UNIVERSITY OF GHANA

DEPARTMENT OF AGRICULTURAL ENGINEERING

NOISE ABATEMENT IN MACHINE SHOPS THROUGH THE USE OF RECYCLED COCONUT FIBRE AND POLYVINYL CHLORIDE SHEETS AS NOISE ABSORBING MATERIALS

BY

NANA OPOKU WARE OFORI AGYEMAN-PREMPEH

(10249795)

THESIS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON,
IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE
AWARD OF MASTER OF PHILOSOPHY DEGREE IN
AGRICULTURAL ENGINEERING
(MACHINE SYSTEM OPTION)

JULY, 2014

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DECLARATION

I hereby declare that with the exception of references to other people's work which have duly been acknowledged, this compilation is the result of my own research work and no part of it has been presented for another degree in this University or elsewhere.

………………………… Date…………………………

NANA OPOKU WARE OFORI AGYEMAN-PREMPEH

(STUDENT)

I hereby declare that the preparation for this project was supervised in accordance with the guidelines of the supervision of Thesis work laid down by the University of Ghana.

………………………… Date…………………………

ING. DR. ALIU ADUNA MAHAMA

(PRINCIPAL SUPERVISOR)

………………………… Date…………………………

ING .PROF. EDWARD A. BARYEH

(CO-SUPERVISOR)

ABSTRACT

Machine shop workers are exposed to noise levels between 83 - 110 dB(A), however, levels above 85 dB (A) are hazardous to the ear. A study was conducted at GRATIS Foundation in Tema Industrail Area in Ghana, using sound level meters to determine noise levels and propose solutions. Sound levels during peak hours of operation in the machine shop were found to be above 95 dB(A). To reduce these high noise levels, Coconut Fibre (CF) a naturally occurring sound absorber, was combined with Polyvinyl Chloride Sheets (PVCS) or "Flexi Banner" to create a sound insulating panel. These combinations: CF, "PVCS + CF", "PVCS + CF + PPVCS" and "PVCS + CF +PVCS" were tested in the lab for sound Insertion Loss (IL) and Transmission Loss (TL). In the test, CF thicknesses (10, 20 and 30 mm) were varied and 10 Octave band center frequencies of sound between 31.5 to 16000 Hz passed through the specimens. Analysis of Variance on results for TL test concluded that, thickness, frequency, and combination sequence (CS) and Frequency (FQ) interactions, had significant effect on TL, from 1000 – 16000 Hz. CS of PVC + 30 mm CF + PVC was selected as the CS with the most TL over the frequency range. With respect to IL test, it was concluded that, CS, Thickness, FQ, and CS and FQ interactions, also had significant effect on IL. PVCS + 30 mm CF + PVCS was selected for its high IL for higher frequencies from 4000 to 16000 Hz. It was also noted that, PVCS + CF + PPVCS could be used in place of PVCS + CF + PVCS to achieve similar IL averages, over the frequency spectrum. By combining CF with PVCS, it increased its TL by 24.5 dB(A) and IL by 26.02 dB(A) at 8000 Hz. After insulating the highest noise source in the machine shop (hand Held Grinder) with PVCS + 30 mm CF + PVCS, sound levels ranges dropped from 75 - 105 dB(A) (beyond standards) to 65 - 85 dB (A) range (safe zone). Hence, abating noise in the machine shop through combined CF and PVCS was successful.

DEDICATION

To everyone who helped me in one way or the other to acquire this degree, especially, my parents, siblings, relatives, friends, the Department of Agricultural Engineering at the University of Ghana and Meltwater Entrepreneurial School of Technology.

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List of Abbreviations

ANOVA	Analysis of Variance
CF	Coconut Fibre
CFPVCS	Coconut Fibre and Polyvinyl Chloride Sheets
CS	Combination Sequence
dB	Decibels
dB(A)	Decibels "A" Weighted Average
df	degree of freedom
EPA	Environmental Protection Agency
F pr	F probability
Hz	Hertz
IL	Insertion Loss
ISO	International Standard Organization
kHz	Kilo Hertz
ms	mean square
NAC	Noise Absorption Co-efficient
NIHL	Noise Induced Hearing Loss
NMP	Noise Measuring Position
NR	Noise Reduction
NRC	Noise Reduction Co-efficient
NRR	Noise Reduction Rates
PPE	Personal Protection Equipment
PVCS	Polyvinyl Chloride Sheet
SAA	Sound Absorption Average
SAC	Sound Absorption Coefficient

SIL	Sound Intensity level
SLM	Sound Level Meter
ss	sum of squares
TL	Transmission Loss
vr	variance ratio

List of Symbols

c	Speed
I	Sound Intensity
I_{ref}	Intensity Reference Level
Lp_1	L_p measured at the front of the specimen
Lp_2	L_p measured behind the specimen
Lp_a	L_p measured at a particular point before the introduction specimen
Lp_b	L_p measured at a particular point after the introduction of an specimen
Lp_{ince}	Incident Sound Pressure Level
Lp_{trans}	Transmitted Sound Pressure Level.
L_i	Sound Intensity Level
Lw	Sound Power Level
L_p	Sound Pressure Level (SPL).
L_{pt}	Sum Total Sound Pressure Level.
L_{ps}	Total Subtracted Sound Pressure Level.
LpB	Sound Pressure Level recorded at point “B” without specimen installed.
LpB2	Sound Pressure Level recorded at point “B” with specimen installed.
LpF	Sound Pressure Level recorded at point “F” without specimen installed.
LpF2	Sound Pressure Level recorded at point “F” with specimen installed.
Pa	Pascal.

P_{rms}	Maximum root mean square value of amplitude.
P_{max}	Maximum amplitude.
r	Distance from Sound Source
T	Period.
W	Sound Power
W_{ince}	Incident Sound Energy
W_{trans}	Transmitted Sound Energy
α	Sound Absorption Coefficient (SAC).
f	Frequency.
λ	Wave length.
τ	Transmission Coefficient.
σ	Airflow Resistance.
φ	Porosity
ρ	Density
γ	Specific Heat Ratio

CHAPTER ONE

1. INTRODUCTION

1.1 Machine Shop noise and its Effects

Noise in machine shops has a lot of negative effect on workers. In Ghana's manufacturing industry, the situation is not different. Hence the need to develop a readily available, affordable and adoptable solution that can easily be implemented, to eliminate or reduce the negative effect of noise on Ghanaian industrial workers.

With a growing and robust economy, Ghana's manufacturing industry is gradually picking up. Several manufacturing companies and their associated machine shops have been built over the decade. In GRATIS Foundation, the bulk of the machines and machine-parts being produced are targeted at the agrarian industry, while other machine shops focus on providing services for industries such as oil and gas, telecommunications, automobile and aerospace (Quansah, 2012). The nature and mode of operation of most machine shops gives off high levels of noise, hence, there is a need to abate this noise to create good working conditions for workers.

The high noise levels and the absence of noise control measures, endanger the hearing/auditory health of shop workers. Working with tractor operators Baryeh et al., (2003) found that 57% of tractor operators had impaired hearing after 15 years of operating tractors due to the noise they generated. Noise in machine shops is mostly generated by machine operation and machine tool interaction with a work piece. The noise produced by each machine can vary. Tables 1 and 2 show Sound Pressure Level (SPL) variations of different machines.

Table 1. Average SPLs of some machines in the machining section of a Machine shop[1].

Machine Name	Estimated Average Sound level Range in dBs
Lathe Machine.	102 - 108
Milling machine	85 - 90
Pedestal Grinding Machine	90 - 95
Cutter Machine	95 - 101
Band Saw	94 - 95

Table 2. Average SPLs of some machines in the fabrication section of a machine shop[2].

Machine Name	Estimated Average Sound level Range in dBs
Press	95 - 110
Guillotine	95 - 100
Riveting Machine	100 - 110
Welding	99 - 100
Disc Grinding Machine	83 - 110
Disc Cutting Machine	98 - 110

Frequencies of noise generated by most of these machines have been found to be within the ranges of 1,000 Hz (1 kHz) to 8,000 Hz (8 kHz) (Chathurangani *et al.*, 2012). This implies that, any noise redactor, barrier or absorber designed to counteract the noise should be able to reduce/filter noise across all these frequencies.

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[1] Source:_(WorkCover Tasmania ISBN: 978 1 876712 13 9) (Nelson, Nelson, Concha-Barrientos, Fingerhut, P.H, & M.D., 2005)

[2] (Executive, Health & Safety, 2010)

1.1.1 Definition of noise

Noise may be defined as sound that is loud, unpleasant or that causes disturbance (Crea, 2008). It can also be said to be unwanted sound (Essandoh, 2011). Sound on its own may be defined as pressure variations that the ear can detect, ranging from the weakest sound level to levels that are damaging to the ear. This reveals the fact that, what one may claim as noise (unpleasant or unwanted) may be relatively pleasant sound to someone else. In 1990, a general consensus by most countries including Ghana agreed to the fact that noise levels above 85 dB(A) for 8-hours (daily personal noise exposure or $L_{EP,D}$) exposure was potentially damaging (Myers *et al.,* 2002). Generally, noise is workshops are high as observed in Table 1 and Table 2.

1.1.2 Effect of workshop noise on workers

The effects of high noise levels on workers in machine shops are very significant, and may be felt over a short term or long term period. Some of these effects are accidents; Noise Induced Hearing Loss (NIHL), financial loss to employers and employees, tinnitus, nervousness, fatigue, sleepiness, annoyance, stress, disputes (Morris, 2006), anxiety, chronic fatigue, gastro intestinal problems, ear pain and reduce scholastic work (Morris, 2006). Baryeh *et al.,* (2003) have also quoted Febo *et al.,* (1995) as stating that, noise increases blood pressure and heart beat in the cardio circulatory system, increases acid secretion in the gastro entaric trout and induces insomnia and headache in the psyche. Details of some selected effects are:

a) Accidents:

Noise at work places impairs/distracts vigilance and the ability to identify hazards resulting in more accidents (Myers et al., 2002).

reduces his family's net income. Workers who may also be maimed from accidents as a result of noise distractions may be limited to fewer kinds of jobs.

e) Tinnitus:

The individual who experiences Tinnitus hears hissing, whistling or roaring sounds when there is no sound. This is a very unpleasant experience and sometimes leaves the individual angry.

1.1.3 Factors affecting high noise generation in machine shops and some solutions

Machine shop workers may experience high noise levels of 85 dB(A) and above for six (6) or more hours of work per day. Some factors that may contribute to high noise levels are the:

a) Age of machines being used.

Generally, older machines produce higher noise due to the wear and tear that has occurred in them over long periods of use. This causes revolving/rotating parts to knock together rather than smoothly run over each other. Purchasing of new machines with appropriate sound reduction features incorporated in their design is very helpful, but sometimes costly.

b) Irregular maintenance of machinery.

Most machines make a lot of noise because of the absence of maintenance practices such as greasing, cleaning and tightening of loose bolts. These simple maintenance activities can substantially reduce the noise generated. For example, greasing rotating parts reduces friction, hence lesser noise is generated. Tightening loose bolts holds parts in place and prevents rattling sounds.

f) Size of work shop.

Smaller workshops tend to concentrate the sound produced while very large rooms tend to reverberate the sound generated. Appropriate design of workshop buildings with advice from acoustic engineers would be very helpful.

g) Type of activity being carried out.

A lot of necessary workshop activities such as hammering, grinding and cutting generate a lot of noise; however, these activities can be managed such that they produce lower noise. A sheet of plywood put beneath the work piece would absorb some or a greater part of the impact and noise from hammering.

h) Noise from the environment/background.

Background noise or noise from the environment is often hard to handle, however, if workshops are cited away from possible noise sources, it would reduce the total amount of background noise. Secondly, insulation of workshop buildings with appropriate materials will help reduce the effect.

i) Intensity level of the sound being produced.

This is often hard to deal with; however, if managed through effective tool speed selection, coolant use, and noise insulation, the intensity of the noise produced will be reduced.

j) Duration of the sound.

When machining or fabricating activities are being undertaken, the duration of the activity determines how long the sound will last. Therefore, if breaks are taken within each activity, the sound level duration will be reasonably reduced, giving the ear time to adjust to the sound.

k) Individual susceptibility to noise.

The individual's susceptibility to noise is also influenced by age. The type of sound being heard also influences what noise is and is not, as different people perceive the same sound level differently. Hence workers need to wear appropriate Personal Protection Equipment (PPE) specifically designed for them.

l) Size and type of material being worked on.

Hollow materials make much more noise compared to solid materials, therefore a worker needs to anticipate the level of noise he/she would be generating and make every possible effort to manage it.

m) Rate at which work is being done.

Sometimes, very fast work requires that large chucks of material are cut off quickly; this produces a lot of noise. Therefore, work must be appropriately scheduled to ensure that it is done at a reasonable and productive pace.

n) Number of machines working simultaneously.

Sound waves build up when they combine or superimpose on each other. Working with several machines simultaneously tends to compound the noise produced. Hence, planning operations such that, all machines do not necessarily operate at the same time will contribute to noise reduction. Such a plan need not reduce productivity of the workshop.

o) Type of machine being used.

The type of machine used (lathe machines, power hacksaw, drilling machines, surface grinding machine etc.) produces its own noise level as explained in Table 1 and 2. Certain machines tend to produce more noise than others. To prevent excess noise, it will be important to use the right tool for the right job in order to prevent excess noise. For example use a press rather than a hammer to insert a bearing or a slot.

p) Type of work being done.

The type of work being done: for example facing, grinding, boring, drilling etc. may produce a lot of noise compared to bending. Correct working procedures must be used for the right kind of job. This will reduce the noise generated.

q) The nature of the material being worked on.

Certain hard materials such as stainless-steel tend to produce more noise compared to softer materials, such as aluminium. Materials that tend to produce high noise levels can be replaced with other materials that produce less noise for example, adhesives replacing riveting if the change will not affect the performance of the machine.

r) The working hour.

At peak working hours, greater noise is generated since a lot of machines are operated simultaneously. Work must be scheduled so that it is evenly distributed throughout the working hours of the day.

1.2 Justification of Study

From the preceding discussions above, it is clear high noise levels in machine shops needs to be addressed. This would involve the reduction in noise levels to safe values. A safe value is reached if an individual experiences noise levels of 70 dB(A) and below as advised by the Environmental Protection Agency (EPA) Ghana for industrial areas (Environmental Protection Agency Ghana, 2013). However, the International Standard Organization's (ISO) standards require noise levels below 85 dB(A) in machine shops. Despite these standards, research has shown that noise levels reached in most machine shops are much higher than 70 dB(A) (Tasmania, 2008). Reducing noise to a safe level may be approached in three major ways, they are:

1. Managing noise at the source;
2. Mitigating the noise during its propagation to the receiver and;
3. Controlling the noise at the receiver's end.

Though controlling noise produced at the source is the best option (Witt, 2008), it will require tailor-made solutions for every machine, complicating the solution process. This will mean extra cost for each custom made solution. Similarly, controlling noise at the receiver's end through the use of Personal Protection Equipment (PPE) comes at a high cost and may not be used appropriately. Even with one-on-one education on how to use these devices, lapses may still occur (Morris, 2006). Therefore, the best possible alternative is to control noise during its propagation from its source to the receiver.

In controlling noise during its propagation phase, it could either be completely stopped or reduced. To completely stop sound during its propagation, a sound barrier (for example concrete wall) may be used between the source and the receiver, whiles in reducing sound level, a sound absorber such as glass wool maybe used to lag the source. In workshops, sound level reduction may be better than completely stoping sound travel. This is because workers tend to communicate among themselves on the work floor to ensure efficiency, good coordination and high productivity. Failure to communicate may lead to accidents and errors in work. Sound barriers such as a wall may restrict communication and movements. Therefore, sound absorbers (which will reduce the sound levels to safer values) are preferred over sound barriers.

Sound absorbers reduce sound energy as it propagates through pores of fibrous material. Different fibrous materials are used in designing sound absorbers. Some are synthetic or mineral-based, while others are made from natural materials. Some examples of synthetic sound absorbing materials are fibre glass, rock wool and urethane sponge, whiles some natural sound absorbing materials are sheep wool, cotton, cellulose, jute, kenaf and Coconut Fibre (CF). Generally, synthetic sound absorbing materials are better at absorbing sound than natural fibres (Asdrubali , 2006), but, they possess some critical environmental problems. Most of these mineral based products are not bio degradable and can be health hazards. They are often not readily available and much more expensive to produce than natural materials. This makes natural sound absorbing materials a better option.

Among natural sound absorbing materials which are locally available in Ghana are cotton, sheep wool, kenaf, palm nut fibre, plantain stem fibre, sawdust, jute and coconut Fibre. Out of these, CF is readily available and largely sold for domestic consumption; secondly it is often burnt after consumption or discarded as agricultural waste. On the international market, CF in comparison with industrial glass wool is less expensive. Spun CF cost about US$ 0.875/kg, whiles glass wool cost US$ 1.250/kg (Alibaba.com, 2014). Glass wool is known to be carcinogenic while CF has no negative health implications. Finally, CF is being extensively being studied by lots of researchers in the fields of acoustics and engineering, for example, Suddell & Rosemaund (2009), Mahzan *et. al.*, (2010) and Chathurangani *et al.*, (2012). The study of Chathurangani *et al.,(* 2012) has been very inspirational to this research. In his work, he used CF mixed with sawdust to produce a noise reducing wall title and obtained NRC of 0.01 to 0.6. All these discoveries have created an opportunity to contribute more to this area of study. In most of these studies conducted, CF was hardened into rigid panels for testing. Implementing these rigid panels in a workshop will take up space and restrict movement on the workshop floor, hence the need to have a flexible sound absorbing medium that still maintains or enhances CF's sound absorbing properties within a machine shop. This flexible CF layer must include materials that are durable, able to hold CF and will contribute to the total noise reduction of the composite layer.

