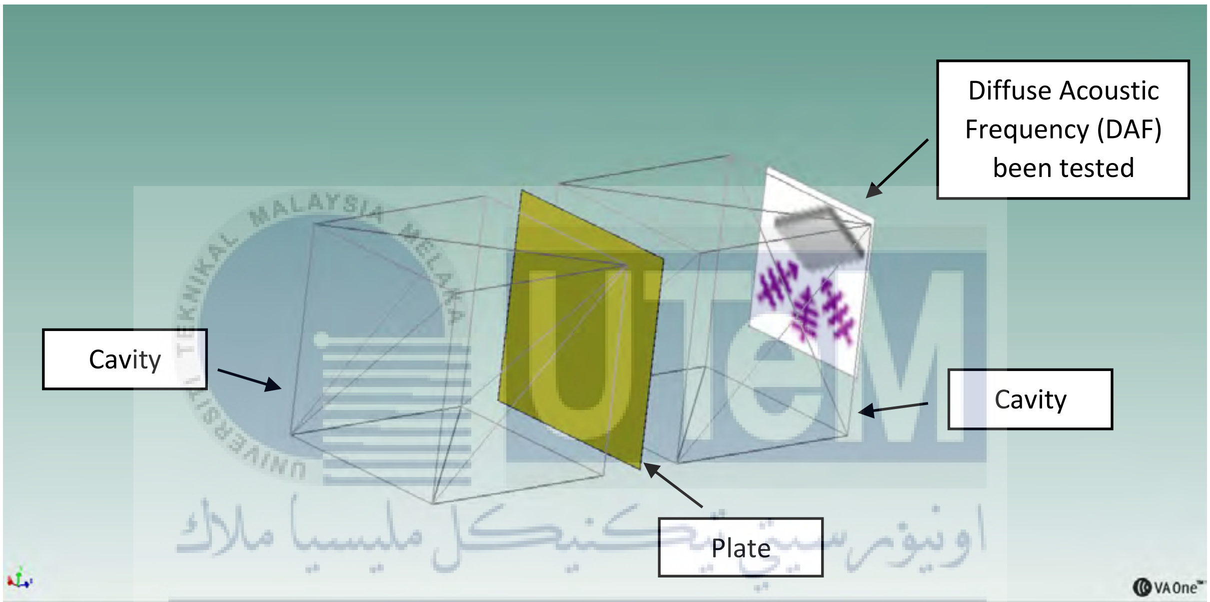


Figure 3.5: Simulation of the sound pressure level was tested on a plate

Next, figure 3.6 shows the simulation model for a car door. In this model, the concept of the model is to make the model more attractive and sturdy. The sidewall of a car door was tested by using different acoustic properties.

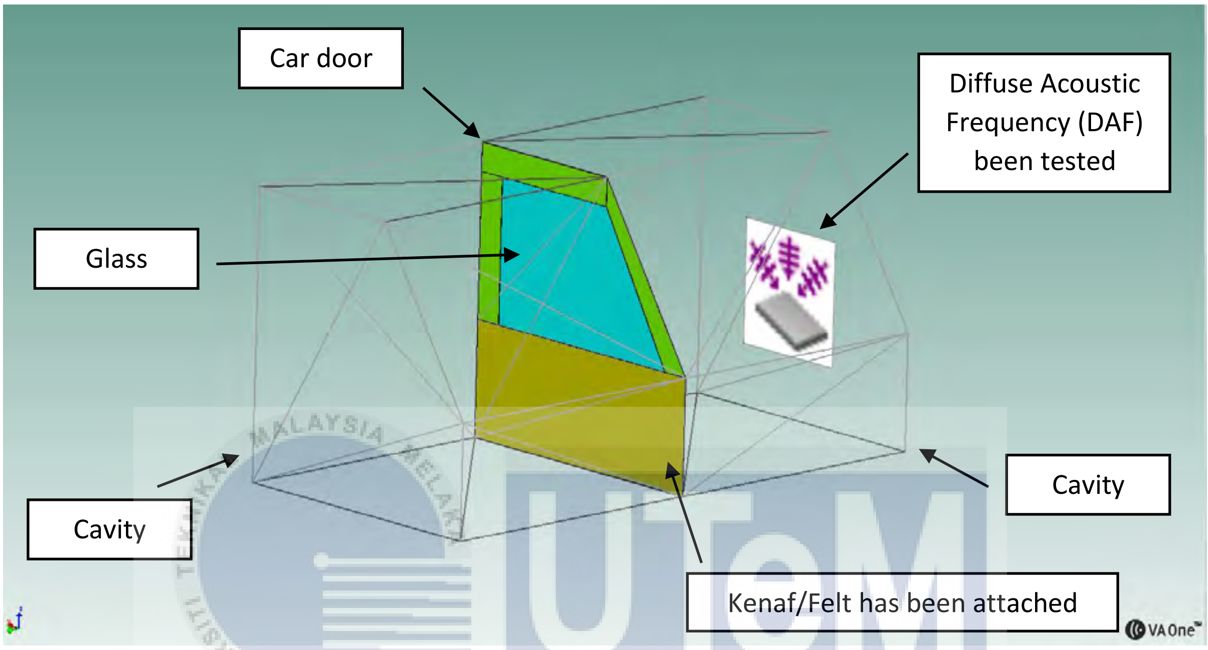


Figure 3.6: Simulation of the sound pressure level was tested for a car door

Figure 3.7 shows the process of modelling a car with conventional trim material and kenaf fibre. According to the Sang-Kwon Lee et al, (2018), the study has been conducted to optimize acoustic absorption material to improve car sound quality. This model is developed based on the processing technique and it is used to simulate the internal noise that is appropriate to the different insulation material attached to the car side-wall. Different materials have been tested and estimated using acoustic properties of insulation materials such as conventional trim materials and kenaf fibres.

