UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

PADDY FIBER AS AN ALTERNATIVE SUSTAINABLE ACOUSTIC ABSORBER MATERIAL

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DECLARATION

I declare that this thesis entitle ”Paddy fiber as an alternative sustainable acoustic absorber material” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATION

”To my beloved parents and wife”

ABSTRACT

The use of synthetic materials as acoustic absorbers is still applied extensively in building industry. These non-biodegradable materials do not only cause pollution to the environment, but also contribute significantly in increasing the CO_2 causing the effect of global warming. Therefore researchers have now driven their attentions to find sustainable and eco-friendly materials to be an alternative sound absorber. This study discusses the use of natural waste fibers from dried paddy as fibrous acoustic material. Since this is one of common natural waste materials found across South East Asia, the usage will also minimize the production cost. Samples of sound absorbers from paddy fibers were fabricated and the acoustic properties were determined through experiment. The paddy fibers are found to have good acoustic performance with normal incidence absorption coefficient greater than 0.5 from 1 kHz and can reach the average value of 0.8 above 2.5 kHz. The sound absorption performance can be further increased at lower frequency range by 50% with a layer of polyester cloth added to its front surface. The absorption coefficient result from sample with weight of 3 grams and thickness of 20 mm is found to be comparable against that from the commercial synthetic glass wool.

ABSTRAK

Penggunaan bahan-bahan sintetik sebagai penyerap bunyi masih lagi digunakan secara meluas di dalam industri pembinaan. Bahan yang tidak-terbiodegradasi ini tidak hanya akan menyebabkan punca pencemaran kepada alam sekitar, tetapi juga menyumbang kepada peningkatan CO_2 yang boleh menyebabkan kesan pemanasan global. Justeru, para penyelidik telah didorong untuk mencari bahan-bahan yang mampan dan mesra alam untuk menjadi penyerap bunyi alternatif. Kajian ini membincangkan mengenai bahan buangan semulajadi daripada padi sebagai bahan akustik berserat. Memandangkan bahan-bahan buangan semulajadi ini biasanya terdapat di seluruh Asia Tenggara, penggunaannya juga dapat mengurangkan kos pengeluaran. Panel penyerap bunyi dari jerami padi telah dibentuk dan ciri-ciri akustiknya telah dikaji melalui eksperimen. Panel ini didapati mempunyai prestasi penyerapan bunyi yang baik dengan pekali penyerap bunyi yang melebihi 0.5 pada 1 kHz dan mencapai nilai purata 0.8 pada frekuensi melebihi 2.5 kHz. Prestasi bunyi dapat ditingkatkan lebih 50% pada frekuensi rendah dengan menambah kain polyester pada permukaannya. Manakala hasil untuk sampel yang seberat 3 gram dengan ketebalan 20 mm adalah setanding dengan penebat gentian bulu kaca yang terdapat di pasaran kini.

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LIST OF ABBREVIATIONS

DAS	**D**ata **A**cquisition **S**ystem
dpf	**d**enier **p**er **f**ilament
EPS	**E**xpanded **P**oly**S**tyrene
FFT	**F**ast **F**ourier **T**ransform
GWP	**G**lobal **W**arming **P**otential
IRM	**I**nverted **R**esearch **M**icroscope
kHz	**k**ilo **H**ertz
NF	**N**atural **F**iber
NWC	**N**on **W**oven **C**loth
Pa	**P**ascal
SF	**S**ynthetic **F**iber
TLF	**T**ea **L**eaf **F**iber
WCC	**W**oven **C**otton **C**loth

LIST OF SYMBOLS

A	Cross-sectional area
c_o	Speed of sound
d	Diameter of the tube
E_i	Incident energy
E_r	Reflected energy
E_t	Transmitted energy
f	Frequency
f_l	Lower frequency range of the tube
f_u	Upper frequency range of the tube
G_{11}	Auto-spectrum
G_{12}	Cross-spectrum
H_{12}	Transfer function between microphone-1 and microphone-2
$j = \sqrt{-1}$	Imaginary unit
k_o	Acoustic wavenumber
M	Acoustic reactance
m	mass per unit area of the panel sample
R	Acoustic resistance
R_s	Specific flow resistance
r	Reflection coefficient
s	Spacing between microphones
t	Thickness of panel
V	Volume
v	Particle velocity
W	Weight of the sample
Z_{tot}	Total of impedance
Z_D	Impedance of air gap
z_f	impedance of air

q_v	Volumetric airflow rate
α	Sound absorption coefficient
ϕ	Porosity of porous material
λ	Acoustic wavelength
ρ	Density of air
ρ_b	Density of sample
ω	Angular frequency
η	Coefficient of viscosity of air