Some readily available materials that can be considered are; used cloth(en) (cotton or polyester base), nets (fishing nets) and Polyvinyl Chloride Sheets (flexi banners – used for printing). Cotton is generally used as raw material in the textile industry, hence a bigger market is in need of it.

Nets (Fishing Nets) are very strong and do well under harsh conditions, but are rarely available, expensive and needed by the country's growing fishing industry. Secondly, they have large holes in them and so discourage sound absorbing.

Finally, Polyvinyl Chloride Sheets (PVCS) commonly known as Flexi-Banners are often discarded after advertisement or used as covering materials for shelters and are readily available as industrial waste product. Also, PVCS is a rubber based product. It is tougher, showing signs of a potential sound blocking and absorption, a property that will add up to the total sound reduction of CF.

On that note, further research is needed to ascertain the possibility of Coconut Fibre combined with Polyvinyl Chloride Sheets as an affordable, available and viable noise reduction material.

The use of agricultural and industrial waste as a possible noise absorbing material will ultimately contribute to a cleaner and healthier environment. Beyond mitigating the negative health effects of high noise levels, findings from this work may help reduce noise in other agro processing or engineering companies. A reduction in noise levels will ultimately protect the auditory health of employers and employees. This study will initially reveal the true state of noise in some machine shops in Ghana. Data collected will either support or not support the need to undertake such a research. It will also make it possible to predict the likelihood of workers in these companies encountering noise related health issues.

Considering the area to collect this data, Ghana's most industrialised community, particularly Tema Industrial Area, affords numerous machine shops and large machinery on which to carry out this study. This will mimic general machine shop working environments and conditions. Some of the most predominant industries in Tema include oil and gas, harbours and fisheries, cement manufacturing and food processing. The GRATIS Foundation in Team industrial area offers an effective study environment. Very often, machine parts from processing and manufacturing companies in Tema are brought to GRATIS Foundation for either repair or remanufacturing. Their machines work very often, hence generating a lot of noise in the process. This creates the right environmental factors for this research to be conducted.

1.3 Aims and Objectives

The ultimate aim of this study is to reduce noise in machine shops, through insulation of noise sources using a combination of Coconut Fibre and Polyvinyl Chloride Sheets as noise absorbing materials. Specific objectives are:

i) Determination of noise levels in GRATIS machine shop.

ii) Determination of the best combination sequence(s) of Coconut Fibre and Polyvinyl Chloride Sheets (PVCS) that achieves greater sound transmission (TL) and insertion losses (IL) than CF.

iii) Experimental determination of the effect of the best combination of CF and PVCS in reducing noise at GRATIS machine shop.

CHAPTER TWO

2. LITERATURE REVIEW

Acoustics as a field of study has evolved over the years. Its basic theories and terminologies have to be understood to appreciate current developments in that field and how recent findings can be used in solving the problem caused by workshop noise. It also makes it easy to understand factors that have to be considered when developing a solution to abate noise in workshops. In this section, literature will be reviewed on topics such as; nature of sound, noise, basic acoustics terminologies like, amplitude, wave length, frequency and velocity of sound, propagation of sound through a medium, properties of sound absorbing materials, sound absorption and noise reduction.

2.1 Nature of sound, noise and basic acoustics

Sound is a perception of the auditory organ (the ear). It can further be defined as fluctuations of atmospheric pressure about its mean value (Hansen & Goelzer, 2001). Noise is simply unwanted sound, it is a factor of sound subject to the perceiver. What may be perceived as noise to someone may not be the same for another.

2.2 Amplitude, Wave Length, Frequency and Velocity of Sound

Natural sound often contains several pressure variations or frequencies (pure tones). The amplitude of the pressure change of a pure tone (single tonne or single frequency) can be represented by the maximum root mean square value P_{rms} or the maximum amplitude P_{max} with units in Pascal (Pa). The P_{rms} value is taken because, sound pressure variations may be positive or negative.

Frequency (*f*) is the number of pressure variation cycles in a medium per unit time. Its unit is Hertz (Hz). The Octave band center frequency is the widest band used for frequency analysis. Its value which is the geometric mean of the upper and lower frequency limits is used in this study. Wave length (λ) of a sound pressure wave is the distance travelled by a point on a single pressure wave during one cycle. Hence its unit of measurement is meter (m). The Period (T) of a pressure wave is the time taken for a cycle of wave to pass a fixed point. Its unit is seconds (s).

$$\mathbf{T} = \frac{1}{f} \quad \text{.....}\mathbf{1}$$

The velocity (c) of a sound pressure wave is the distance covered by the wave per unit time. Its unit is meters per second (m/s). The speed of a sound pressure wave is a product of the frequency and the wavelength.

$$\mathbf{c} = f\lambda \quad \text{.....}\mathbf{2}$$

As the speed of sound is affected by the temperature of the medium through which it travels, the sound speed in Equation 2 can be rewritten as Equation 3. In this work, c is considered as written as in equation 3.

$$\mathbf{c} = \sqrt{\frac{\gamma R \mathrm{T_k}}{\mathbf{M}}} \quad \text{.....}\mathbf{3}$$

$\mathbf{T_k}$ = Temperature in Kelvin (K)

R = Universal Gas Constant (8.314 J/mole °K)

M = Molecular weight of the gas (M_{Air} = 0.029kg/mole)

γ = Specific heat ratio (1.402)

The total Sound Power (W) for a point source of a sound wave radiated uniformly as a sphere can be calculated by Equation 6, and the Sound Power level (Lw) from an agreed international reference power (W_{ref}) of 10^{12} W is given by Equation 7.

$$(\mathbf{W} = 4\pi r^{2} I) \ldots\ldots\ldots 6$$

$$\mathbf{Lw} = 10\log_{10}\frac{(\mathrm{W})}{(\mathrm{W}_{ref})} = 20\log_{10}\mathrm{W} + 120 \ldots\ldots\ldots 7$$

Sound Pressure Level (L_p) is the measure of the pressure fluctuations greater or lesser than the selected reference sound pressure level (P_{ref}) of 20µPa which is about 0 dB(A). This is the lowest pressure level a young, healthy individual unexposed to loud sound can hear. The maximum L_p a human can bear or the point where pain in the ear begins, is 60 Pa, which is equivalent to 130 dB. The human brain does not perceive all the individual levels between the maximum and minimum ranges of sound pressure fluctuations linearly, but rather, in a kind of compressed scale, represented mostly by a logarithmic base of 10. Hence L_p can be written as Equation 8.

$$\mathbf{L_p} = 10\log_{10}\frac{P^{2}{}_{rms}}{P^{2}{}_{ref}} = 20\log_{10}P^{2}{}_{rms} + 94 \ldots\ldots\ldots 8$$

In determining the Sum Total Sound Pressure Level L_{pt} at a point, Equation 9 is used after “i” different Sound Pressure Levels from different sources are measured at one position.

$$\mathbf{L_{pt}} = 10\log_{10}\left(10^{\frac{L_{p1}}{10}} + 10^{\frac{L_{p2}}{10}} + \cdots + 10^{\frac{L_{pi}}{10}}\right) \ldots\ldots\ldots 9$$

In determining the Total Subtracted Sound Pressure Level L_{ps} at a point, Equation 10 is used for adding “i” different sound pressure levels from different sources measured at one position.

$$\mathbf{L_{ps} = 10\log_{10}\left(10^{\frac{L_{p1}}{10}} - 10^{\frac{L_{p2}}{10}} - \cdots - 10^{\frac{L_{pi}}{10}}\right)} \qquad \ldots\ldots 10$$

2.4 Sound propagation

As sound pressure wave travels, it passes through four sound fields/regions. The first field is the Free Field. It is an area of the sound wave propagation where the wave behaves as it would in open air without any interference. This region can be achieved experimentally by creating a chamber that does not reflect sound but, absorbs most of it. This is called an “anechoic” chamber. The next field is the Near Field, which is the region away from the sound source where the acoustic particle velocity is not in phase with the sound pressure. Measurements in this area should be avoided since sound pressure is not in phase with sound velocity. Accurate data can be obtained by taking measurements at distances greater than one (1) meter.

The Far Field begins where the Near Field ends and extends to infinity. In this region, sound radiated by most machine source will decay at a rate of 6 dB each time the distance from the sound source doubles (Hansen & Goelzer, 2001). Within room enclosures there is Direct Field, which is a field that has not experienced any reflection from an obstacle or surface in a room.

Reverberant Field is a field that has experienced at least a reflection from a surface or boundary within an enclosure containing the sound source. Figure 4 shows the fields of sound and their interactions.

One way of dealing with noise in this phase is to increase the distance between the noise source and the receiver, hence making air a sound absorber that reduces the energy carried by the sound waves travelling through it. In another method, noise absorbers such as CF with high sound absorption and reduction properties replaces naturally occurring air to bring about faster decay of the sound energy Mohd *et al*., (2010). With respect to analysis of CF acoustical characteristics, Fouladi *et al*., (2011) studied fresh wet fibre and industrial prepared mix fibre with a binder using an impedance tube.

Another recent noise reduction method is the Active Noise Cancelation. In this method, a sound wave from a noise source is reproduced at an angle that is out of phase with the noise source, such that they cancel out. Noise reduction through job scheduling has also been studied by Liu *et al.,* (2004).

2.6 Transmission Loss and Sound Absorption Process

High amplitude (loud) sound waves propagating from a source to a receiver can be reduced through the introduction of a sound absorbing barrier (porous material) between the two points. This disrupts the sound pressure wave propagation as it goes through the absorber, and it is transmitted at lower sound pressure level than the incident sound pressure level thereby reducing its intensity. This occurs because, porous materials have high volume to surface area contact and good heat conductivity which happen at very low temperatures. Thus, as sound pressure waves pass through the pores of the sound absorber, the compression and vibration motion of the air particles moving at certain frequencies vibrate the sound absorber's materials. This results in friction and heat losses from the sound pressure waves through the porous materials, causing a reduction in sound energy and a subsequent reduction in sound pressure level.

2.7 Factors affecting transmission losses in sound absorbing materials

Considering CF combined with PVCS as the sound absorbing material, factors that influences the loss of sound pressure as it passes through it must be understood.

Fibre Size: Thinner fibres move more easily than thinker fibres when hit by sound waves, providing greater airflow resistance through friction or vibrating viscous air moving through the pores of the fibre. Thinner fibres are required in greater amounts to meet the same density compared to thicker fibres. This gives thinner fibres denser layers with more tortuous paths for sound waves to cover, therefore increasing friction and subsequent reduction of sound (Jayaraman, 2005).

Fibre Surface Area: As sound moves in the air through the tortuous passages of a porous layer, the resistance it faces within the pore walls causes it to lose more energy. Greater surface areas allow greater contact and friction, resulting in larger energy loss. Manmade fibres are often designed to give more surface areas than naturally occurring fibres (Jayaraman, 2005). This creates more room for waves to strike the fibre and loose energy.

Airflow Resistance (σ)**:** Sound wave propagation occurs initially through air. The extent of air movement resistance through a porous layer influences the friction experienced by a wave as it propagates through the tortuous passages of the absorber. The greater the resistance of an absorber to air movement, the greater the loss of sound energy through heat as a result of friction. σ can be empirically estimated using equation 11 (Fouladi *et al.*, 2011).

$$\boldsymbol{\sigma = 490\ \frac{\rho_{bulk}{}^{1.61}}{d_{fibre}}} \qquad \ldots\ldots 11$$

Porosity (φ)**:** Porosity is the measure of void spaces in a medium; it is the ratio of the void volume to the total volume of the medium. As the sound pressure waves move through viscous air, they should be able to enter the material through its pores in order to interact with its fibres for energy transmission. Porosity can empirically be determined by equation 12.

$$\boldsymbol{\varphi = 1 - \frac{\rho_{bulk}}{\rho_{fibre}}} \qquad \ldots\ldots 12$$

Tortuosity: Tortuosity is a measure of the elongation of a pore's passage through a medium compared to its thickness. It may also be said to be the extent to which the pores meander through a material. Tortuosity affects the extent to which high frequency sound is absorbed (Jayaraman, 2005).

Thickness: Thick materials have demonstrated to have a direct relationship with absorption of lower frequency sound waves, whereas it has no significant effect on higher frequencies. Thick materials have greater sound transmission losses than thinner materials because, sound waves will have to travel a longer distance to be able to go through the thick material. As it travels through the material, it loses energy.

Density: Denser materials demonstrate higher resistance to airflow and a greater resistance or friction against sound wave propagation, which results in loss of sound energy. The higher densities of sound barriers have shown greater absorption of sound with middle and high frequencies (Fouladi *et al.*, 2011), ultimately leading to higher sound transmission losses values.

Compression: Compression of a porous layer affects its other characteristics like porosity, tortuosity and flow resistivity. Fouladi *et al.* (2011) have found that higher compression rates give higher absorption due to reduction in pore sizes and an increase in resistivity.

Surface Impedance: Higher surface impedance of materials gives high reflection of sound waves, resulting in lower absorption properties.

2.8 Sound Transmission Loss, Noise Reduction and Insertion Loss

For the scope of this study, Transmission Loss (TL) and Insertion Loss (IL) will be looked at in determining the usefulness of Coconut Fibre and Polyvinyl Chloride Sheets in noise reduction.

2.8.1 Transmission Loss

Transmission loss (TL) describes the amount of sound energy lost as it passes through a medium, it can be determined from SPL by measuring SPL in front of and behind a specimen as sound travels through it. TL is often used to describe the attenuation provided by sound absorbers and barriers. The ratio of the transmitted energy to the incident energy is known as the transmission loss coefficient (τ), which is frequency dependent. The logarithmic inverse of τ defined by Equation 13 is the Sound Transmission Loss and τ is defined by Equation 14 where W_{ince} is the incident sound energy and W_{trans} is the transmitted sound energy (dB) from the medium as shown in Figure 5 (Lamancusa, 2000).

$$\mathbf{STL} = \mathbf{10}\log_{10}\frac{1}{\tau} \quad \text{......} 13$$

$$\tau = \frac{W_{\text{trans}}}{W_{\text{ince}}} \quad \text{......} 14$$

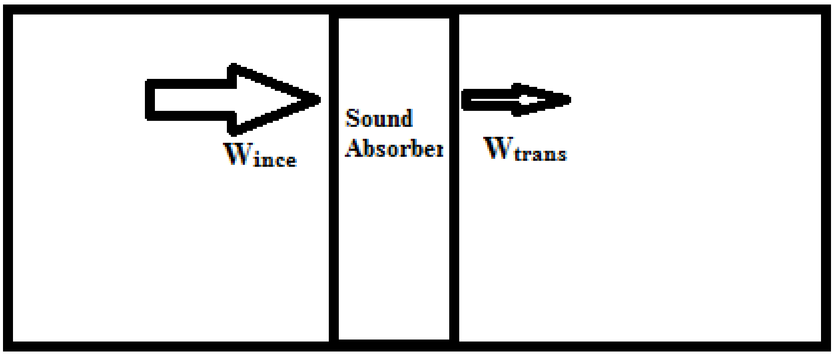

Figure 5. Sound transmission through a medium.

Changing the subject of Equation 7, W, the total sound power from any sound source can be determined using Equation 15.

$$\mathbf{W = W_{ref} 10^{\frac{L_W}{10}}} \quad \text{……………………………………………………15}$$

L_W the Sound Power Level can be determined by Equation 16 which is a combination of Equations 6, 4, 3 and 7.

$$\mathbf{L_W = L_p + 10 \log_{10}\left(\frac{4\pi r^2 P_{ref}}{\rho c W_{ref}}\right)} \quad \text{……………………………………………16}$$

Hence in a Free Field, τ can be determined by measuring the sound pressure level L_p, acoustic impedance ρc and the distance from which the sound source r is measured. Subsequently, replacing the space between these two points with a sound absorbing medium, will give a resultant $\boldsymbol{\tau}$ for that medium as sound waves passes through it. With $\boldsymbol{\tau}$ determined, TL can also be determined using equation 13.

2.8.2 Insertion Loss.

Insertion Loss (IL) is the difference in SPL (Lp_a) at a particular point of reference before the introduction of an obstacle and the SPL (Lp_b) recorded after the introduction of an obstacle at that particular point. It is a positive insertion if sound levels are reduced after insertion and negative if sound levels increase as shown in equation 17. This value is helpful in determining the usefulness of a sound insulating/absorbing material (Hansen & Goelzer, 2001).

$$\mathbf{IL = Lp_a - Lp_b} \quad \text{……………………………………………………………17}$$

2.8.4 Noise Reduction Co-efficient

Noise Reduction Co-efficient (NRC) is the arithmetic average of the Sound Absorption Coefficient for four audible frequencies 250, 500, 1000 and 2000 Hz. A newer method being employed is the Sound Absorption Average (SAA) (Bécot *et al.*, 2013). However in Chathurangani *et al.,* (2012). Noise Reduction Co-efficient of an absorbing material was expressed as shown in equation 18. It was defined as the ratio of the difference in sound pressure level of the incident and transmitted sound to the incident sound on that material.

$$\left(\mathbf{NRC} = \frac{\mathrm{Lp}_{ince} - \mathrm{Lp}_{trans}}{\mathrm{Lp}_{ince}}\right) \ldots\ldots 18$$

$\mathbf{Lp}_{ince}$ = Incident SPL $\mathbf{Lp}_{trans}$ = Transmitted SPL.