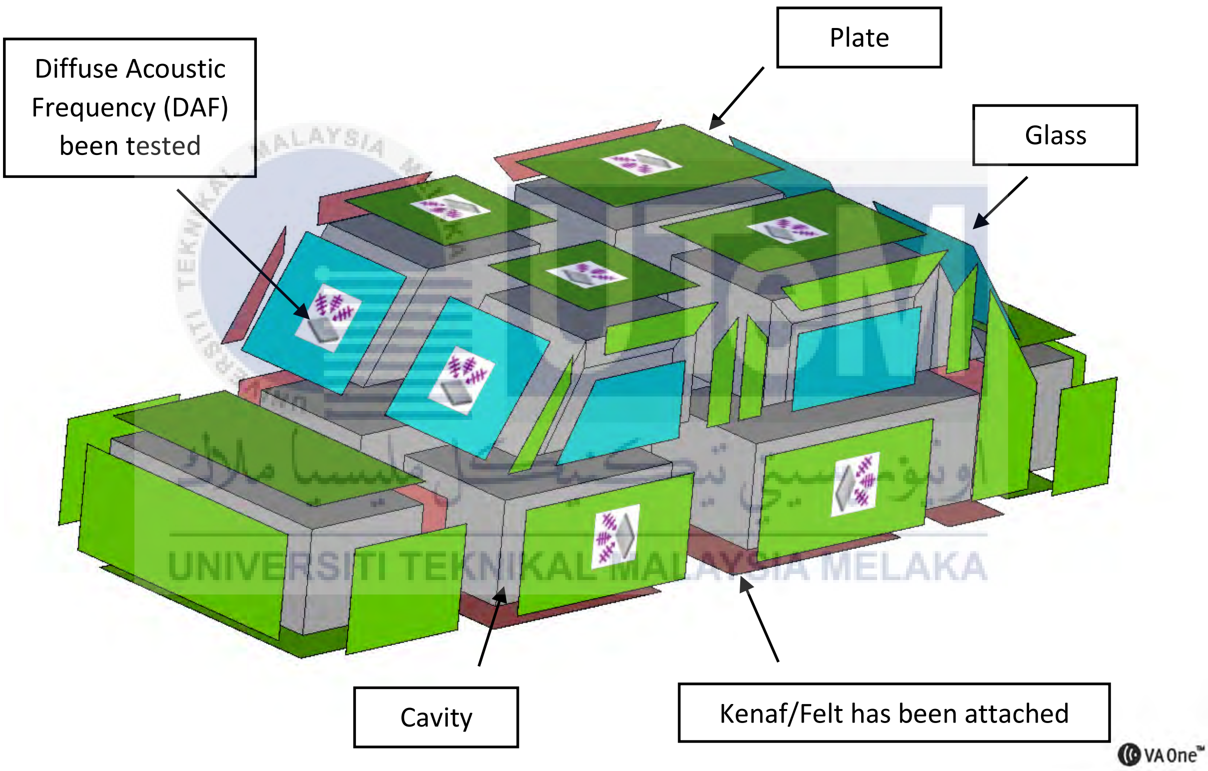


Figure 3.7: Process of modelling a car with conventional trim material and kenaf fibre

3.5.1 Vehicle Structure was Divided Into Plate/Shells and Acoustic Subsystem

Figure 3.8 shows the structure was divided into plates/shells and acoustic subsystem. Plate/shell subsystem was used to represent the doors, windows, roof, dash, and firewall. The interior was subdivided into acoustic spaces which they are classified into driver and passenger's cavity.

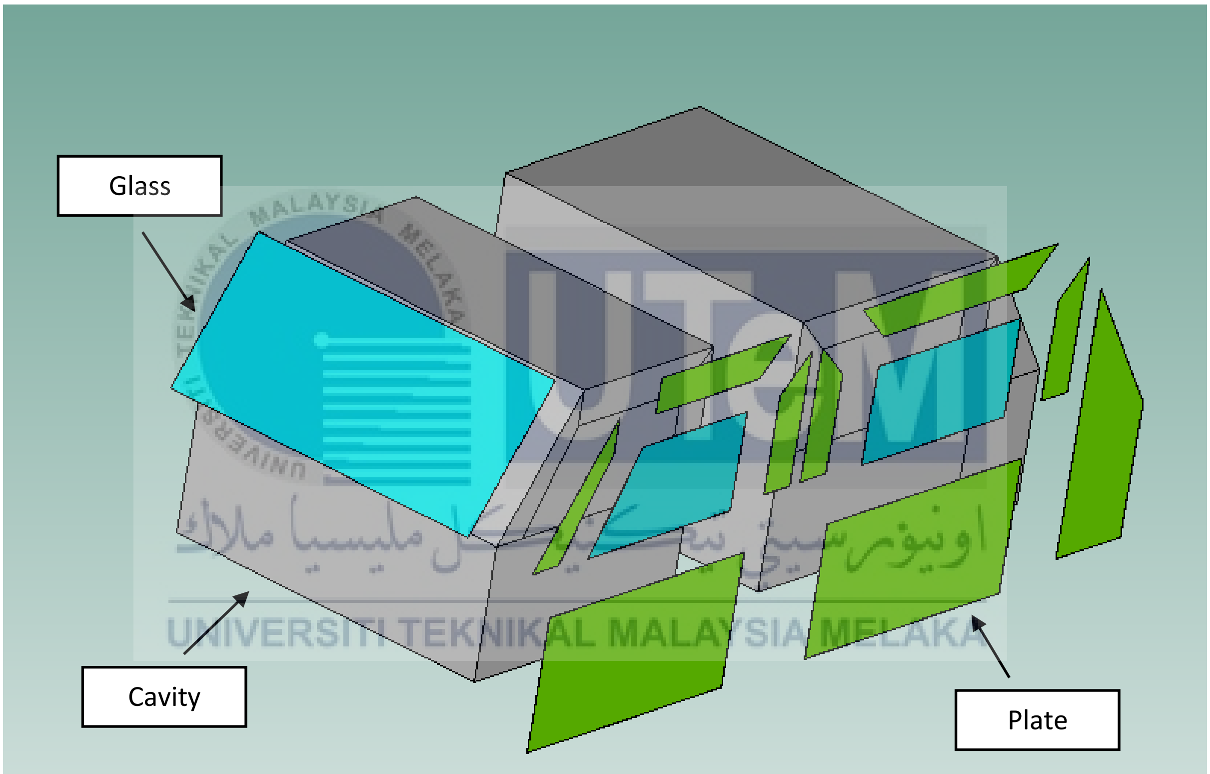


Figure 3.8: Plate/shells subsystem

3.5.2 Respond Selected By the Simulation

Figure 3.9 shows the cavities at driver and passenger position. The respond that has applied from outside of the car cabin will be selected based on these cavities.