2.8.5 Noise Reduction

Noise Reduction (NR) describes the amount of sound lost when an obstacle is placed between the sound source and the receiver. It is defined mathematically in Equation 19 as the difference between the SPL measured at the front of the obstacle (Lp_1) and that observed behind it (Lp_2). Considering the Free field region of sound wave travel, and ignoring/preventing sound losses over the edges of the obstacle, the noise reduction has been found to be equal to the sound transmission loss (Hansen & Goelzer, 2001).

$$\mathbf{NR = Lp_1 - Lp_2} \quad \text{.........} \quad 19$$

These theories together with literature that has been reviewed sets the foundation for a study into noise abatement.

CHAPTER THREE

3. MATERIALS AND METHODS

In the quest to fulfil the objectives of the study, the experiment has been divided into four (4) main sections. They are:

a) Determination of workshop noise level in GRATIS workshop;
b) Testing of a sound measuring chamber;
c) Determine the best combination sequence(s) of Coconut Fibre and Polyvinyl Chloride Sheets (PVCS) that achieves the greatest sound transmission (TL) and insertion losses (IL) through experimentation and statistical analysis (ie. Analysis of Variance (ANOVA)).
d) Determination of the effect of such a specimen in (c) on workshop noise level;

Factors that will be varied during experimentation will be the thickness of CF and the combination sequence of the PVCS and the CF. These two will be considered because the size of the curtain will be a very critical factor if the outcome will have to be installed in a workshop floor, secondly, available resource for testing other factors.

3.1 Determination of workshop noise level

Noise level at GRATIS Foundation in Tema Industrial Area was determined in a noise survey carried out during peak working and non-working hours. The following materials were used for the experiment: Surveyor's Tape Measure; Engineers Chalk and Sound Level Meter – Extech Digital Datalogging Model HD600 Table 7.

The design and planning of the measuring process is shown in Figure 7, an outline of the workshop floor was drawn using AutoCAD-2006 software. The position of each machine on the workshop floor was measured and transferred onto the outline. Each machine's position was referenced from the lower right hand comer of the workshop floor which had coordinates 0, 0. Points where workers often stood to operate the machines were also marked on the outline. The entire outline was divided into a grid with a spacing of 3500.00 mm by 4000.00 mm on the ground, with each area measuring $14X10^6$ mm^2. Points where lines intersected were chosen as positions from which measurements will be taken as shown in Figure 7. These measuring positions were also selected in accordance with ISO 16032 standard (ACOUSTICS – Measurement of sound pressure level from service equipment in buildings – Engineering method). This standard required that the SLM was placed one meter (1m) away from the noise source. This made it possible to take measurements in the Free Field zone of the sound wave, where acoustic particle velocity was in phase with the pressure it exerted, allowing for correct results for the sound level measured. Finally, the points generated on the outline were transferred onto the shop floor using a chalk and a surveyor's tape measure.

The unit of observation selected for the SPL measurements was the "A" weighted decibels dB(A) scale. The "A" weighted scale was chosen because it gave results similar to sound perceived by the human ear. The first set of measurements was scheduled to be taken in the morning when no sound producing engineering activity was being performed and no machine was in use. The second set was taken in the afternoon when all machines were in use, and other engineering activities were being conducted.

Table 3. Positions and state of Machine in GRATIS workshop with respect to workshop floor in Figure 7.

Machine Number	Machine Name	Operational State	X	Y	Z
			Position Coordinate (mm)		
1	Pedestal Grinder 1	Operational	6820	1130	860
2	Pedestal Grinder 2	Non-Operational	5760	1130	980
3	Hobbing (Gear Cutting Machine)	Non-Operational	3060	1240	1190
4	Universal Milling Machine 1	Non-Operational	2940	12450	1160
5	Universal Milling Machine 2	Non-Operational	3150	14780	1360
6	Universal Milling Machine 3	Non-Operational	3020	16740	1270
7	Lathe Machine 1	Operational	3070	19220	1210
8	Lathe Machine 2	Operational	2720	22550	1080
9	Drilling Machine 1	Non-Operational	3550	24850	640
10	Lathe Machine 3	Operational	10380	11470	1320
11	Drilling Machine 2	Non-Operational	7530	10010	830
12	Surface Grinder	Non-Operational	7230	17490	1040
13	lathe Machine 4	Non-Operational	17250	7030	1030
14	Hydraulic Press	Non-Operational	19030	22550	1450
15	Hand Held Grinding Machine	Operational	17900	33420	1000
16	Shaping Machine	Non-Operational	10250	22320	1010

Then after, the sound pressure level was measured as follows:

i. With the SLM held 1.5 m above the ground, Sound Pressure Level (L_p) was taken for the first marked position.

ii. The measurement was instantly recorded.

iii. Procedures i and ii were repeated for all sixty nine (69) marked positions until noise level covering the entire workshop floor was measured. The points are clearly shown with the round donuts in Figure 7.

iv. Finally, iii was repeated for the afternoon session when all the functioning machines were actively being used.

After measuring sound pressure levels, the data was analysed as follows:

i. Two noise maps were plotted using colour codes which symbolised different sound level ranges. The first map represented no engineering activity or machine operation while the second represented active engineering activity and machine operation.
ii. The two noise maps were compared to identify how much noise was generated after operations begun.
iii. The second noise map was analysed to identify the areas (machines) that generated highest noise levels.
iv. The noise levels measured were compared to the recommended standard to determine if they were above or below.

3.2 Testing of sound measuring chamber

The sound measuring chamber shown in Figure 8 and Figure 9 was the environment within which varying frequencies of sound will be produced and measured across each specimen. Sound level measurements were taken in front of and behind each specimen. Thus the chamber had a holder that kept the specimens in position for each test. It was installed in a physics laboratory which had its windows insulated with foam, this helped cut out noise from outside. The experiment was also carried out at periods when there was very little human activity, particularly early in the morning.

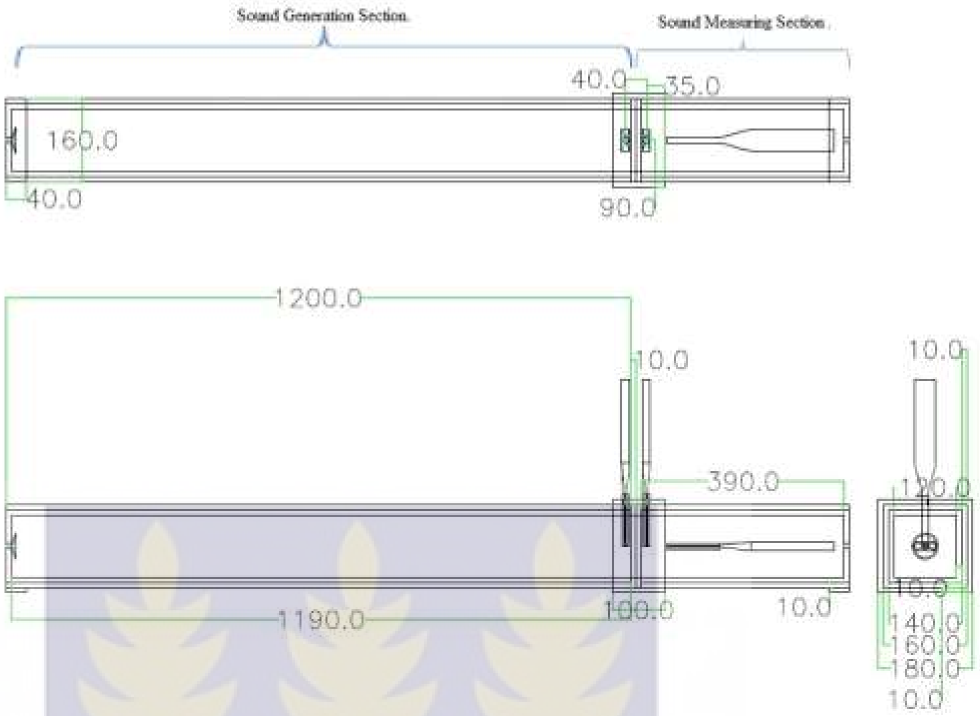

Figure 8. Sound Measuring Chamber

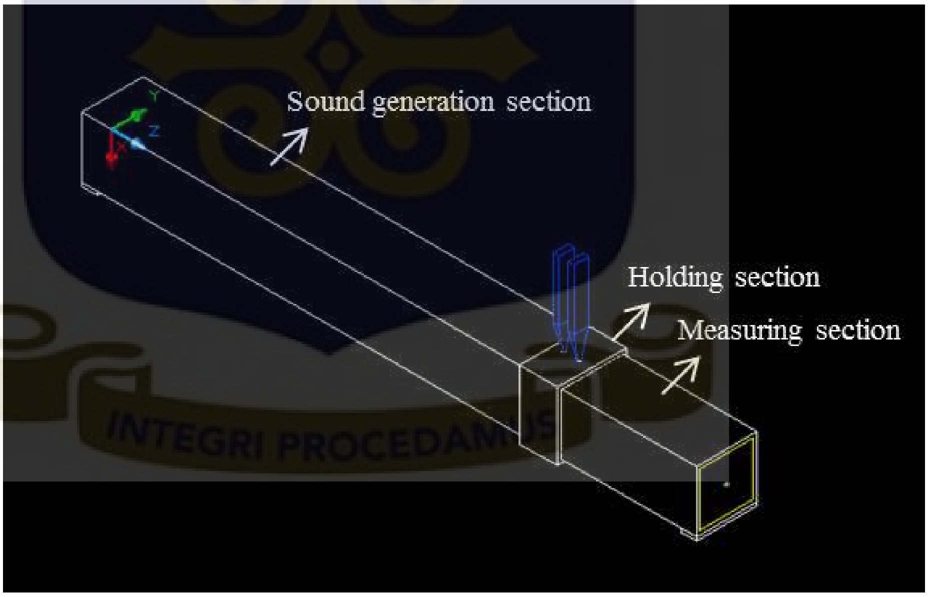

Figure 9. Isometric View of Sound Measuring Chamber.

To conduct the experiment, the following materials were used; Plywood (10 mm thick); Formaker glue and nails (Fasteners); Foam; Four Ohms (4Ω) speaker and Electrical Wire. The sound measuring chamber was then fabricated; it was made from a single layer of 10 mm thick plywood, lined with 10 mm foam sheet and held together by nails and glue. Glue was introduced so as to make the joints bond stronger. After construction, the sound measuring chamber had a total length of 1590 mm, and a height and width of 180 mm each. The length of 1590 mm was divided into two (2) sections: the sound generation section and the sound measurement section. In order to make correct measurements of the sound generated, the SLM had to be placed at least, one meter (1 m) away from the sound source. For that reason, the speaker was placed at the extreme end of the sound generation section, which was 1200 mm away from the point of measurement.

The inner portions of the chamber was lined with foam, to prevent reverberation of sound waves from the wall of the chamber by absorbing it, hence, allowing sound waves directly from the speaker to hit the specimen directly. It also contributed to the insulation of the sound chamber from external sound. The inner section of the measuring chamber had an area of (120 x 120 mm) 14400 mm^2. This was selected so that specimens which were designed to have an area of (160 x 160 mm) 32400 mm^2 could overlap the edges of the measuring chamber and also be held in place by the casing of the Holding Section which had an area of 32400 mm^2. The empty cavity of area 14400 mm^2 is the section where sound will pass through the chamber and the specimen. This setup also prevents sound from passing over the edges but rather, through the specimen, this can be clearly seen in Figure 8. The holding section allows sound passing through the specimen to travel to the other side of the chamber. Figure 9 and Figure 10 give details of the chamber. The sound measuring chamber was set up in a lab which had all its windows sealed with foam so that noise front the environments will be minimised to the barest minimum. The quality of the sound measuring chamber had to be tested. Details of this test are outlined below.

To test the chamber, the following process where followed:

i. The sound measuring chamber was setup at a location within the physics lab where the sound measurements would be taken.

ii. Sound level measurement was taken right above the setup at 4 different locations as shown with black donuts in Figure 10 one after another.

iii. Sound level measurements were then taken within the chamber at position B.

iv. Since these measurements were to ascertain whether the measuring chamber could isolate its cavity from the environment, the SPL of the external environment ie. the environment above the measuring chamber and its internal cavity were compared to find any considerable differences in measurements.

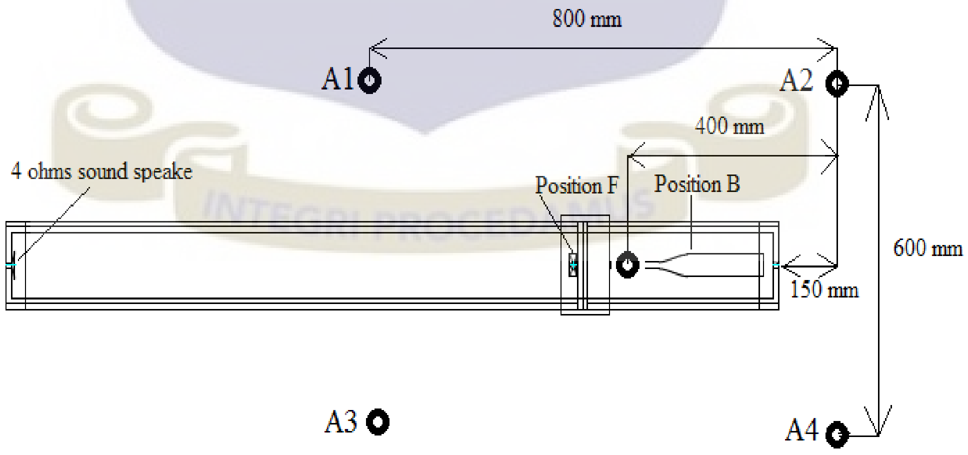

Figure 10. Sound level measurement positions around sound measuring chamber.

The averages of the SPL measured at the four donut positions were compared to the mean SPL measurement within the measuring chamber. This was repeated four times. Then after, the difference of the two (2) measurements (environment and the measuring chamber) was determined.

3.3 Determination of the best combination sequence(s) of Coconut Fibre (CF) and Polyvinyl Chloride Sheets (PVCS) that achieves the greatest sound transmission (TL) and insertion losses (IL)

With the aim of using agricultural and advertisement/industrial waste (Coconut Fibre and Flexi Banner/ Polyvinyl Chloride Sheet) as resources for the development of a noise insulation material, the waste materials had to be prepared into appropriate forms to be tested in the lab. The following materials were selected; Knife; Pair of scissors; Soldering iron; Wooden Mould; Hydraulic Press; Coconut Fibre; Polyvinyl Chloride Sheets; Sound Measuring Chamber; Signal Generator; Sound Level Meter (Extech Digital Datalogging Model HD600) and; a computer. Then after, Coconut Fibre was collected and prepared into slabs for testing. First a coconut dump site as shown in Figure 11, was located on the east side of the University of Ghana Campus and some dry coconut husk selected from the dump. Using a machete, the husk was cut to expose most of the fibre so it could be stripped out manually. After stripping, it was dried in the sun for twenty four (24) hours, which is two (2) days of sun drying as shown in Figure 12. Samples were placed in an oven at a temperature of one hundred degrees (100°) for 24 hours. Moisture content (mc) calculated on wet bases.

$$\textbf{Miosture Content} = \frac{\textbf{Weight before drying} - \textbf{Weight after drying}}{\textbf{Weight before drying}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{20}$$

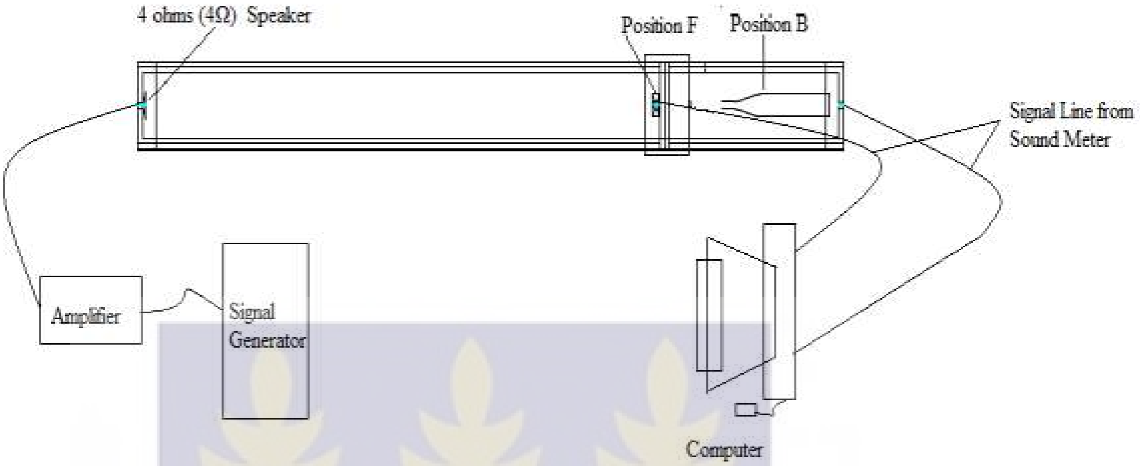

Figure 15. Sketch of Experimental Setup.