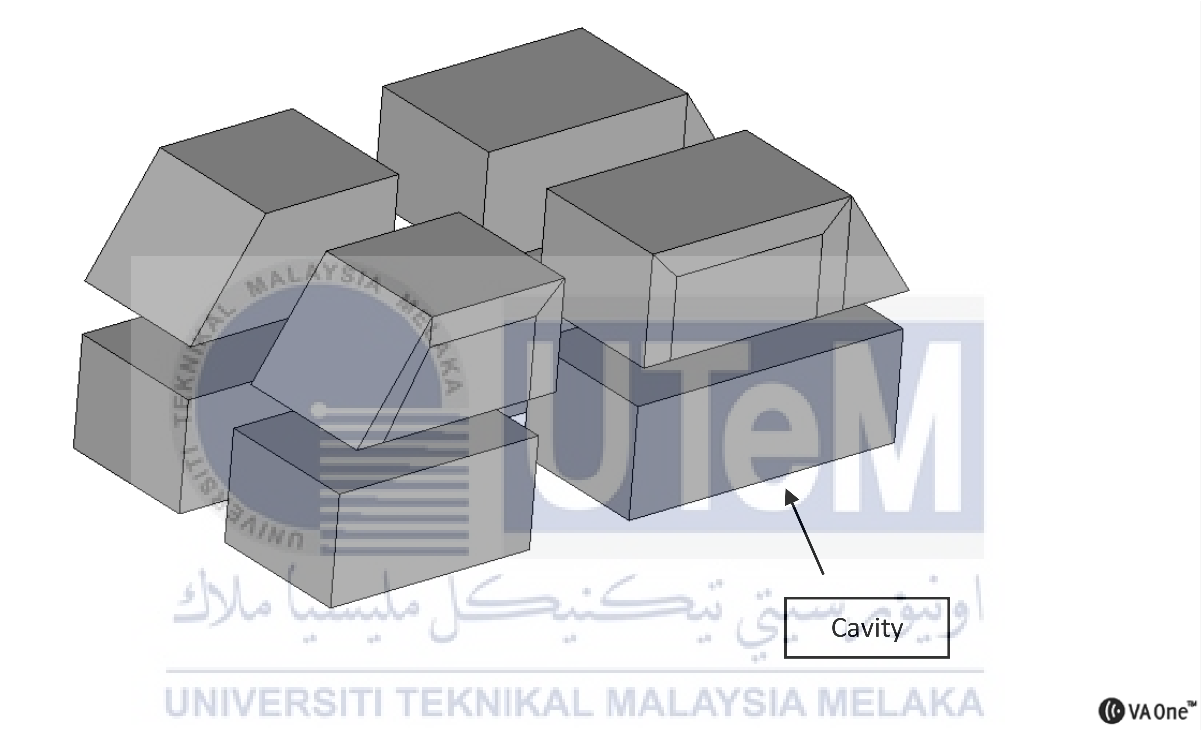


Figure 3.9: Entire cavity for driver and passenger position

3.6 Experimental and Theoretical Study of Transmission Loss

Barnard and Rao, (2004) mention that transmission loss is a major quantification of the effectiveness of acoustic treatments for engineering application. The sound transmission coefficient, τ, acoustic treatment is a function of frequency defined as the ratio of the sound energy transmitted through the treatment to the amount of sound energy incident beside material source. Sound transmission loss (STL) is the only defined as the transmission coefficient is expressed in decibels (dB) by Eq. (3.1) below

$$STL = 10\ log_{10}\left(\frac{1}{\tau}\right)\quad dB \tag{3.1}$$

The fully reflective material has a transmission coefficient 0 (STL = ∞), while the opening transmission coefficient is 1.0 (STL = 0). It should be noted that ordinary materials tend to be better at blocking higher frequencies. Transmission loss can be measured directly (but not easily) by mounting a test panel between two reverberation rooms and measuring the sound pressure level on each side.

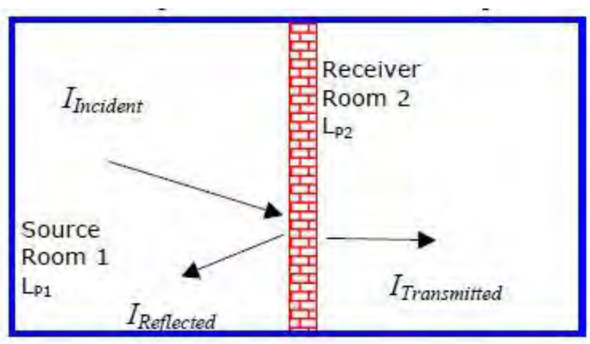


Figure 3.10: When sound strikes a partially absorbing partition between two rooms, some is reflected back into room, some transmits into adjacent room (Lamancusa, 2000)

3.6.1 Measurement of Transmission Loss of Kenaf Fibre

To measure the transmission loss of kenaf fibre, Jung et al, (2008) mention that, impedance tubes are used to measure the sound transmission loss consisted of three parts: an upstream tube with a loudspeaker, a removable test sample holder and a downstream tube with a semi-anechoic termination, as shown in figure 3.9. Impedance tubes are made of two cylindrical metal tubes and having inner diameters of 31.1mm (for test frequency up to 6400 Hz) and 100mm (for test frequency up to 1600 Hz). Two sets of two microphones are placed, one set of upstream tubes and one at the downstream tube, with the same space of 50 and 25 mm between two microphones for larger and smaller inner diameter tubes respectively. White noise was generated by using a spectrum analyser (B&K 3550) and was amplified with a power amplifier (B&K 2706).