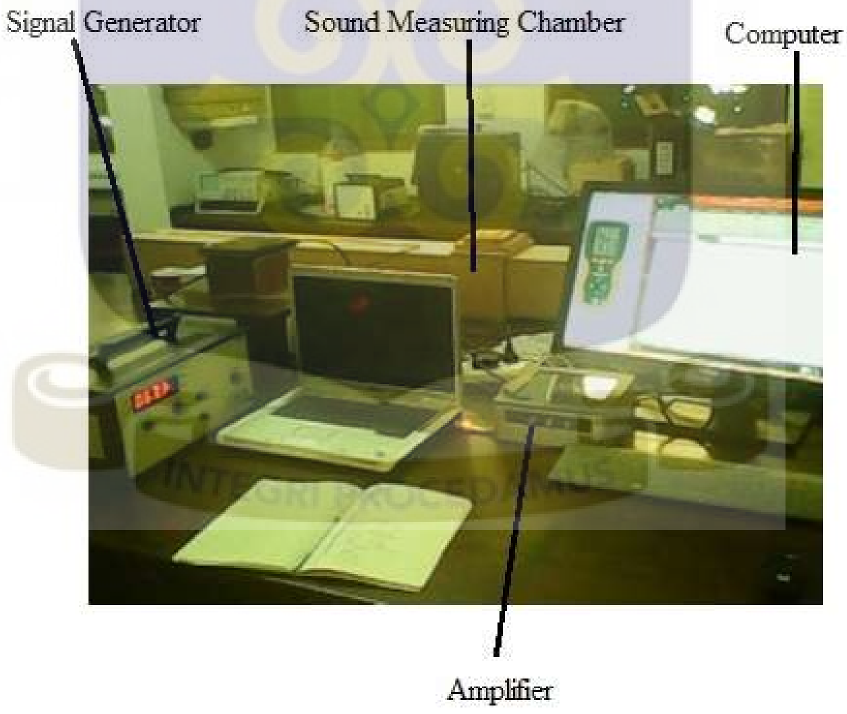

Figure 16. Laboratory Setup for the determination of sound insertion and transmission losses.

After setting up, the procedure used were as follows:

1. At the extreme end of the sound producing chamber, a loud speaker of four (4) ohms was electrically connected to a signal generator.
2. With the chamber empty, a SLM was placed at “F” shown in Figure 15 to measure the ambient sound level in front of the specimen.
3. With the amplifier at a fixed amplification turned off, the signal frequency was set to 31.5 Hz, and the amplifier was turned on.
4. The sound level was measured and recorded by the SLM in dB(A) as “L_pF”.
5. Steps 3 and 4 were repeated for octave band center frequencies 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16000 Hz.
6. Coconut Fibre of 10 mm thickness was introduced and secured uprightly in the holding section by pushing the sound generating and measuring chamber together until the specimen was firmly held in place.
7. Activities 4 and 5 were repeated, but this time, the sound level measured was recorded as “LpF2”.
8. Activities 2, 3, 4, 5, 6 and 7 were repeated, but this time with the SLM at position “B”, the sound level when empty recorded as “L_pB” and with specimen as LpB2”.
9. Activities 2,3,4,5,6,7 and 8 were repeated for all the specimens, namely:
    a. PVCS[3];
    b. 10 mm CF+ PVCS;
    c. Perforated PVCS (PPCVS) + 10 mm CF + PVCS;
    d. PVCS + 10 mm CF + PVCS;
    e. CF 20 mm;

---

[3] The specimen is arranged in the manner stated from left to right considering Figure 9

f. PVCS;
g. 20 mm CF+ PVCS;
h. Perforated PVCS (PPCVS) + 20 mm CF + PVCS;
i. PVCS + 20 mm CF + PVCS;
j. CF 30 mm;
k. PVCS;
l. 30 mm CF+ PVCS;
m. Perforated PVCS (PPCVS) + 30 mm CF + PVCS and
n. PVCS + 30 mm CF + PVCS.

In analysing the data, sound level measurements from the workshop, before and after work were compared to reveal whether or not sound experienced in the workshop was above or below the expected levels. The second set of data was measurement in the laboratory. For every sound level recorded for each specimen, a comparison of insertion loss was done for different thicknesses of the CF combined with Polyvinyl Chloride Sheets. This was also repeated for Transmission loss of the same set of specimens.

Finally, using a complete randomised design, an analysis of variance was calculated using the GenStat Software Release 9.2, to find out if the sound transmission and insertion losses were significantly different for the five (5) sound absorbers combination sequences, three (3) thickness and the ten (10) frequencies used. The specimen (combination sequence) with the highest loss (ie. TL and IL) were selected as the most effective sound absorbing material and implemented in the workshop.

The follow hypothesis will be tested for Transmission Loss (TL):

1. H_0: CF and PVCS combination sequences will have no effect on TL.

   H_1: CF and PVCS Combination sequences do have a significant effect on TL.
2. H_0: Thickness will have no significant effect on TL.

   H_1: Thickness does have a significant effect on TL.
3. H_0: Frequency will have no effect on TL.

   H_1: Frequency does have a significant effect on TL.
4. H_0: CF and PVCS combination sequences and Thickness interaction will have no effect on TL.

   H_1: CF and PVCS combination sequences and Thickness do have a significant effect on TL.
5. H_0: CF and PVCS combination sequences and Frequency interaction will have no effect on TL.

   H_1: CF and PVCS combination sequences and Frequency do have a significant effect on TL.
6. H_0: Frequency and Thickness interaction will have no effect on TL.

   H_1: Frequency and Thickness interaction do have a significant effect on TL.
7. H_0: Combination Sequences, Frequency and Thickness interactions will have no effect on TL.

   H_1: Combination Sequences, Frequency and Thickness interactions do have a significant effect on TL.

The following hypothesis will be tested for Insertion Loss (IL).

1. H_0: CF and PVCS combination sequences will have no effect on IL.

   H_1: CF and PVCS Combination sequences do have a significant effect on IL.
2. H_0: Thickness will have no significant effect on IL.

H_1: Thickness does have a significant effect on IL.

3. H_0: Frequency will have no effect on IL.

   H_1: Frequency does have a significant effect on IL.

4. H_0: CF and PVCS combination sequences and Thickness interaction will have no effect on IL.

   H_1: CF and PVCS combination sequences and Thickness do have a significant effect on IL.

5. H_0: CF and PVCS combination sequences and Frequency interaction will have no effect on IL.

   H_1: CF and PVCS combination sequences and Frequency do have a significant effect on IL.

6. H_0: Frequency and Thickness interaction will have no effect on IL.

   H_1: Frequency and Thickness interaction do have a significant effect on IL.

7. H_0: Combination Sequences, Frequency and Thickness interactions will have no effect on IL.

   H_1: Combination Sequences, Frequency and Thickness interactions do have a significant effect on IL.

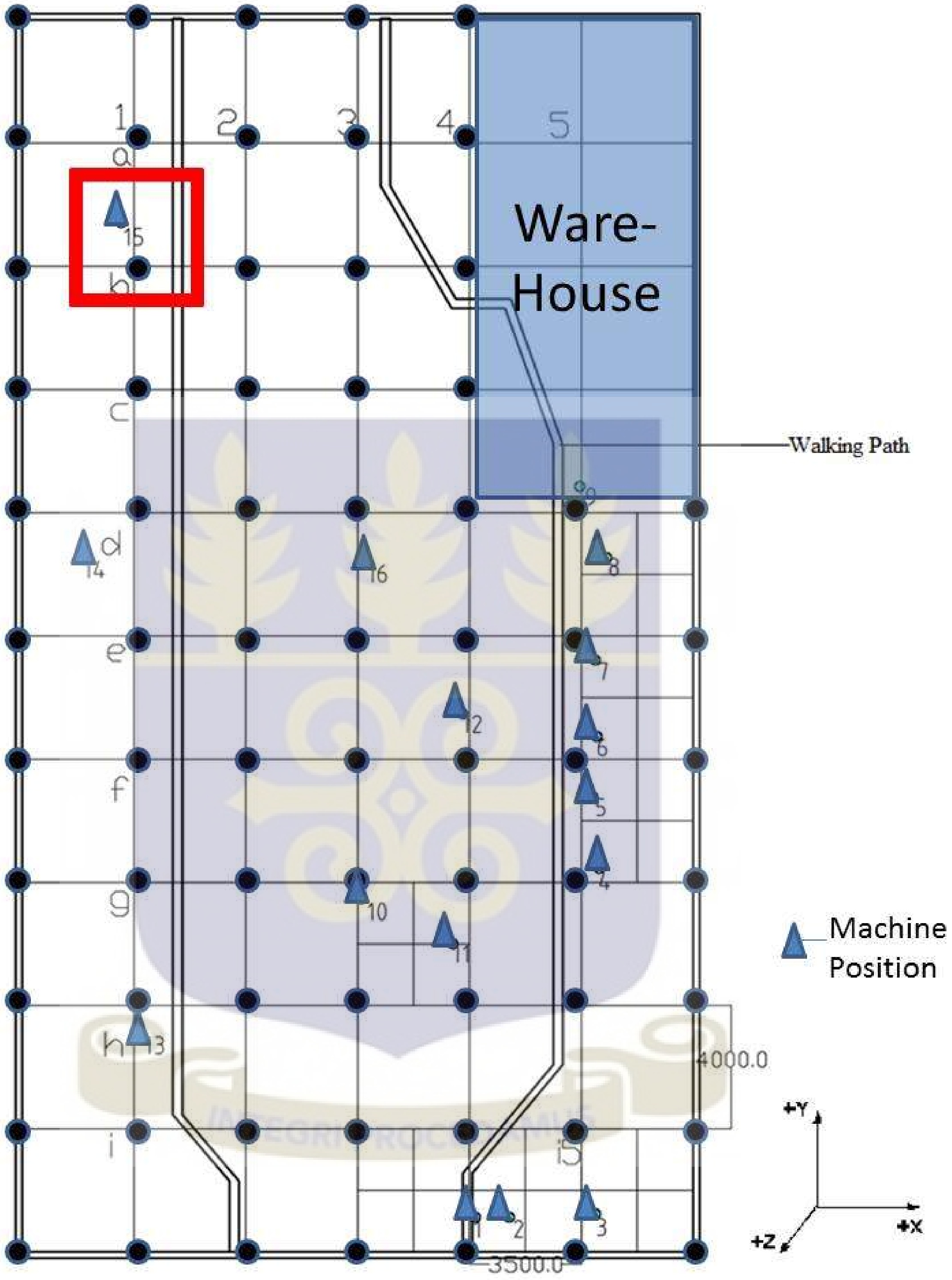

Figure 18. Insulating area shown on the workshop floor.

To analyse the results, the procedure below was followed;

i. The (third) noise map generated from the SPL measurements in the workshop from the above experiment was compared to the second noise map (in the workshop during peak hours, without any noise abatement solution). This was to find out if there had been any rise or drop in the SPL measured after installing the fabricated noise insulation compartment.

ii. The noise levels measured from the third survey were compared to the recommended standard to determine they were above or below.


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4.2 Testing of the sound measuring chamber

Results from measurements of SPL in the lab room and the sound measuring chamber where the experiments were going to take place, are outlined in Table 4.

Table 4. Sound Level Measurement above the chamber and within the chamber.

	A1 dB(A)	**A2 dB(A)**	**A3 dB(A)**	**A4 dB(A)**	**POINT B dB(A)**
1	36.4	36.4	36.4	36.4	30.4
2	36.4	36.4	36.4	36.4	30.4
3	36.4	36.4	36.4	36.4	30.4
4	36.4	36.4	36.4	36.4	30.4
Average	36.4 dB(A)				30.4 dB(A)
Difference	6.0 dB(A)				

An average of 36.4 dB (A), was obtained for the SPL measured at the four (4) different positions (A1, A2, A3 and A4). Then after, SPL was measured in the chamber to find out if there were any variations in results. The average SPL recorded in the measuring chamber was 30.4 dB (A), which was 6 dB (A) below the SPL in the lab.

With a SPL reduction of 6.0 dB (A) within the measuring chamber, from external sound in the fairly quiet laboratory, it was clear that the chamber substantially reduced external noise from the outside. This meant external sound would rarely affect internal SPL measurements during the experimentation.

Figure 22. Plain Polyvinyl Chloride Sheet. and Figure 23. Perforated Polyvinyl Chloride Sheet were samples combined in varying combination sequences with CF for testing in a sound measuring chamber.

4.3.1 Transmission Loss

After testing for TL in four (4) variations of 10 mm CF combined with PVCS, it was observed that a combination sequence of “PVCS, 10 mm CF and PVCS” produced the greatest TL as shown in Figure 24. The reason is possibly due to the absence of passage ways/air pores in the PVCS that wrapped around both sides of the CF. The effectiveness of this combination can be clearly seen by comparing the TL of 10 mm thick CF with Combined “PVCS, 10 mm CF and PVCS”. At 8000 Hz, TL increased from 8.7 dB(A) to 37.1 dB(A) on 10 mm CF to Combined “PVCS, 10 mm CF and PVCS” as shown in Figure 24. At 2000 Hz, a significant drop is observed for PVCS. This is possibly due to the vibration of the membrane by the incidence sound wave as it hits it, this causes the air behind it to vibrate more and hence increase the SPL behind it, causing a negative TL.

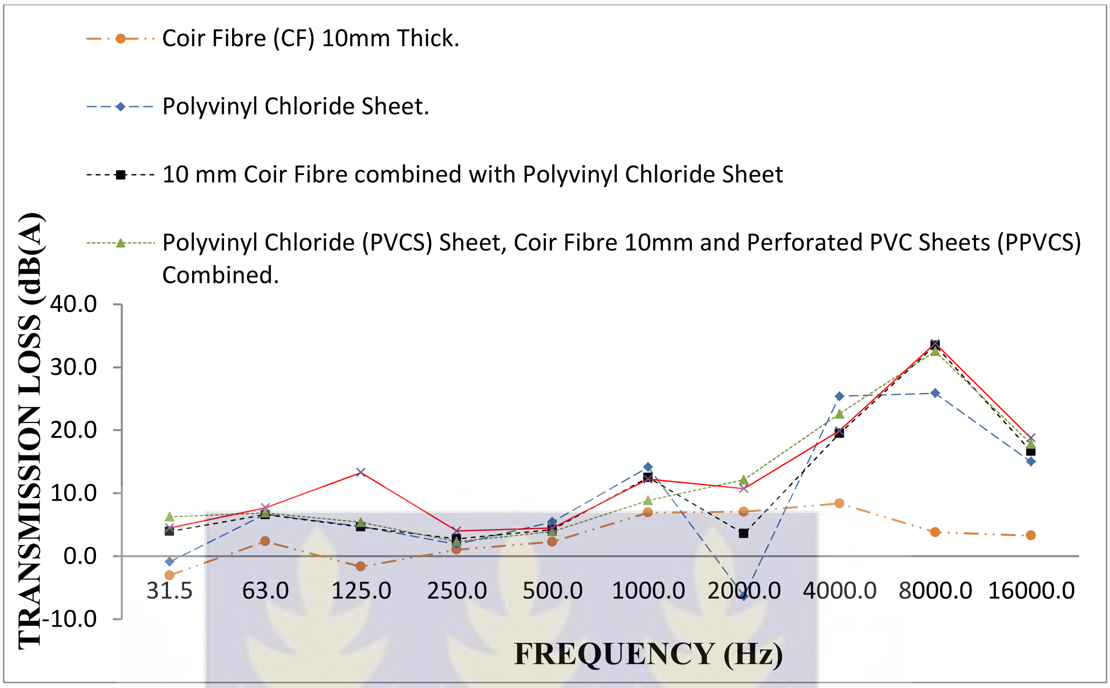

Figure 24. A graph of transmission loss against frequency of varying combinations of 10 mm CF with PVCS.

After repeating the experiments for 20 mm and 30 mm CF with varying combinations of PVCS similar to the 10 mm CF combinations, TL was observed to be rising with combination sequences of 20 mm and 30 mm thick CF combined with PVCS. They were arranged in the order; “PVCS, 20 mm CF and PVCS” (for 20 mm CF) and “PVCS, 30 mm CF and PVCS” (for 30 mm CF). These observations are shown in Figure 25 and Figure 26. However, comparing the results of combined” PVCS, CF and PVCS” for 10 mm, 20 mm and 30 mm thick CF, it was observed that Combined “PVCS, 30 mm CF and PVCS” produced the highest TL along most frequencies as shown in Figure 27. The highest TL of 37.1 dB (A) was observed at 8000 (Hz). A possible explanation is that, Combined “PVCS, 30 mm CF and PVCS” having a thicker CF lining reflects and absorbs more sound energy compared to Combined “PVCS, 10 mm CF and PVCS” and Combined “PVCS, 20 mm CF and PVCS”. It must be noted that from Figure 25, Figure 26 and Figure 27, combined “PVCS, CF and

PPVC" arrangements have TL values slightly lesser than combined "PVCS, CF and PVC". It recorded a high TL of 38.6 dB(A). This possibly implies that when developing noise reduction panels with PVCS collected of the street with perforations/cuts in them, they can be combined with CF achieve high TL.