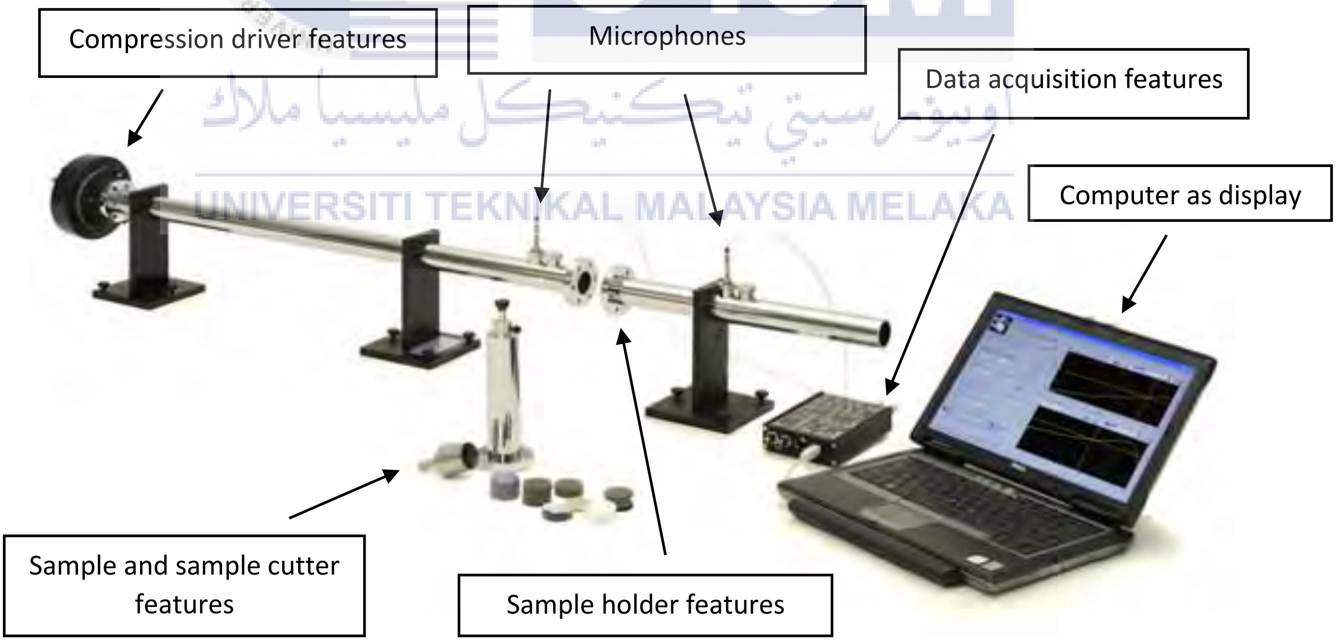


Figure 3.11: ACUPRO impedance tube construction features

The use of impedance tubes is to measure sound transmission loss on kenaf fibre and conventional trim material. According to Jung et al, (2008), based on the experiment that had been made, proved that the present manufactured apparatus is stable and the impedance tube method is suitable for measuring the sound transmission loss of sound absorbent materials. This will be useful for comparing the sound transmission losses among samples and for developing new materials.

3.6.2 Felt Fibre Sample Preparation

Felt (see Figure 3.12) is a material of synthetic fibre used as conventional trim materials in the automotive industry. Felt fibre was cut into a cylindrical shape with a diameter of 31.1mm by using utility drill machine.

Figure 3.12: Felt Fibre

3.6.3 Kenaf Fibre Sample Preparation

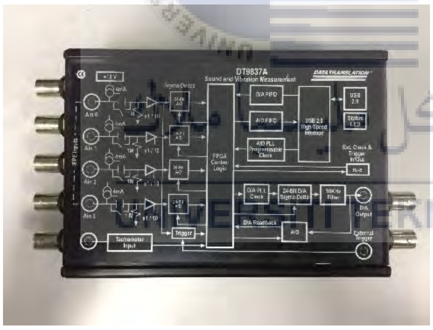
Kenaf fibre (see Figure 3.13) is a material of natural fibre which is environmentally friendly and biodegradable used as a replacement of conventional trim material. Kenaf was cut into a cylindrical shape with a diameter of 31.1mm by using utility drill machine.

Figure3.13: Kenaf Fibre

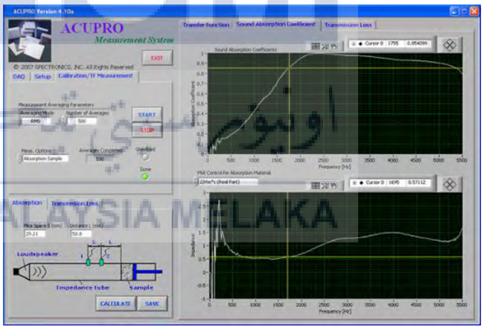
3.6.4 ACUPRO Impedance Tube Testing

Figure 3.14 shows the apparatus and instrumentation used in the measurement of transmission loss. The measurement of transmission loss was conducted by using the impedance tube following the ISO 10534-2 (European Committee for Standardization, 2001).

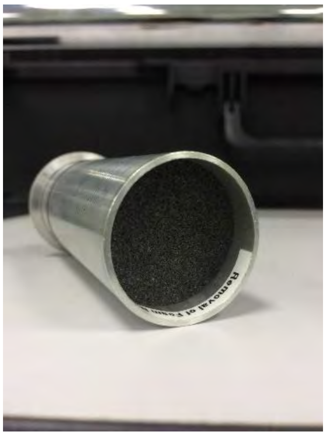
(a) Impedance tube



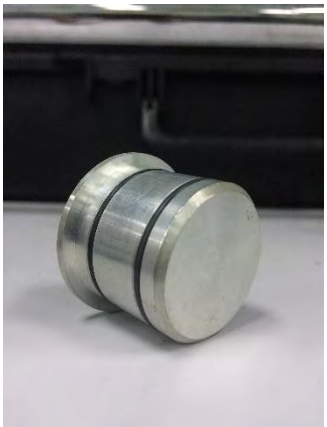
(b) Data Acquisition



(c) computer display



(d) Anechoic cover



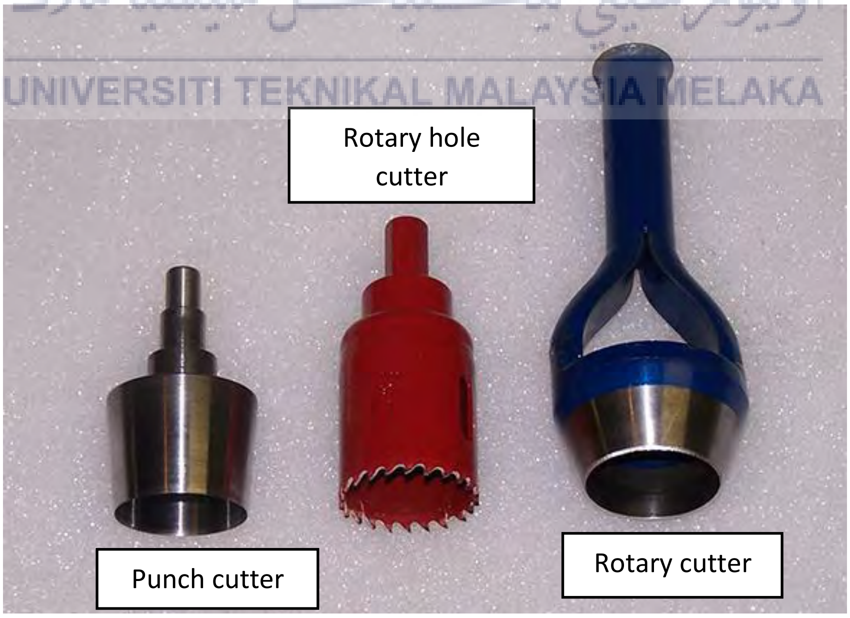
(e) Reverberant cover

(f) Compression driver

(g) Microphones

(h) Sample holder

(i) Samples of the experiment



(i) Sample cutter

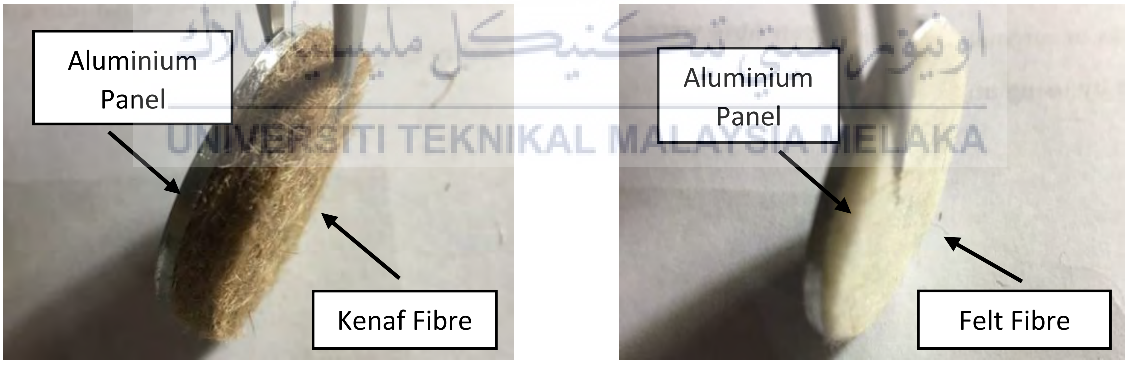
Figure 3.14: Apparatus and instrumentation involved in the impedance tube testing

3.6.5 Experimental Setup

The sample was fitted into 31.1mm diameter sample holder as shown in Figure 3.15 (b) before start an experiment.

(a) (b)

Figure 3.15: (a) The empty sample holder of impedance tube (b) The sample fitted into the holder



(a) (b)

Figure 3.16: Sample for experimental work (a) Kenaf fibre with aluminium panel (b) Felt fibre with aluminium panel

Figure 3.17 shows how the process of transmission loss of kenaf and felt fibre is achieved. The noise generated by the microphone is named as an incident sound and the sound that penetrates the panel is a transmit sound. The concept of this experiment describes the way noise generated from outside the vehicle is named as an incident sound and a sound penetrated in a vehicle named transmit sound.

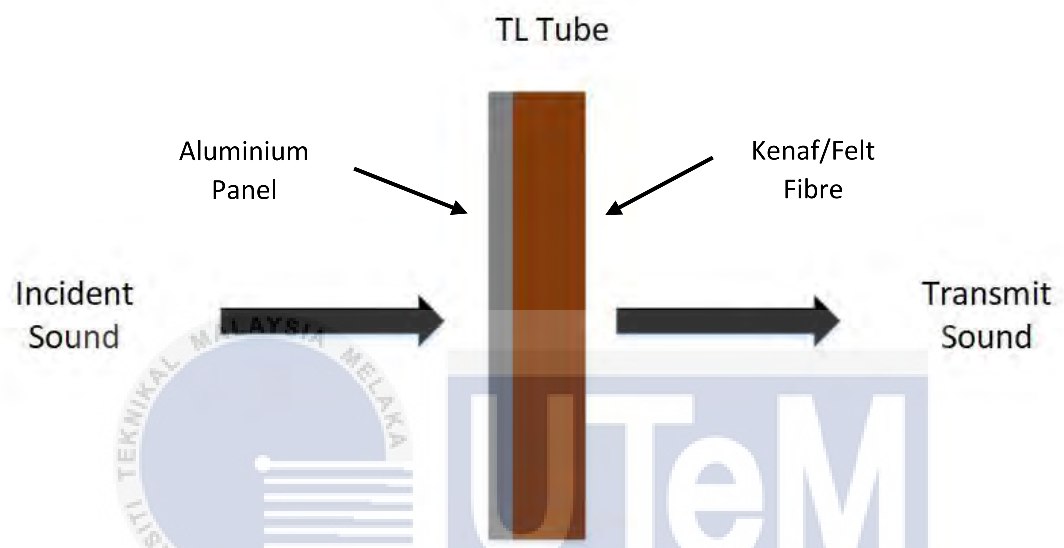


Figure 3.17: Process of Transmission Loss

The measurement setup is shown in Figure 3.18. The sample was fitted into 31.1mm diameter sample holder as shown in Figure 3.15. Before measurement was taken, the impedance tube needs to be calibrated for stabilizing the system. These calibrations are carried out prior to making transmission loss measurements and should be repeated at the beginning of each measurement day and whenever any of the microphones is replaced or if the position of any of the microphones is changed. After calibration, set the system in the mode of transmission loss. Then start running the experiment to take the data measurement. Lastly, the data will show as computer displays after the experiment has completed.