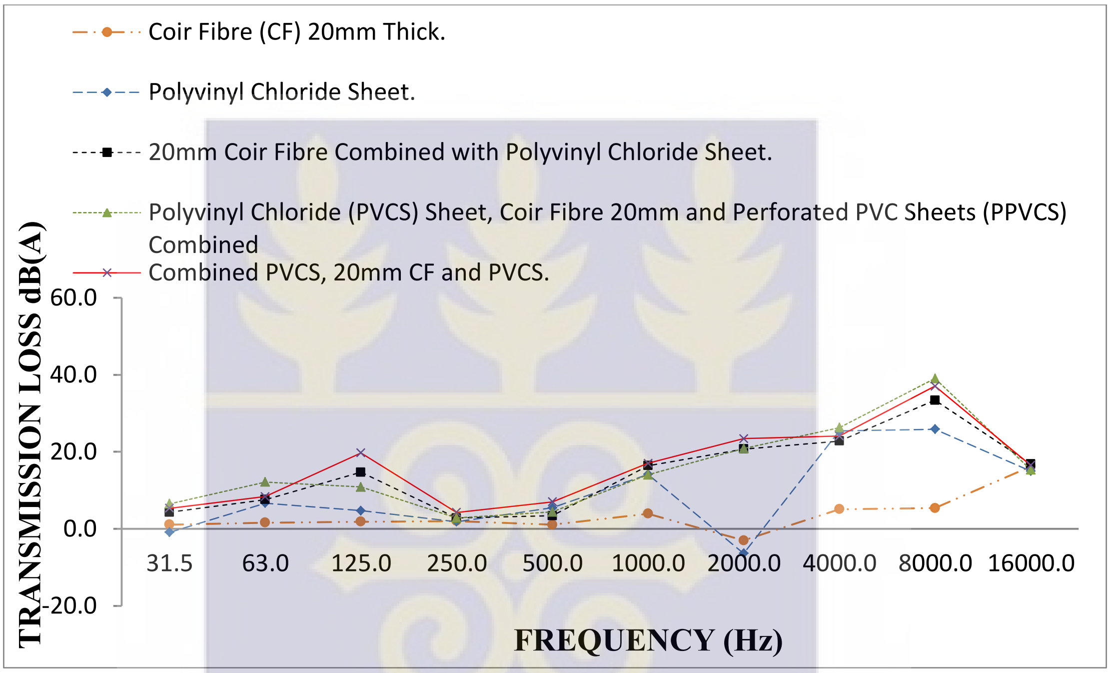

Figure 25. A graph of transmission loss against frequency of varying combinations of 20 mm CF with PVCS.

Combined PVCS, CF and Perforated CF had the second highest TL because, the perforations in the PVCS made it possible for sound waves to penetrate the CF and be absorbed as it passed through the tortuous passages. "PVCS, CF and Perforated PVCS" for 10 and 20 recorded their highest TL of 32.5 dB (A) at 8000 Hz, 39.0 dB (A) at 8000 Hz respectively. Yet still, their TL performance was generally below the results of the combination sequence PVCS, CF and PVCS for 10, 20 and 30 mm.

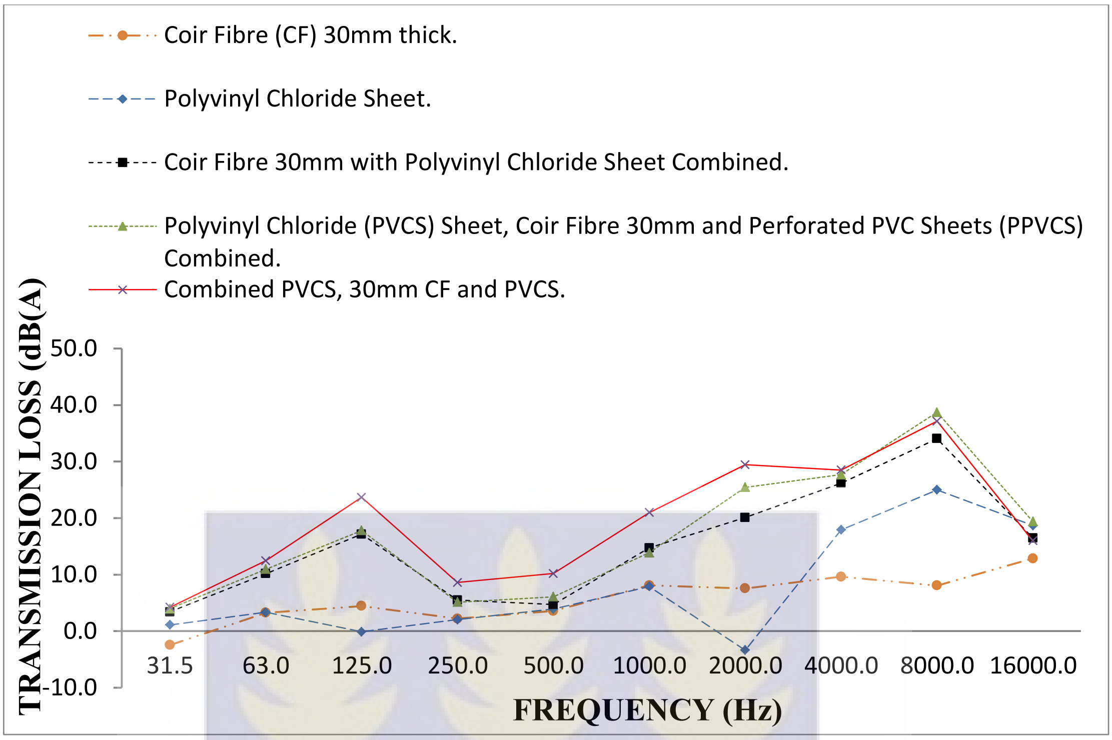

Figure 26. A graph of transmission loss against frequency for varying combinations of 30 mm CF with PVCS.

In the case of using only CF as a sound absorber as shown in Figure 28, it was identified that, 30 mm CF produced the highest TL of 12.9 dB(A) at 16000 Hz compared to 8.4 dB(A) at 10 mm CF and 12.4 dB(A) at 20 mm CF. This trend shows that increasing thickness has an effect on TL.

Further statistical analysis was carried out to find out if the TL recorded were significantly different for the four (4) sound absorbers combination sequences, three (3) thickness and the ten (10) frequencies used for the TL test.

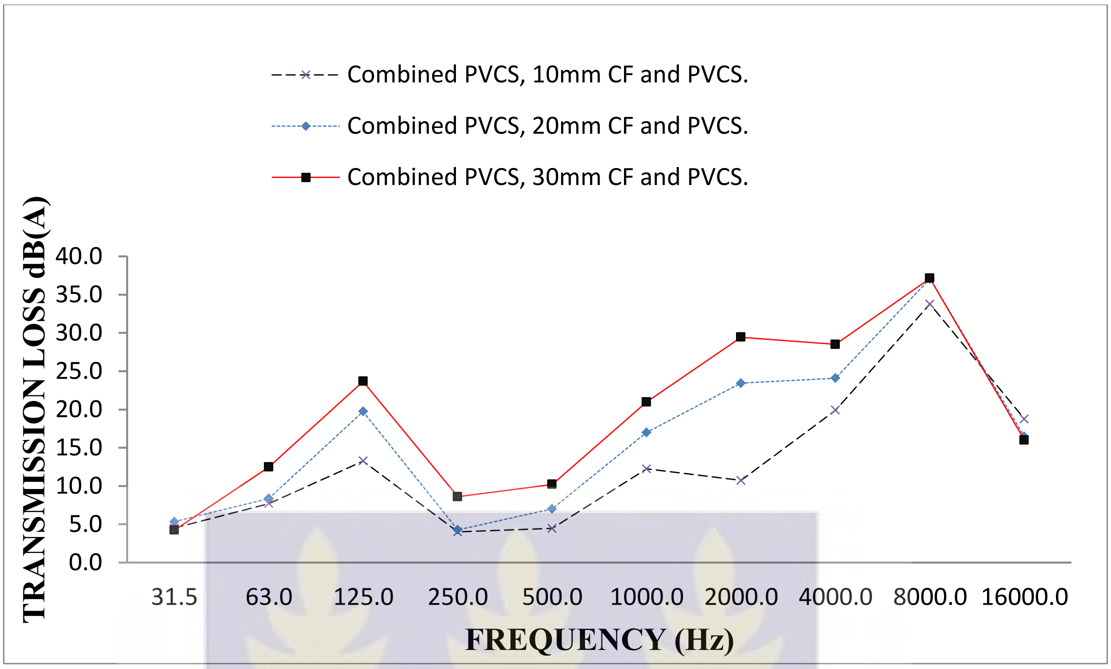

Figure 27. A graph of transmission loss against frequency for 10, 20 and 30 mm CF combined with PVCS on both ends.

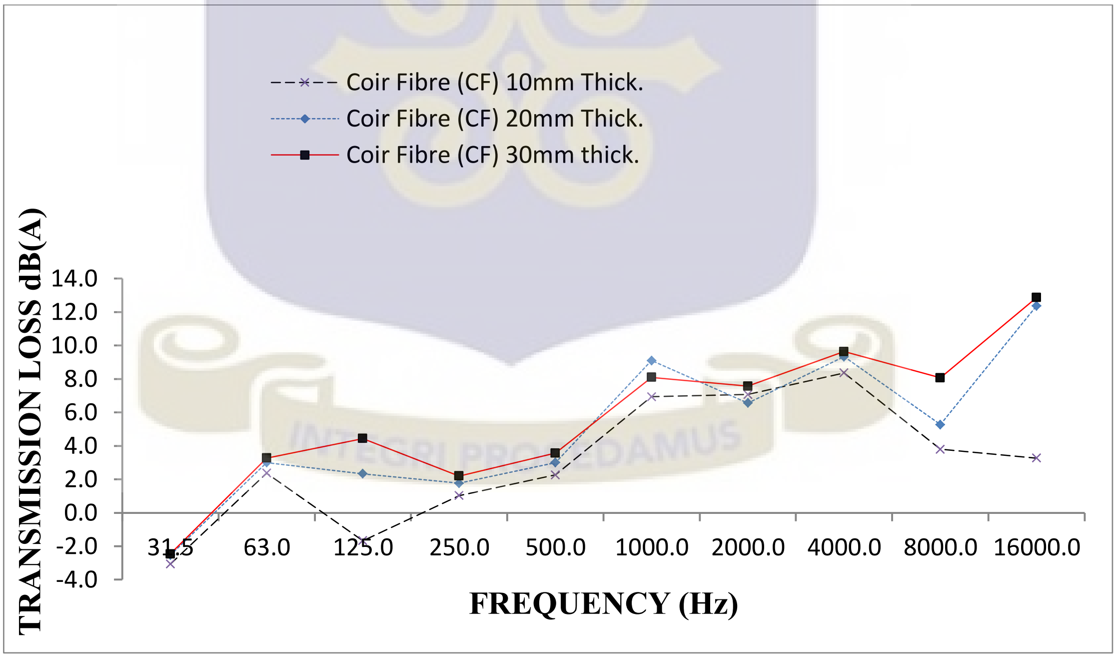

Figure 28. A graph of transmission loss against frequency for 10, 20 and 30 mm CF.

From Table 5, the ANOVA results showed that, there were significant differences in the sound absorption performances of the four sound absorber combinations used. It was found that, the performances of PVCS + CF + PVCS had a greater TL average of 15.96 dB (A) and was significantly different from PVCS + CF + PPVCS which had a TL of 13.48 dB (A). These averages were also significantly different from the performance of CF and PVCS + CF, with PVCS + CF being higher than CF. This observation was as a result of the differences between their means being greater than the l.s.d of 1.64. Hence, H_0 was rejected and H_1 accepted .i.e., CF and PVCS combination sequences (CS) did have a significant effect on TL. PVCS + CF + PVCS being the most appropriate absorber panel to be selected.

Table 5. Analysis of variance (ANOVA) for TL.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CS	3	7161.89	2387.30	76.52	<0.001
TH	2	1372.74	686.37	22.00	<0.001
FQ	9	15975.55	1775.06	56.90	<0.001
CS.TH	6	136.70	22.78	0.73	0.626
CS.FQ	27	2875.31	106.49	3.41	<0.001
TH.FQ	18	574.24	31.90	1.02	0.435
CS.TH.FQ	54	504.68	9.35	0.30	1.000
Residual	240	7487.57	31.20		
Total	359	36088.67			

ss = sum of squares, df = degree of freedom, ms = mean square, vr = variance ratio, F pr = F probability.

From Table 5, there were significant differences in TL as a result of the 3 varying thickness of the CF and PVCS combinations. Hence we rejected H_0 and accepted H_1, therefore thickness did have a significant effect on TL. With an l.s.d of 1.42, 30 mm thick combination sequence (CS) performed better than 20 and 10 mm thick CSs. This implied that, when making sound absorbers from CF, thicker fibres produce better TLs. results.

With respect to the frequency having an effect on TL, H_0 was rejected and H_1

accepted, i.e. Frequency does have a significant effect on TL. With an l.s.d of 2.593, it was observed that, at 8000 Hz, the highest TL average of 25.15 dB(A) were experienced, followed by 16000 Hz at 19.31 dB(A), 4000 Hz at 19.14 dB(A), 2000 dB(A) at 14.94 dB(A) and 1000 Hz at 10.5 dB(A). This implies that, the various CS were most effective within the frequency ranges of 1000 - 16000 Hz. These frequency ranges are the frequencies within which most workshop machines often operate.

Considering the interaction of CS and thickness, H_0 was rejected, which implied that, PVCS combination sequences and thickness interaction will have no significant effect on TL. However, with an l.s.d of 2.841, it was observed that, PVCS + 30 mm CF + PVCS and PVCS + 30 mm CF + PPVCS had the highest TL average of 19.1 and 17.1 dB(A). Even though results were not significantly different, it was inferred from the performances that, PVCS + 30 mm CF + PVCS combinations will be much appropriate. However, if the PVCS available have perforations in them, they could be still be effectively used i.e. PVCS + 30 mm CF + PPVCS.

When CS and frequencies interactions were considered, H_0 was rejected and H_1 accepted. That is, CS and frequencies had a significant effect on TL. It was identified that PVCS + CF + PVCS, PVC + CF + PPVCS and PVCS + CF had higher TL than CF only at frequencies from 31.5 – 16000 Hz and they could also be used interchangeably. Their best TLs were observed at 8000 Hz with values of 30.27, 32.7 and 31.08 dB (A) respectively. Other frequencies they performed well at were 4000, 16000, 2000 and 1000 Hz. From this analysis, it has been realised that, thicker CF with PVC lining produced significantly higher TL between 1000 – 16000 HZ.

4.3.2 Insertion Loss

After testing for IL on “10 mm thick CF”, PVCS, “10 mm CF combined with PVCS”, “PVCS combined with 10 mm CF and PPVCS” and “Combined PVCS, 10 mm CF and PVCS”, it was observed that “Combined PVCS, 10 mm CF and PVCS” produced the greatest IL as shown in Figure 29. The reason for this is possibly due to the absence of passage ways/air pores in the PVCS that was wrapped around both sides of the CF, which reduced the movement of sound waves via air through the medium. After repeating the same experiments for 20 mm and 30 mm CF with four (4) similar varying combinations of PVCS and CF, IL results shown in Figure 30, Figure 32 and Figure 33 revealed that, maximum IL occurred when the combination sequences for CF of thicknesses 10 mm, 20 mm and 30 mm were combined in the order, PVCS, 10 mm CF

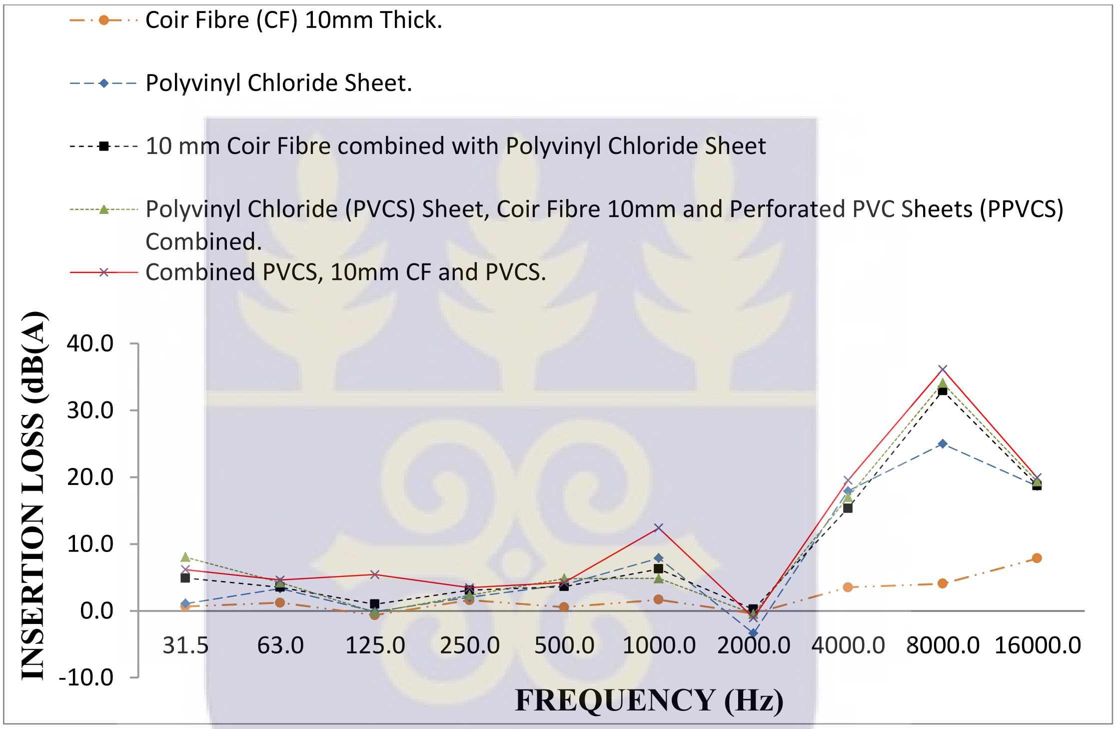

Figure 29. A graph of insertion loss against frequency for varying combinations of 10 mm CF and PVCS.

and PVCS , "PVCS, 20 mm CF and PVCS" (for 20 mm CF)

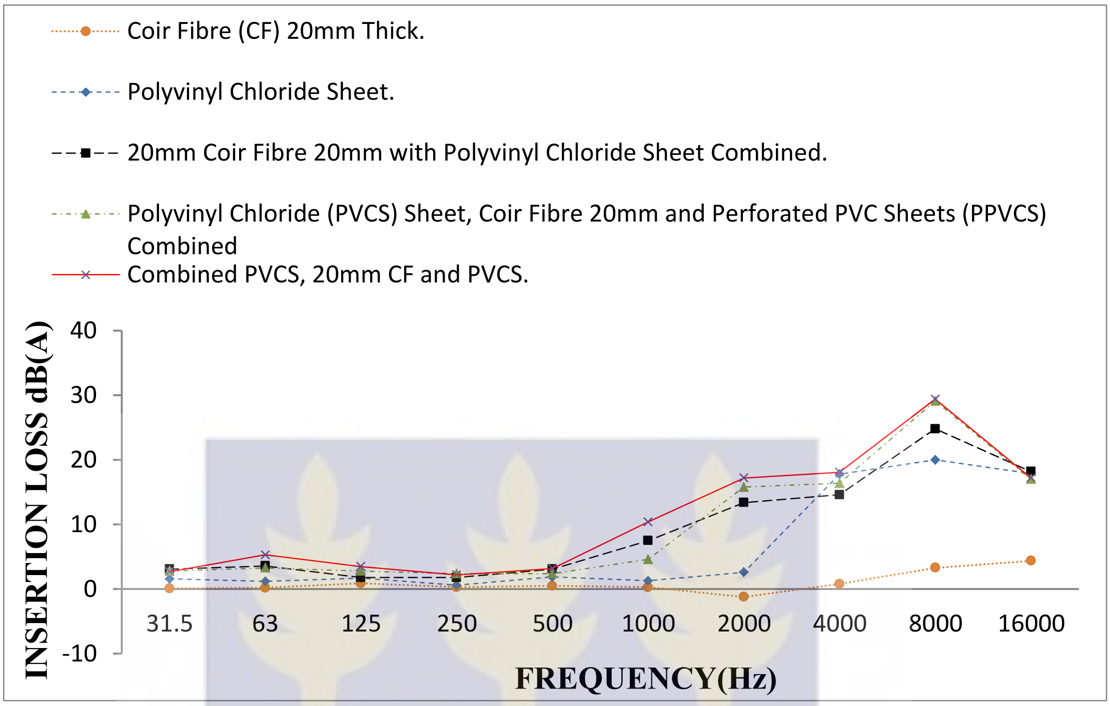

Figure 30. A graph of insertion loss against frequency for varying combinations of 20 mm CF with PVCS.

and "PVCS, 30 mm CF and PVCS" (in the case of 30 mm CF). After comparing the results of these three (3) specimens, it was observed that Combined PVCS, 30 mm CF and PVCS generally produced the highest ILs across the frequencies as shown in Figure 32. Its highest IL of 36.7 dB (A) was observed at 8000 Hz. A possible explanation is that, Combined PVCS, 30 mm CF and PVCS's high performance is due to thicker CF lining that absorbs more sound energy through friction, and the PVCS covering that resists airflow through the medium and possibly reflects some sound waves. Combined PVCS, 10 mm CF and PVCS and Combined PVCS, 20 mm CF and PVCS, absorbed and reflected lesser sound energy compared to Combined PVCS, 30 mm CF and PVCS. In summary, thicker inner CF lining with PVCS covering on both ends produces better IL results.

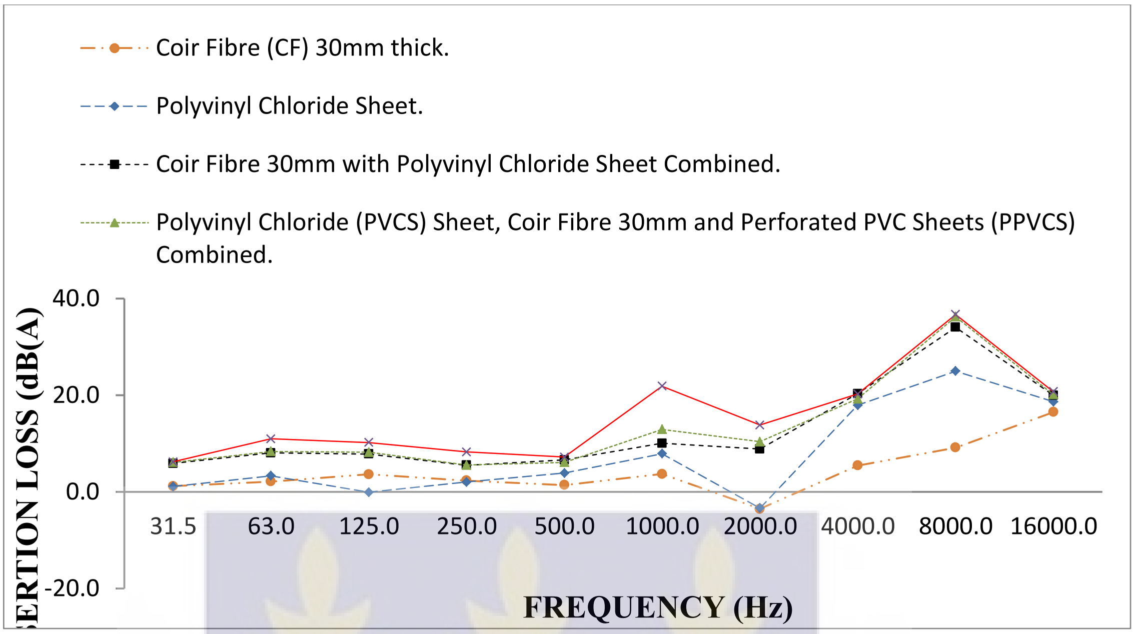

Figure 31. A graph of insertion loss against frequency for varying combinations of 30 mm CF with PVCS.

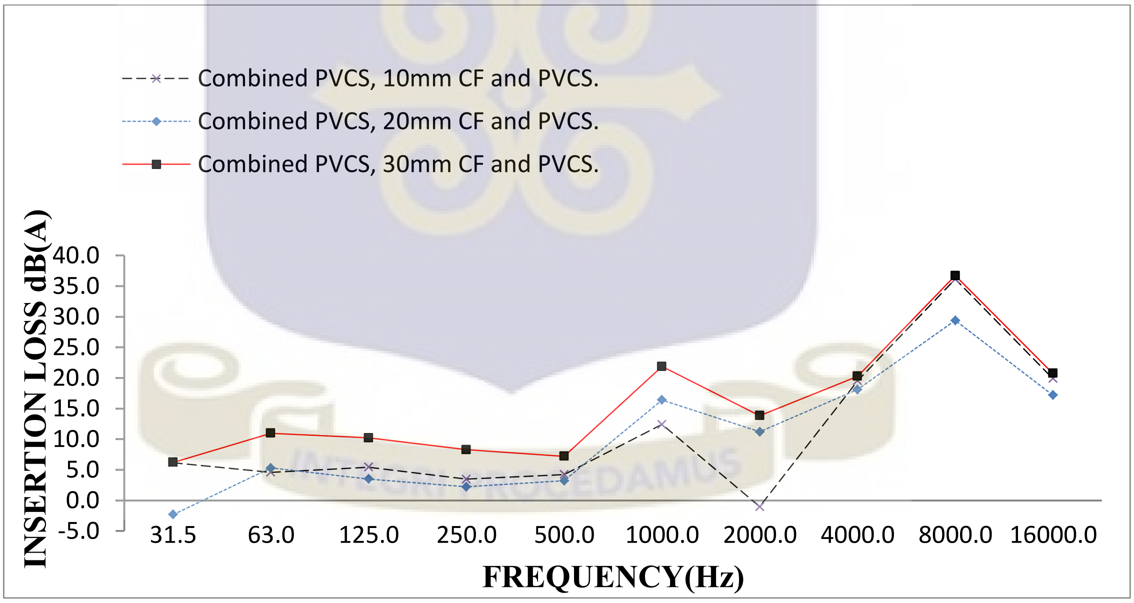

Figure 32. A graph of insertion loss against frequency for 10, 20 and 30 mm CF combined with PVCS on both ends.

When only CF with thicknesses 10, 20 or 30 mm were tested in the sound measuring chamber, the results as shown in Figure 33 where similar to results observed in Figure 32, that is, the IL for 30 mm thick CF was generally greater than 20 mm CF, and 20 mm CF generally greater than 10 mm CF across the frequency spectrum. A possible reason for this observation is because; sound waves will have to travel longer tortuous passages in the thicker specimen, and in the process, loose sound energy. Secondly, there is less reflection since there is no film/PVCS to reflect the sound waves, therefore IL values were lower than that of CF with PVCS on both ends. This can be clearly seen by comparing Figure 33 to Figure 32. It is also observed that IL increases as frequency increased. This is consistent with findings from (Mohd et al, 2010) that show that, thicker CF panels, produce higher IL particularly at higher frequencies, that is between 2000 – 1600 (Hz).

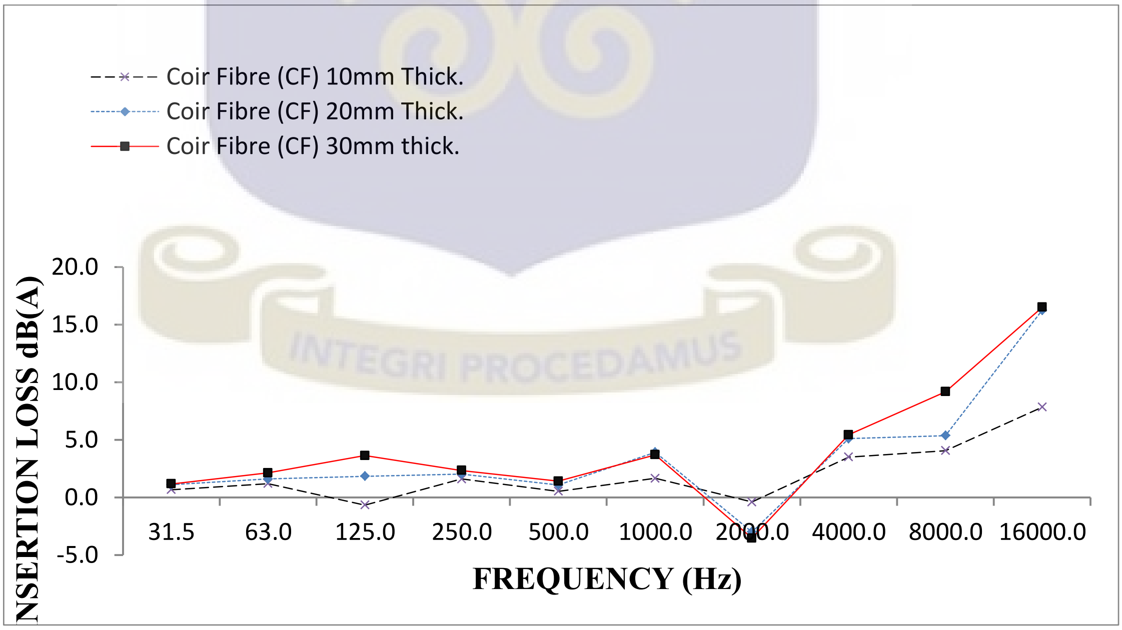

Figure 33. A graph of insertion loss against frequency for CF of thicknesses 10, 20 and 30 mm.

Statistical analysis was carried out to determine whether, IL for the four (4) sound absorber combinations, were significantly different. The same was determined for the three (3) thicknesses and the ten (10) Octave band frequencies.

From Table 6, the ANOVA results showed that, there were significant differences in the sound IL performance of the four (4) sound absorber combination used. It was found that, the performance of PVCS + CF + PVCS had a greater IL average of 14.04 dB (A) and was significantly different from PVCS + CF + PPVCS which had an IL average of 12.46 dB (A). These averages were also significantly different from the performance of CF and PVCS + CF, with PVCS + CF being higher than CF. These observations were made based on the differences between their means being greater than the l.s.d of 1.409. Hence, H_0 was rejected and H_1 accepted .i.e., CF and PVCS combination sequences (CS) did have a significant effect on IL and PVCS + CF + PVCS would be a more appropriate absorber panel to be used in the workshop.

Table 6. Analysis of variance (ANOVA) for IL.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
CS	3	5708.43	1902.81	82.63	<0.001
TH	2	1003.93	501.97	21.80	<0.001
FQ	9	18351.16	2039.02	88.54	<0.001
CS.TH	6	116.19	19.37	0.84	0.539
CS.FQ	27	2962.55	109.72	4.76	<0.001
TH.FQ	18	260.29	14.46	0.63	0.876
CS.TH.FQ	54	403.66	7.48	0.32	1.000
Residual	240	5527.02	23.03		
Total	359	34333.23			

ss = sum of squares, df = degree of freedom, ms = mean square, vr = variance ratio, F pr = F probability.

From Table 6, there were significant differences in IL as a result of the 3 varying thickness of the CF and PVCS combinations. Hence we rejected H_0 and accepted H_1, .i.e. thickness did have significant effect on IL. With an l.s.d of 1.22, 30 mm thick combination sequence (CS) performed better than 20 and 10 mm thick CS. This implied that, when making sound absorbers from CF, thicker fibres produced better IL results.

With respect to frequency having an effect on IL, H_0 was rejected and H_1 accepted, i.e. Frequency does have a significant effect on IL. With an l.s.d of 2.228, it was observed that, at 8000 Hz, the highest IL average of 25.66 dB(A) was experienced, followed by 16000 Hz at 21.44 dB(A) and 4000 Hz at 14.86 dB(A) This implies that, the various CS were most effective within the frequency ranges of 4000 - 16000 Hz. This implied that, for very high frequency producing workshop activity, introducing a panel between the noise source and the receiver would be very effective at cutting out noise and ensuring safety of workers at higher frequencies.

However, considering the interaction of CS and thickness, H_0 was not rejected, which implied that PVCS and CF combination sequences and thickness interactions had no significant effect on IL. With an l.s.d of 2.441, it was observed that, PVCS + 30 mm CF + PVCS, PVCS + 30 mm CF + PPVCS followed by PVCS + 20 mm CF + PVCS had the high IL averages of 16.86, 14.18 and 14.1 dB (A) respectively. Even though results were not significantly different, it was inferred from their performances that, PVCS + 30 mm CF + PVCS combinations will be a much appropriate alternative. However, if the PVCS available had perforations in them, they could still be effectively used i.e. PVCS + 30 mm CF + PPVCS would also produce a high IL.

When CS and frequencies interactions were considered, H_0 was rejected and H_1 accepted. That is, CS and frequencies had a significant effect on IL. It was identified that PVCS + CF + PVCS, PVC + CF + PPVCS and PVCS + CF had higher and significantly different IL than the rest of the CS at frequencies from 31.5 – 16000 Hz and could be used interchangeably. Their best ILs were observed at 8000 Hz with IL averages of 32.91, 32.33 and 30.5 dB (A) respectively. Other frequencies where CS also performed above 10 dB(A) were 4000 and 16000 Hz. CF alone did not perform so well. From this analysis, it has been realised that, thicker CF with PVC lining produced significantly higher IL between 4000 – 16000 Hz.

The pattern of the results obtained from statistical analysis in TL and IL experiments and statistical analysis are similar to that obtained in experiments, carried out by Chathurangani *et al.*, (2012) when they set out to determine the utilization of Sawdust and Coconut Fibre, for producing noise reducing wall titles. Secondly, the pattern of IL and TL from the experiment slightly resemble a sinusoidal wave because of the 10 Octave band center frequencies used, hence the results obtained along the octave band frequencies.

4.4 Determination of the effect of Combined Coconut Fibre (CF) and Polyvinyl Chloride Sheets (PVCS) on workshop noise level

Figure 34 reveals the noise level of the workshop when machines are in operation and shop activities are going on with the highest noise source insulated. The highest noise source is the Hand Held Grinding machine. The noise map revealed that, after insulation with PVCS + 30 mm CF + PVCS, the noise levels dropped from sound ranges of 75 to 105 dB(A) to ranges of 65 to 85 dB(A). These values are within the suggested ranges of the of the EPA standards. Thus, workers were no longer endangered since they were not exposed to high noise levels. This supports the fact that, wrapping both ends of CF with PVCS and applying it as a sound insulator in noisy workshops, is able to reduce large noise levels to required sound levels.