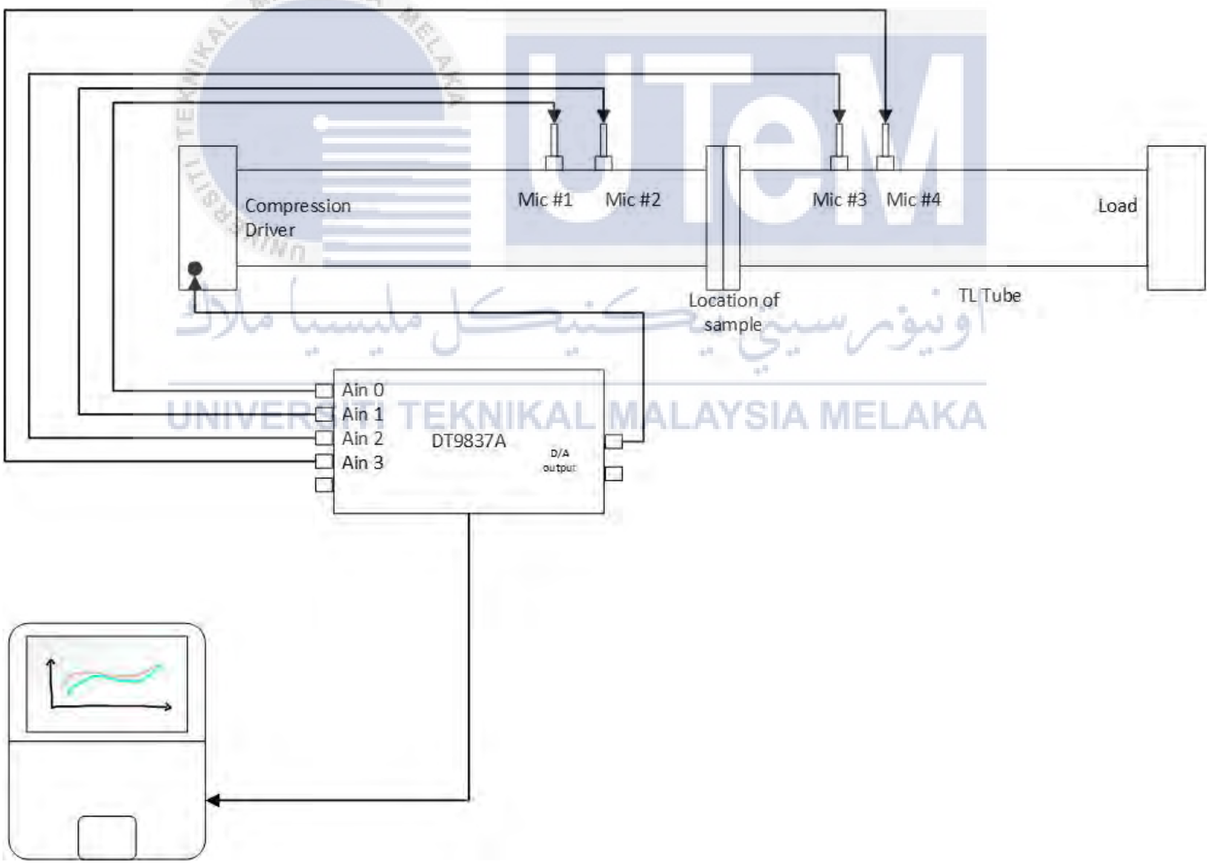


Figure 3.18: Experimental setup for the measurement of transmission loss

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Sound pressure level and transmission loss by simulation and experimental works are shown in this chapter. This is done to show how the simulation and experimental works are made. Simulation is conducted by using VA-One software to study simulation and theoretical sound pressure level in car cabin for driver and passenger position. For the investigation on the simulation and theoretical sound pressure level in car cabin for driver and passenger position, the thickness of the samples is constant while the material of the samples is varied. The experimental work by using impedance tube according to ISO 10534-2 (European Committee for Standardization, 2001) is conducted to study the comparison experimental and theoretical transmission loss for kenaf and felt fibre, the effect of the thickness and improvement of the transmission loss. For the investigation of the comparison experimental and theoretical transmission loss for kenaf and felt fibre, the thickness of the sample is constant while the materials are varied. As for the effect of thickness on the sound transmission loss performance of the fibres, the variations in the thickness of the samples are designed and the density of the samples is maintained. For improvement of transmission loss, the thickness of the kenaf sample is increased.

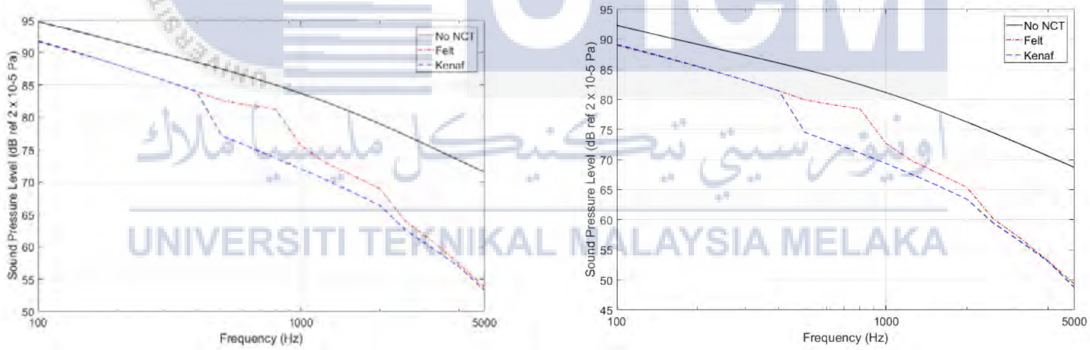
Results presented in this section are frequency response function, and they are plotted in one-third octave for better visual analysis. The simulation results shown are the sound pressure level in the cabin of the car while the experimental results showed transmission loss for the materials that have been used. The comparison between simulation and experimental result are made.

4.2 Sound Pressure Level in Car Cabin

The sound pressure level data is obtained from the simulation works by using VA-One software. The thickness of the samples is constant while the material is varied. These simulation works are made to obtain the data of the sound pressure level in a car cabin. The data is made to ensure that it is the same as the research study.

4.3 Simulation and Theoretical Sound Pressure Level in Car Cabin for Driver and Passenger Position

Figure 4.1 shows the result of the sound insulation at the driver and passenger position. Based on the graph, it shows that there are a difference in the reading of the sound pressure level of the material felt and kenaf fibre. Felt represent as a synthetic fibre while kenaf represents as natural fibre. Based on the simulation result, kenaf fibre shows good performance at a sound pressure level at 500Hz to the 2000Hz frequency range. Literally felt is slightly higher at range 500Hz to 2000Hz by 5dB. It can be concluded that felt that has a superb vibration testing, made of chemical resistant, etc. is higher the sound pressure level compared natural fibre which is kenaf.