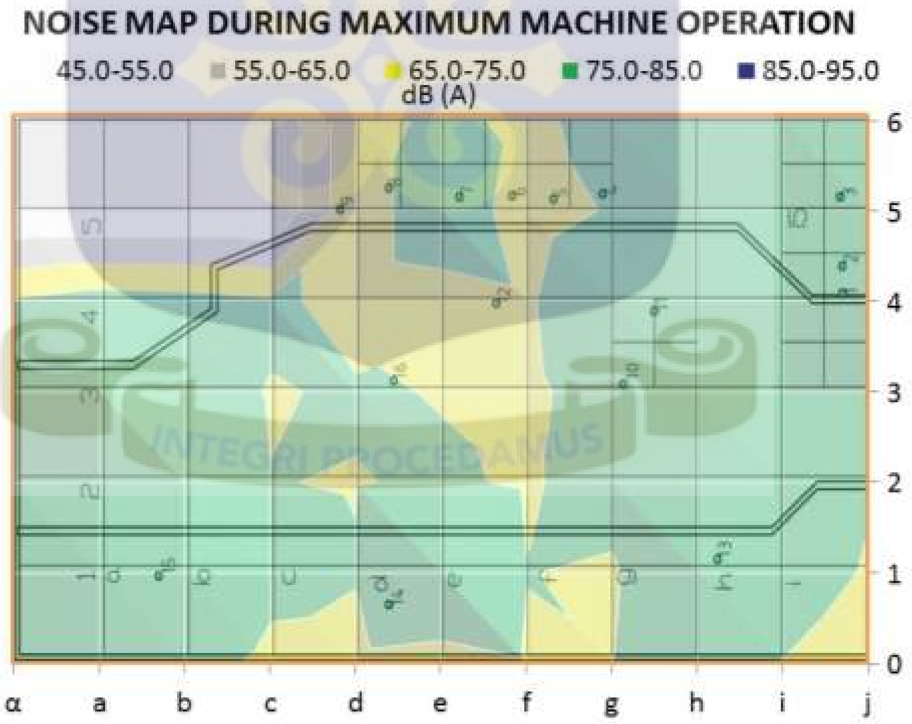

Figure 34 Noise map after installing the sound insulating materials in the workshop.

CHAPTER FIVE

5 CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSIONS

From SPL measurements recorded at the beginning of the study, it was identified that noise levels in Tema Industrial area, particularly GRATIS foundation, are above expected standard, that is 95 to 105 dB (A). This was mainly due to some high noise generating machines such as the Hand Held Grinding and the Pedestal Grinder.

A sound measuring chamber was successfully designed and tested. It was able to cut out 6 dB (A) of external noise and maintain a uniform sound level within the chamber to where measurements were taking place. That is 30.4 dB (A) compared to an ambient sound level of 36.4 dB (A).

Three samples each of Coconut Fibre were appropriately prepared to thicknesses of 10 mm thick at 29.4 g, 20 mm thick at 58.7 g and 30 mm thick at 87.4 g. Polyvinyl Chloride Sheets was also cleaned, cut and prepared. They were placed in the sound measuring chamber where transmission loss and insertion loss were measured for frequencies from 3.15 to 1600 Hz. Out of four (4) combination sequences, three (3) thicknesses and ten (10) frequencies, the following statistical conclusions were made for TL and IL.

<u>Conclusion on Transmission Loss</u>

With respect to CS, it was found that, the performances of PVCS + CF + PVCS had the greatest TL averages of 15.96 dB(A).

When the effect of thickness on TL was analysed, 30 mm thick CS performed better than 20 and 10 mm CS.

Frequency that experienced significant TL was found to be 8000 Hz, followed by 4000, 6000, 2000 and 1000 Hz. Hence frequency ranges between 1000 – 16000 Hz of sound were the ranges within which the CS performed best. Finally, when CS interacted with frequency, it was observed that PVCS + CF, PVCS + CF + PPVCS and PVCS + CF + PVCS performed equally (statistically) well with TLs of 32.7 and 31.08 dB(A) respectively. With these four significant results from ANOVA, it was concluded that PVCS + 30 mm + CF + PVCS was the optimum combination sequence of PVCS and CF that could produce the highest TL in the workshop for frequencies between 1000 to 16000 Hz. This made it the right choice for noise insulation in the workshop.

Conclusion on Insertion Loss

With respect to the CS in IL, it was found that, the performance of PVCS + CF + PVCS had the greatest IL average of 14.04 dB(A). When the effect of the thickness on IL was analysed, 30 mm thick combination performed best with IL of 12.35 dB(A). It was followed by 20 and 10 mm combinations.

Frequencies that experienced the highest IL of 25.66 dB(A) were found to be 8000 Hz, followed by 16000 Hz at 21.44 dB(A) and then 4000 Hz at 14.86 dB(A). Their IL were above 10 dB(A). Finally, when CS interacted with frequency, it was observed that PVCS + CF + PVCS, PVCS + CF + PPVCS and PVCS + CF performed best or equally well at 8000 Hz, with IL of 32.91, 32.33, 30.50 dB(A).

From these four significant conclusions that were drawn from ANOVA, PVCS + 30 mm CF + PVCS was accepted as the optimum combination sequence that could produce the highest IL, especially at higher frequencies from 4000 to 16000 Hz.

Conclusion on noise abatement in machine shop

These findings from IL and TL experiments concluded that, combined PVCS + 30 mm CF + PVCS will be the best material to be used as a noise absorbing material to insulate noise in the workshop.

After insulating highly noisy areas within the workshop, that is the hand held grinding tool area with CF wrapped on both sides with PVCS, the sound level dropped to the safe zone, that is between 65 to 85 dB(A). This can clearly be seen by comparing area α2, c2, α0, c0 in Figure 20 and Figure 34. The colour code changes from red to green. In conclusion, the use of CF combined/wrapped with Polyvinyl Chloride Sheets on both sides to insulate/abate noise in workshop successfully reduces noise.

5.2 RECOMMENDATION

Further research can be conducted on the effect of noise level reduction on the performance of workers in the workshop. Secondly, the entire SPL measurement in the sound measuring chamber can be repeated such that, the chamber has an open end at the sound measuring section. The purpose of this will be to verify whether or not more accurate results will be obtained in determining IL and TL. Furthermore, the entire specimens can be tested in an impedance tube to arrive at more accurate results that can be compared with findings from this study. Also, thicker samples such as 30, 60 and 90 mm should be used for subsequent studies to find out its effect in comparison to 10, 20 and 30 mm thick samples.

Finally, other factors that affect IL and TL not yet considered in this research such as tortuosity, air resistance, density and fibre size can all be varied during the determination of IL and TL of the combination sequences.

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APPENDICES

APPENDIX ONE

1. Measurement tool.

Table 7. Specifications of Extech Digital Data Logging Sound Level Meter Model HD600.

Applicable Standards	EC61672-1: 2002 Class 2; IEC60651: 1979 Type 2; ANSI S1.4:1983 Type 2,
Accuracy	±1.4dB (under reference conditions)
Frequency Range	31.5 Hz to 8 kHz
Dynamic Range	50 dB
Frequency Weighting	A and C
Time response	Fast (125ms) and Slow (1 second)
Measurement Ranges	30 to 80 dB, 50 to 100 dB, 80 to 130 dB and autoranging (30 to 130 dB)
Memory	20,000 records with date and time
Microphone	1⁄2” electret condenser
Calibration	Requires external calibrator
Display	4 digit LCD with bar-graph and backlighting
Display update rate	2 times/second
Range indicators	“OVER” and “UNDER” range indication
Battery life	30 hours (approximately)
Power supply	One 9 V battery (NEDA1604 or equivalent) or 12V/1A AC adaptor
Auto Power Off	After approx. 15 minutes of inactivity with disable
Analog Outputs	AC: 1 Vrms full scale; Output impedance: 100Ω
	DC: 10 mV/1dB; Output impedance: 1kΩ
Operating conditions	32 to 104 F (0 to 40 C); 10% to 90% relative humidity
Storage conditions	14 to 140 F (-10 to 60 C); 10% to75% relative humidity
Dimensions	10.9 x 3 x 1.97” (278 x 76 x 50 mm)
Weight	12.35 oz. (350 g)

Determination of Porosity

Diameter of Core = 6.4 cm, Length of Core = 3.5 cm, Volume of core = 112.594 cm3, (W_{dry}) Dry Weight of Coconut Fibre = 20.2 g, (W_{sub}) Submerged Weight of Coconut Fibre = 19.8 g, (W_{sat}) Saturated Weight of Coconut Fibre = 75.7 g

Porosity = (W_{sat} - W_{dry})/ (W_{sat} - W_{sub}) Archimedes Method for determining Porosity

Porosity = 98.7%

APPENDIX TWO

2. Summary of laboratory results on Insertion Loss (IL) and Transmission Loss (TL)

Table 8. Experimental results for Transmission and Insertion Loss.

Transmission Loss			Insertion Loss					
1	2	3	1	2	3	Combination Sequence	Thickness	Frequency
-3.1	-3.2	-2.9	0.7	0.6	0.7	CF	10	31.5
2.3	2.5	2.3	0.8	1.2	1.6	CF	10	63.0
-1.7	-1.6	-1.7	-0.8	-0.8	-0.4	CF	10	125.0
1.1	0.8	1.2	1.6	1.6	1.6	CF	10	250.0
2.2	2.4	2.2	0.5	0.6	0.5	CF	10	500.0
6.6	5.3	8.9	1.0	1.2	2.9	CF	10	1000.0
7.6	6.7	6.9	0.0	-0.5	-0.7	CF	10	2000.0
7.6	8.9	8.6	2.8	4.1	3.6	CF	10	4000.0
3.3	4.4	3.7	3.5	4.8	3.9	CF	10	8000.0
3.3	3.9	2.6	8.1	7.3	8.0	CF	10	16000.0
5.2	3.2	3.4	6.3	3.9	4.5	PVCS + CF	10	31.5
5.9	6.9	7.0	2.8	3.9	3.9	PVCS + CF	10	63.0
5.3	3.7	4.9	1.4	0.6	1.0	PVCS + CF	10	125.0
2.8	2.7	2.8	3.0	3.2	3.0	PVCS + CF	10	250.0
4.3	3.9	4.4	3.6	3.6	3.7	PVCS + CF	10	500.0
12.9	14.3	10.3	7.7	6.1	5.1	PVCS + CF	10	1000.0
3.7	4.2	2.8	0.8	0.0	-0.1	PVCS + CF	10	2000.0
18.7	19.4	20.3	14.5	15.4	16.1	PVCS + CF	10	4000.0
33.1	35.2	32.1	33.0	33.8	32.0	PVCS + CF	10	8000.0
16.9	16.4	16.7	18.8	18.7	18.6	PVCS + CF	10	16000.0

Transmission Loss			Insertion Loss					
1	2	3	1	2	3	Combination Sequence	Thickness	Frequency
5.8	6.2	6.8	7.7	8.0	8.4	PVC + CF + PPVCS	10	31.5
7.6	5.8	7.2	4.7	3.9	4.1	PVC + CF + PPVCS	10	63.0
6.2	6.0	3.9	-0.6	0.0	0.0	PVC + CF + PPVCS	10	125.0
2.4	2.5	2.0	2.4	2.2	2.4	PVC + CF + PPVCS	10	250.0
3.4	4.1	4.3	4.5	5.0	5.0	PVC + CF + PPVCS	10	500.0
9.0	8.8	8.8	4.9	5.3	4.5	PVC + CF + PPVCS	10	1000.0
9.4	15.4	11.6	-2.5	1.6	-0.5	PVC + CF + PPVCS	10	2000.0
20.6	22.8	24.4	14.5	16.7	19.8	PVC + CF + PPVCS	10	4000.0
34.1	30.1	33.4	35.5	30.5	36.3	PVC + CF + PPVCS	10	8000.0
18.1	17.3	18.1	18.9	19.5	19.5	PVC + CF + PPVCS	10	16000.0
4.5	4.7	4.3	6.3	6.3	5.9	PVCS + CF + PVCS	10	31.5
7.8	7.9	7.4	4.7	4.8	4.3	PVCS + CF + PVCS	10	63.0
15.9	13.5	10.4	5.9	4.9	5.5	PVCS + CF + PVCS	10	125.0
4.3	4.1	3.6	3.8	3.6	3.0	PVCS + CF + PVCS	10	250.0
4.2	4.5	4.7	4.1	4.2	4.4	PVCS + CF + PVCS	10	500.0
14.9	14.1	7.7	16.3	12.0	9.0	PVCS + CF + PVCS	10	1000.0
11.7	13.5	7.0	-1.4	2.0	-3.7	PVCS + CF + PVCS	10	2000.0
22.5	15.2	22.0	20.2	16.9	21.5	PVCS + CF + PVCS	10	4000.0
31.6	36.0	33.7	36.1	36.2	36.1	PVCS + CF + PVCS	10	8000.0
19.5	19.4	17.4	20.1	20.1	19.4	PVCS + CF + PVCS	10	16000.0
-2.5	-2.6	-2.5	1.3	1.0	1.0	CF	20	31.5
2.9	3.0	3.1	1.6	1.6	1.6	CF	20	63.0
2.0	3.6	1.4	0.1	2.8	2.6	CF	20	125.0
2.0	1.7	1.6	2.0	2.1	2.0	CF	20	250.0
3.1	3.1	2.8	0.9	1.3	1.0	CF	20	500.0
6.3	9.2	11.8	1.8	5.1	5.0	CF	20	1000.0

Transmission Loss			Insertion Loss					
1	**2**	**3**	**1**	**2**	**3**	**Combination Sequence**	**Thickness**	**Frequency**
4.5	8.2	7.0	-4.9	-1.0	-3.1	CF	20	2000.0
10.4	9.4	8.2	6.1	5.2	4.0	CF	20	4000.0
4.9	5.4	5.5	4.1	6.9	5.1	CF	20	8000.0
11.6	11.2	14.3	17.0	14.4	17.2	CF	20	16000.0
5.1	3.5	4.3	7.1	5.5	6.3	PVCS + CF	20	31.5
6.8	7.7	7.6	4.3	4.7	5.1	PVCS + CF	20	63.0
12.5	14.9	14.7	4.3	7.1	6.7	PVCS + CF	20	125.0
3.6	3.4	2.8	3.6	3.6	3.4	PVCS + CF	20	250.0
4.0	3.9	3.4	5.1	5.4	4.8	PVCS + CF	20	500.0
17.6	16.4	16.4	12.2	10.8	10.0	PVCS + CF	20	1000.0
20.9	21.2	20.7	12.1	12.8	11.9	PVCS + CF	20	2000.0
25.0	21.3	22.8	18.9	17.0	18.9	PVCS + CF	20	4000.0
28.6	34.8	33.4	30.5	35.7	33.2	PVCS + CF	20	8000.0
16.0	18.4	16.8	19.5	19.6	19.3	PVCS + CF	20	16000.0
6.9	6.2	6.4	8.9	8.4	8.6	PVC + CF + PPVCS	20	31.5
12.4	14.3	9.8	9.4	11.4	7.5	PVC + CF + PPVCS	20	63.0
10.5	12.7	9.4	1.1	1.8	0.8	PVC + CF + PPVCS	20	125.0
2.8	3.6	2.1	3.2	4.0	2.5	PVC + CF + PPVCS	20	250.0
4.4	5.1	3.7	4.9	6.4	5.0	PVC + CF + PPVCS	20	500.0
10.9	17.4	13.8	8.5	14.3	10.7	PVC + CF + PPVCS	20	1000.0
23.0	21.7	17.8	7.6	6.9	2.8	PVC + CF + PPVCS	20	2000.0
25.9	25.8	27.1	18.2	17.6	18.9	PVC + CF + PPVCS	20	4000.0
39.6	38.8	38.7	36.2	35.7	36.1	PVC + CF + PPVCS	20	8000.0
17.7	17.4	10.9	19.9	20.1	19.9	PVC + CF + PPVCS	20	16000.0
6.1	5.6	4.3	6.6	7.1	6.7	PVCS + CF + PVCS	20	31.5
9.3	8.4	7.4	6.3	5.3	5.9	PVCS + CF + PVCS	20	63.0