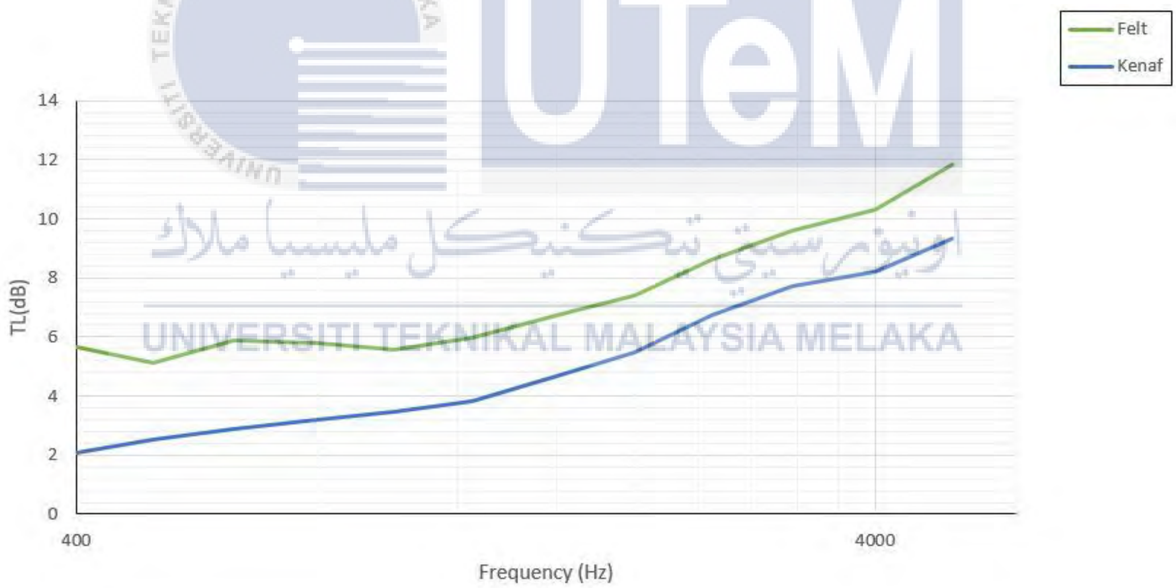


(a) (b)

Figure 4.1: Sound pressure level at (a) Driver position and (b) Passenger position

4.4 Comparison Experimental and Theoretical Transmission Loss for Kenaf and Felt

Figure 4.2 plots the transmission loss for kenaf and felt at fixed 5mm thickness. Based on the experimental results, it shows that felt is slightly higher than kenaf fibre in transmission loss for a full range of frequency. As we know synthetic fibre are currently used in industries for car cabin. The different between felt and kenaf fibre is almost 10 dB. This means that natural fibre still can replace a synthetic fibre because of the intermediate gap between the two materials is not too far.

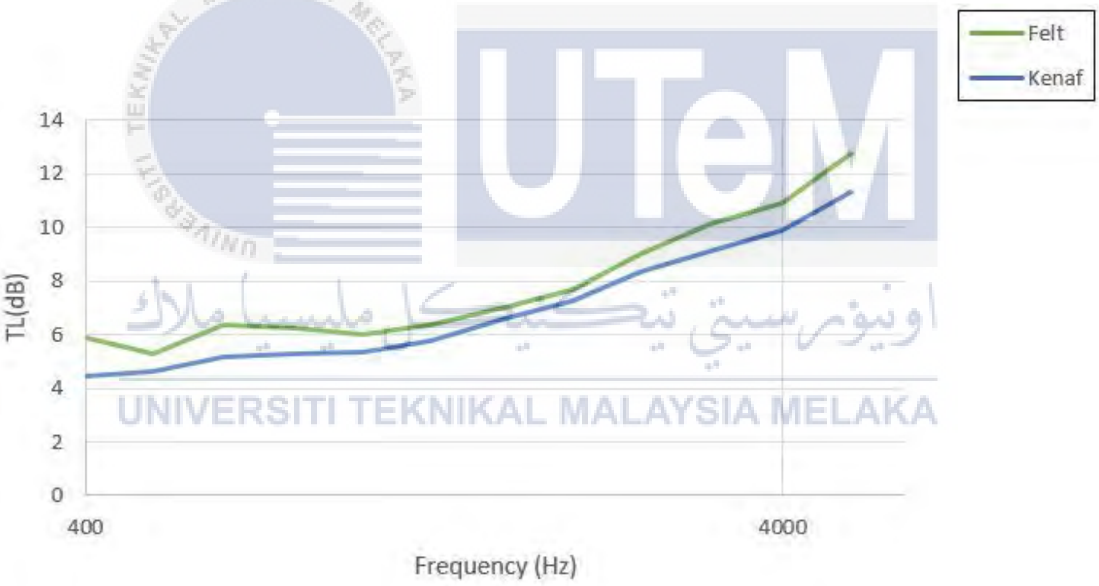


(a)

Figure 4.2: Transmission loss for thickness 5mm of kenaf and felt fibre

4.5 Comparison Experimental and Theoretical Transmission Loss for Kenaf and Felt for thickness 10mm

Figure 4.3 shows the 10mm of the kenaf and felt thickness has been tested. Here, it can be seen the results indicates that kenaf can approach the felt if it is further enhanced by its thickness. The relationship between kenaf and felt is not much different and very close. It shows that when the kenaf thickness is increased, the gap between kenaf and felt is almost the same. Furthermore, based on this result, it shows very good potential to replace the conventional trim materials with kenaf fibre.



(c)

Figure 4.3: Transmission loss for thickness 10mm of kenaf and felt fibre

4.6 Improvement of transmission loss

Figure 4.4 shows that 10mm of kenaf fibre is almost similar in transmission loss compared to felt. This is proven if the kenaf thickness increases then it can match the conventional trim material.