Transmission Loss			**Insertion Loss**					
1	**2**	**3**	**1**	**2**	**3**	**Combination Sequence**	**Thickness**	**Frequency**
18.6	19.7	20.9	6.7	8.6	9.0	PVCS + CF + PVCS	20	125.0
4.3	4.4	4.1	4.0	4.5	4.0	PVCS + CF + PVCS	20	250.0
7.0	6.7	7.3	4.9	5.7	4.9	PVCS + CF + PVCS	20	500.0
19.7	15.2	16.1	19.2	15.7	15.9	PVCS + CF + PVCS	20	1000.0
20.1	27.9	22.3	5.7	12.7	6.9	PVCS + CF + PVCS	20	2000.0
26.1	20.3	25.9	18.0	19.6	18.2	PVCS + CF + PVCS	20	4000.0
37.6	34.2	39.4	35.6	36.8	36.5	PVCS + CF + PVCS	20	8000.0
18.0	14.9	16.5	19.5	20.3	20.0	PVCS + CF + PVCS	20	16000.0
-2.2	-2.6	-2.6	1.4	1.1	1.0	CF	30	31.5
3.1	3.3	3.4	2.4	2.0	2.0	CF	30	63.0
4.6	3.3	5.4	3.9	3.5	3.5	CF	30	125.0
2.4	2.0	2.2	2.4	2.4	2.2	CF	30	250.0
3.7	3.5	3.5	1.6	1.3	1.3	CF	30	500.0
7.7	7.3	9.3	3.2	2.8	5.2	CF	30	1000.0
7.2	8.6	6.9	-3.9	-2.5	-4.2	CF	30	2000.0
12.8	8.2	7.9	9.1	3.6	3.6	CF	30	4000.0
10.7	7.8	5.7	10.9	9.8	6.8	CF	30	8000.0
13.9	13.4	11.3	17.0	15.8	16.6	CF	30	16000.0
3.5	2.6	4.1	5.9	5.2	6.5	PVCS + CF	30	31.5
9.7	10.3	10.5	7.8	8.0	8.4	PVCS + CF	30	63.0
15.6	17.6	18.3	7.8	7.1	8.6	PVCS + CF	30	125.0
5.3	4.9	6.3	5.3	4.9	6.3	PVCS + CF	30	250.0
4.5	5.3	4.3	6.2	6.8	6.8	PVCS + CF	30	500.0
14.5	14.7	15.0	9.7	10.1	10.5	PVCS + CF	30	1000.0
16.0	22.1	22.2	5.2	10.2	11.2	PVCS + CF	30	2000.0
27.3	26.0	25.3	20.5	20.9	19.6	PVCS + CF	30	4000.0

Transmission Loss			Insertion Loss					
1	**2**	**3**	**1**	**2**	**3**	**Combination Sequence**	**Thickness**	**Frequency**
32.0	34.8	35.4	30.8	35.3	36.1	PVCS + CF	30	8000.0
17.9	18.7	12.8	19.8	20.3	19.7	PVCS + CF	30	16000.0
3.7	3.9	4.3	5.3	5.9	7.1	PVC + CF + PPVCS	30	31.5
10.5	11.9	10.5	8.2	9.4	7.5	PVC + CF + PPVCS	30	63.0
17.0	19.2	17.2	8.8	9.1	6.7	PVC + CF + PPVCS	30	125.0
4.5	5.3	5.6	5.3	5.5	5.8	PVC + CF + PPVCS	30	250.0
5.9	6.1	6.3	6.0	6.3	6.0	PVC + CF + PPVCS	30	500.0
13.7	15.1	12.8	12.8	13.8	12.3	PVC + CF + PPVCS	30	1000.0
26.1	27.3	23.0	11.3	12.0	7.8	PVC + CF + PPVCS	30	2000.0
28.8	26.4	27.9	20.8	17.8	19.2	PVC + CF + PPVCS	30	4000.0
37.9	38.9	39.4	35.7	36.3	36.7	PVC + CF + PPVCS	30	8000.0
19.0	19.0	20.2	20.0	20.0	20.3	PVC + CF + PPVCS	30	16000.0
4.0	4.3	4.4	6.4	6.1	6.1	PVCS + CF + PVCS	30	31.5
10.7	14.0	12.7	9.2	12.5	11.2	PVCS + CF + PVCS	30	63.0
20.0	25.8	25.2	7.1	12.1	11.4	PVCS + CF + PVCS	30	125.0
7.0	7.9	10.9	7.1	7.9	9.8	PVCS + CF + PVCS	30	250.0
9.4	10.4	10.8	6.0	7.6	8.0	PVCS + CF + PVCS	30	500.0
28.7	18.2	16.0	26.6	20.9	18.2	PVCS + CF + PVCS	30	1000.0
31.6	29.3	27.4	16.0	13.9	11.6	PVCS + CF + PVCS	30	2000.0
26.5	29.3	29.7	19.6	20.8	20.4	PVCS + CF + PVCS	30	4000.0
39.8	36.0	35.6	37.1	36.7	36.3	PVCS + CF + PVCS	30	8000.0
17.0	17.2	13.8	20.7	20.9	20.5	PVCS + CF + PVCS	30	16000.0

Table 9 Sample Excel Table for Coconut Fibre 10 mm from which IL and TL were calculated in the lab.

Coconut Fibre 10mm Coconut Fibre 10mm Thick.

No.	Octave band center frequency	Sound Pressure Level recorded at point b without incident sound in chamber	Sound Pressure Level recorded at point b after incident sound without Specimen installed **LpB**	Sound Pressure Level recorded at point b after incident sound with Specimen installed **Lp2**	Sound Pressure Level recorded at point f after incident sound without Specimen installed **LpA**	Sound Pressure Level recorded at point f after incident sound with Specimen installed **Lp1**	Calculated Sound Power Level recorded as **"Lw1"** in front of Specimen	Calculated Sound Power Level recorded as ` **"Lw2"** behind Specimen	Calculated Incident Sound Power recorded as **"W1"** infront of Specimen	Calculated Incident Sound Power Level recorded as **"W2"** behind of Specimen	Noise Reduction for Specimen **(Lp1-Lp2)**	Transmission Coefficient **τ =W2/W1**	Sound Transmission Loss **"TL"** **10Log1"0 (1 / τ)**	Insertion Loss **"IL"** for Specimen **(LpB-Lp2)**
1	31.5	31.4	43.7	43.1	41.7	39.9	50.84	54.0	1.21E-07	2.536E-07	-3.2	2.08929	-3.2	0.6
2	63	31□4	68.7	67.5	71.7	70	80.94	78.4	0.000□24	6.984E-05	2.5	0.562341	2.5	1.2
3	125	31.4	72.6	73.4	70.6	71.8	82.74	84.3	0.000188	0.0002717	-1.6	1.44544	-1.6	-0.8
4	250	31.4	82.0	80.4	81.0	81.2	92.14	91.3	0.001637	0.0013618	0.8	0.831764	0.8	1.6
5	500	31.4	85.6	85	87.2	87.4	98.34	95.9	0.006825	0.0039275	2.4	0.57544	2.4	0.6
6	1000	31.4	77.5	76.3	83.3	81.6	92.54	87.2	0.001795	0.0005298	5.3	0.295121	5.3	1.16
7	2000	31.4	63.8	64.3	70.0	71	81.94	75.2	0.000156	3.343E-05	6.7	0.213796	6.7	-0.5
8	4000	31.4	56.6	52.5	62.8	61.4	72.34	63.4	1.71E-05	2.209E-06	8.9	0.128825	8.9	4.1
9	8000	31.4	69.8	65	69.6	69.4	80.34	75.9	0.000108	3.927E-05	4.4	0.363078	4.4	4.8
10	16000	31.4	54.4	47.1	49.9	51	61.94	58.0	1.56E-06	6.37E-07	3.9	0.40738	3.9	7.34

NB: Insertion Loss (IL) and Transmission Loss (TL) in the last two (2) columns.

Other parameters in excel sheets.

Room Temperature °C	=	Temperature K		
31.1	=	304.25		
ρ Density of Air @ 20 °C	=	1.2041		
c Speed of sound at a particular temperature	=	**349.70**	1.402	Specific Heat Ration (1.402)=
ρc Accoustic Impedance	=	**421.07**	8.314	Universal Gas Constant (8.314 J/mole ^{o}K)=R
			304.25	Temperature K
			0.029	Molecular Weight of the gas (M_{Air} = 0.029kg/mole) = M

Total Length	=	**(r1)**m Distance for Measuring Soud Pressure 1 (Lp1) dB(A)	**(r2)**m Distance for Measuring Soud Pressure 2 (Lp2) dB(A)
		1.02	1.04

3rd Term in the Lw equation	=	**10.77**	0.00002	Pref
			1E-12	Wref

S Surface area of specimen	=	0.01	m^2
S2 Total area of receiving chamber	=	0.09	m^2
Alpha	=	0.6	
R	=	0.015	

APPENDIX THREE

3. Results from GenStats software after ANOVA for IL and TL

Table 10 Tables of means TL from ANOVA in GenStats

Variate: TL

CS = Combination Sequence

TH = Thickness

FQ = Frequency

Grand Means 12.24

CS	CF	PVC + CF + PPVCS	PVCS + CF	PVCS + CF + PVCS	
	4.67	14.86	13.48	15.96	

TH	10	20	30
	9.61	12.84	14.28

FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
	6.93	6.02	10.12	6.3	4.44	10.05	14.94	19.14	25.15	19.31

CS	TH	10	20	30
CF		3	5.53	5.47
PVC + CF + PPVCS		11.92	15.56	17.1
PVCS + CF		10.77	14.22	15.43
PVCS + CF + PVCS		12.73	16.04	19.1

CS	FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
CF		2.21	1.02	2.13	1.64	2.44	6.76	7.34	8.3	6.56	8.26
PVCS + CF + PPVCS		9.7	8.42	11.16	6.56	4.56	10.22	17.57	24.31	32.7	23.41
PVCS + CF		6.76	6.59	11	6.57	4.02	11.13	15.4	20.29	30.27	22.73
PVCS + CF + PVCS		9.03	8.04	16.2	10.44	6.76	12.1	19.43	23.68	31.08	22.82

TH	FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
10		6.11	4.83	5.18	3.44	3.38	7.76	9.22	15.12	22.91	18.13
20		7.63	6.17	10.89	6.22	4.09	11.26	17.08	19.98	25.58	19.47
30		7.03	7.07	14.29	9.25	5.86	11.14	18.51	22.33	26.96	20.33

CS	TH	FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
CF	10		-1.37	0.53	-0.27	0.13	1.8	5.53	6.3	8.07	5.67	3.63
	20		4.77	1.17	2.67	2.3	2.53	8.03	8.13	8.6	6.77	10.3
	30		3.23	1.37	4	2.5	3	6.7	7.6	8.23	7.23	10.83
PVC + CF + PPVCS	10		9.8	6.4	5.23	3.5	3.63	7.23	11.93	20.87	28.77	21.83
	20		10.33	10.1	12.13	6.13	4.13	12.1	18.97	24.87	34.43	22.37
	30		8.97	8.77	16.1	10.03	5.9	11.33	21.8	27.2	34.9	26.03
PVCS + CF	10		7.23	5.7	5.17	3.07	3.67	9.5	7.1	14.63	28.9	22.77
	20		6.33	6.27	12.43	7.03	3.57	12.23	19.43	21.77	29.83	23.33
	30		6.7	7.8	15.4	9.6	4.83	11.67	19.67	24.47	32.07	22.1
PVCS + CF + PVCS	10		8.77	6.67	10.6	7.07	4.43	8.77	11.53	16.9	28.3	24.27
	20		9.1	7.13	16.33	9.4	6.13	12.67	21.8	24.7	31.3	21.87
	30		9.23	10.33	21.67	14.87	9.7	14.87	24.97	29.43	33.63	22.33

Standard errors of means

Table	CS	TH	FQ	CS	CS	TH	CS
				TH	FQ	FQ	TH
							FQ
rep.	90	120	36	30	9	12	3
d.f.	240	240	240	240	240	240	240
e.s.e.	0.589	0.51	0.931	1.02	1.862	1.612	3.225

Standard errors of differences of means

Table	CS	TH	FQ	CS
				TH
rep.	90	120	36	30
d.f.	240	240	240	240
s.e.d.	0.833	0.721	1.317	1.442

Table	CS	TH	CS
	FQ	FQ	TH
			FQ
rep.	9	12	3
d.f.	240	240	240
s.e.d.	2.633	2.28	4.561

Least significant differences of means (5% level)

Table	CS	TH	FQ	CS
				TH
rep.	90	120	36	30
d.f.	240	240	240	240
l.s.d.	1.64	1.42	2.593	2.841

Table	CS	TH	CS
	FQ	FQ	TH
			FQ
rep.	9	12	3
d.f.	240	240	240
l.s.d.	5.187	4.492	8.984

Table 11.Tables of means IL from ANOVA in GenStats.

Variate: IL

CS = Combination Sequence

TH = Thickness

FQ = Frequency

Grand mean 10.57

CS	CF	PVC + CF + PPVCS	PVCS + CF	PVCS + CF + PVCS
	3.8	12.46	11.97	14.04

TH	10	20	30
	8.34	11.02	12.35

FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
	8.19	4.61	5.59	6.15	4.19	7.92	7.08	14.86	25.66	21.44

CS	TH	10	20	30
CF		2.47	4.4	4.53
PVC + CF + PPVCS		10.38	12.83	14.18
PVCS + CF		9.33	12.74	13.84
PVCS + CF + PVCS		11.18	14.1	16.86

CS	FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
CF		4.7	0.22	2.22	1.89	1.22	3.41	2	4.99	6.89	10.47
PVC + CF + PPVCS		10.3	6.81	5.1	5.88	4.82	8.36	7.33	18.04	32.33	25.64
PVCS + CF		8.03	5.09	6.24	6.92	4.78	7.19	9.74	17.07	30.5	24.12
PVCS + CF + PVCS		9.71	6.33	8.78	9.92	5.93	12.72	9.24	19.34	32.91	25.54

TH	FQ	31.5	63	125	250	500	1000	2000	4000	8000	16000
10		7.58	3.28	2.89	3.18	3.05	5.14	2.82	11.87	24.08	19.5
20		8.67	4.63	5.61	6.04	3.76	8.73	9	15.6	25.83	22.32
30		8.32	5.93	8.26	9.24	5.76	9.89	9.43	17.12	27.07	22.52

CS	TH	FQ	31.5	63	125	250	500	1000	2000	4000	8000
CF	10		1.43	-0.03	0.37	0.5	0.77	2.1	2.57	4.87	5.77
	20		6.47	0.23	2.83	1.83	1.3	4.3	2.57	5.4	6.73
	30		6.2	0.47	3.47	3.33	1.6	3.83	0.87	4.7	8.17
PVC + CF + PPVCS	10		11.03	4.93	2.4	2.83	4	4.7	3.3	16.03	30.4
	20		11.27	8.43	4.13	5.3	4.5	9.57	7.83	18.1	32.97
	30		8.6	7.07	8.77	9.5	5.97	10.8	10.87	20	33.63
PVCS + CF	10		7.73	3.73	2.87	3.7	3.37	5.2	3.4	11.43	28.7
	20		8.7	4.7	7.13	7.23	4.33	8.07	13.7	18.87	30.57
	30		7.67	6.83	8.73	9.83	6.63	8.3	12.13	20.9	32.23

PVCS + CF + PVCS	10		10.1	4.47	5.93	5.67	4.07	8.57	2	15.13	31.43
	20		8.23	5.17	8.33	9.8	4.9	12.97	11.9	20.03	33.07
	30		10.8	9.37	12.07	14.3	8.83	16.63	13.83	22.87	34.23

Standard errors of means

Table	CS	TH	FQ	CS	CS	TH	CS
				TH	FQ	FQ	TH
							FQ
rep.	90	120	36	30	9	12	3
d.f.	240	240	240	240	240	240	240
e.s.e.	0.506	0.438	0.8	0.876	1.6	1.385	2.771

Standard errors of differences of means

Table	CS	TH	FQ	CS
				TH
rep.	90	120	36	30
d.f.	240	240	240	240
s.e.d.	0.715	0.62	1.131	1.239

Table	CS	TH	CS
	FQ	FQ	TH
			FQ
rep.	9	12	3
d.f.	240	240	240
s.e.d.	2.262	1.959	3.918

Least significant differences of means (5% level)

Table	CS	TH	FQ	CS
				TH
rep.	90	120	36	30
d.f.	240	240	240	240
l.s.d.	1.409	1.22	2.228	2.441

Table	CS	TH	CS
	FQ	FQ	TH
			FQ
rep.	9	12	3
d.f.	240	240	240
l.s.d.	4.456	3.859	7.719

APPENDIX FOUR

4. GRATIS FOUNDATION.

GRATIS Foundation, incorporated in December 1999, evolved from the Ghana Regional Appropriate Technology Industrial Service (GRATIS) Project, which was established in 1987 by the Government of Ghana with support from the European Union and the Canadian International Development Agency to promote small-scale industrialization in Ghana.

WEB ADDRESS(S)

http://www.gratis-ghana.com

http://gratis.getafricaonline.com/home

a. ENVIRONMENTAL PROTECTION AGENCY.

The mission of the EPA of Ghana is to co-manage, protect and enhance the country's environment, as well as seek common solutions to global environmental problems. The accomplishment of the mission is to be achieved inter alia through:

- An integrated environmental planning and management system established on a broad base of public participation, efficient implementation of appropriate program and technical services, giving good council on environmental management as well as effective and consistent enforcement of environmental laws and regulations. The EPA is an implementing Agency, a regulatory body and catalyst for change towards sound environmental stewardship. (Ministry of Science and Technology, Governance, Environmental Protection Agency, 2013). Web address :http://www.epa.gov.gh/

APPENDIX FIVE

5. Noise insulation panel development gallery.

Figure 35. Polyvinyl Chloride Sheets (Flexi Banner) after advertisement.

Figure 36. PVCS nailed unto a wooden frame forming single noise insulating panel.

Figure 37. Frame filled with Coconut Fibre.

Figure 38. Compressed Coconut Fibre in noise insulating panel.


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