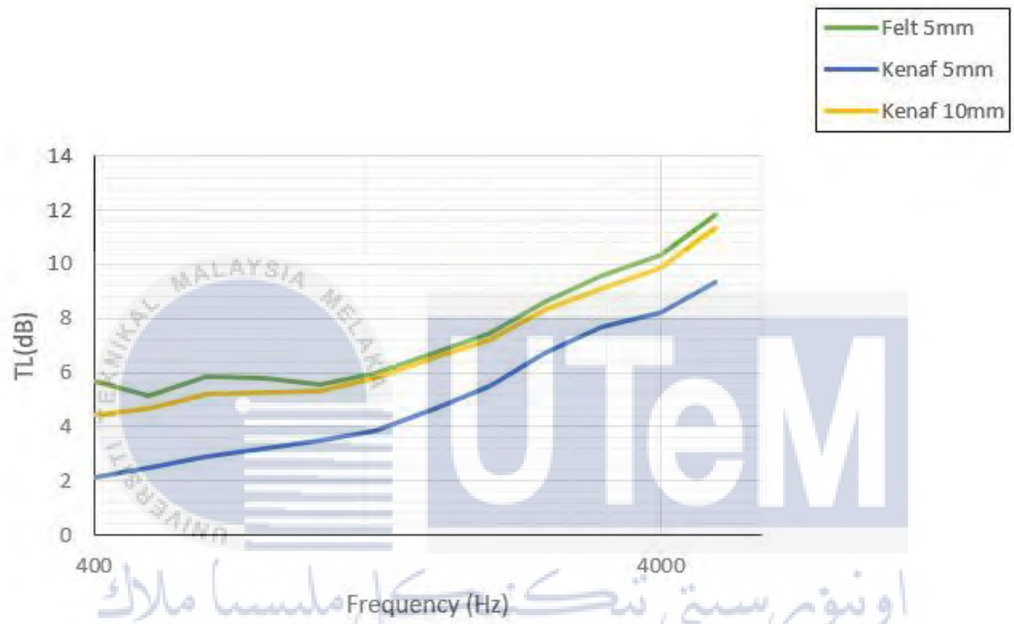


Figure 4.4: Comparison of transmission loss of kenaf and felt for 5mm and 10mm thickness

4.7 Discussion

From the analysis of the simulation and experimental work, it shows that kenaf is able to replace the felt with the result obtained. Natural fibres have received higher attention for acoustic uses. They are competitive materials thanks to their low density, good mechanical properties, easy processing, high stability, minimal health impacts, high quantity availability, low prices and reducing the environmental impact of their production (Berardi and Iannace, 2016).

For investigation on the simulation and theoretical sound pressure level in car cabin for driver and passenger position, kenaf fibre shows good performance at a sound pressure level at 500Hz to 2000Hz frequency range while conventional trim material indicates a relatively high level of sound pressure at 500Hz to 2000Hz.

Comparison experimental and theoretical transmission loss for kenaf and felt fibre shows that felt is slightly higher than kenaf not more than 10dB at 5mm thickness. Improvement of transmission loss has been made by increasing the thickness of 10mm and it shows that the gap between kenaf and felt is almost the same. Figure 4.5 shows the behaviour of basic regions where the experimental results have been classified.

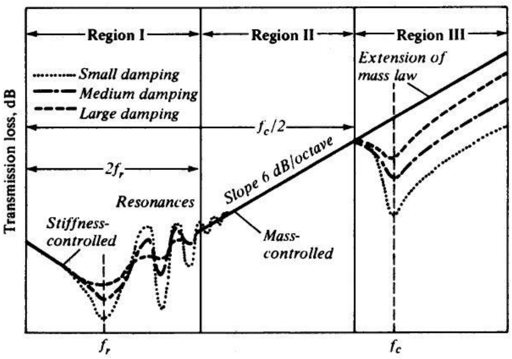


Figure 4.5: Theoretical Transmission loss for basic regions (Lamancusa, 2000)

CHAPTER 5

CONCLUSION

5.1 Conclusion

The sound insulation performance of the kenaf fibres has been investigated to achieve the objectives of this study. The important findings and observations are summarised below.

To reduce the vehicle interior noise using simulation technique were successfully conducted. The simulation results were obtained by applying multiple noise control treatments to the firewall, driver positioned and passenger position. The simulation technique was done by using VA-One software to investigate the performance of the sound pressure level.

The transmission loss of sound from both material which is felt and kenaf fibres using impedance tube technique was successfully conducted. The experimental results were obtained by conducting the transmission loss measurement. Felt and kenaf fibre was measured for their sound of transmission loss. This technique was done by using two load method which is anechoic and reverberant cover. The first measurement is made by using the anechoic which is the cover at the end of the impedance tube. The sound generated by the microphone has resulted in a reflection by anechoic. Then, replace the anechoic with reverberant cover to absorb the sound that has been generated.

The results are compared with theoretical results established to identify the accuracy of the measurement result. From the comparison done, based on the simulation, felt is slightly higher than kenaf in sound pressure level. Kenaf shows a very good agreement with the theory.

Based on the experiment, felt is good in the transmission loss but the results between kenaf and felt, is not much different and exceedingly close. The improvement of the transmission loss has been made by increasing the thickness of the kenaf fibre and after analysed, kenaf shows outstanding potential after being compared to the felt.

This study has proven that kenaf is able to replace the conventional existing material with the potential shown by simulation and experiment.

5.2 Contribution of This Research

This research has contributed to simulation and experimental results to replace existing materials with kenaf fibres in the car cabin. Based on the simulation and experiments, this study proves that the kenaf fibre is able to replace the conventional trim material perceived by some of the advantages of kenaf fibre.

5.3 Recommendations For Future Work

The application of kenaf fibre can be expanded and enhanced by mixing the fibres with different materials to form bio-composites in accordance with its applications. The kenaf fibres can also be treated to enhance its properties. Besides, kenaf fibre can be compressed to increase the density. By increasing the density, the strength of the kenaf fibre is also increased. So it can show more potential against the synthetic fibre. Other than that, kenaf fibre can be improved in terms of an effective bulk modulus, porosity, flow resistivity, tortuosity, viscous characteristic length, thermal characteristic length, and etc. so that kenaf properties become stronger. Furthermore, the thickness of the kenaf can be compact to make it thicker so as to reach the same level as the felt in transmission loss.

The analytical study of other analytical models can be done to investigate the efficiency of these models in predicting sound transmission loss performance.

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APPENDIX

LIST OF APPENDICES

APPENDIX A: GANTT CHART FOR PROJEK SARJANA MUDA I

Project Activities	Weeks														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PSM Title Selection & Study															
Identify the Problem Statement, Objectives & Scope of The Project															
Literature Review															
Equipment Preparation															
Methodology															
Conclusion															
Report															

APPENDIX B: GANTT CHART FOR PROJEK SARJANA MUDA II