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CHAPTER 1

INTRODUCTION

1.1 Background

The issue of conserving environmental condition and its relation with global warming has attracted attention of researchers for new technologies which are more environmentally friendly. Besides finding alternative energy to limit the use of fossil fuels and deforestation, attemps are also directed to create products from re-cycleable and sustainable materials. The synthetic materials especially those made from minerals have been known to have issues concerning their pollution with regards to their disposal.

For application in building acoustics for example, where sound quality in a room such as the theatre hall, music studio, lecture room, teleconferencing room, cinema as well as the meeting room, classical abrasive and porous acoustic materials are still widely used. Demands of acoustic quality in factory and warehouse should also be taken seriously to control the noise level problem.

To increase the sound absorption, the walls in buildings are usually covered by absortive layers using glass wools or acoustic foams made from synthetic chemical substances as seen in Figure 1.1. The room ceiling usually uses the commercial gypsum boards, made by high technology chemical process. Moreover, the production also gives huge contribution to CO_2 pollution to the atmosphere.

It is commonly known that these conventional synthetic absorbers can be harmful for human health if inhaled during handling and can cause skin and eyes irritation (Asdrubali, 2006). Most of the absorbers from synthetics fibers such as foamglass, EPS as well as the

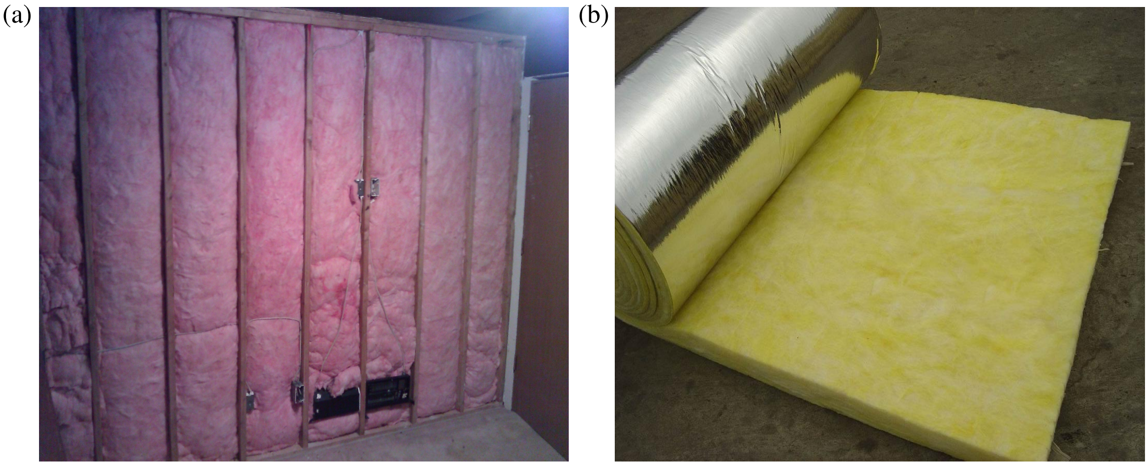

Figure 1.1 (a) Practical noise insulations in a building (Hometheaterfan, 2011) and (b) glass fiber; synthetic fibrous material common used as sound absorber (Anonymous, 2011).

glass fiber are huge contributors to earth global warming. The Global Warming Potential (GWP) chart of sound absorber panels made of natural and synthetic materials as shown in Figure 1.2 represents the 'equivalent' contributions of CO_2 into the atmosphere from the production of an absorber panel from "cradle" to grave (Desarnaulds *et. al.*, 2005). It can be seen that the synthetic-based fibers for example foamglass, contributes high GWP if compared to natural-based fibers for example coconut fibers. Therefore, instead of using the synthetic mineral fibers, researches are directed to find natural fibers as an alternative choice to be developed as sound absorbers. The natural fibers offer some advantages including renewable, biodegradable and cause much less harm to human health. Table 1.1 summarises the advantages of natural fiber compared with the synthetic fibers (Wambua *et. al.*, 2003).

1.2 Problem Statement

Asian countries are mainly agriculture-based economy. Over the year, tonnes of natural wastes including the paddy fibers are disposed and are usually burned which leads to

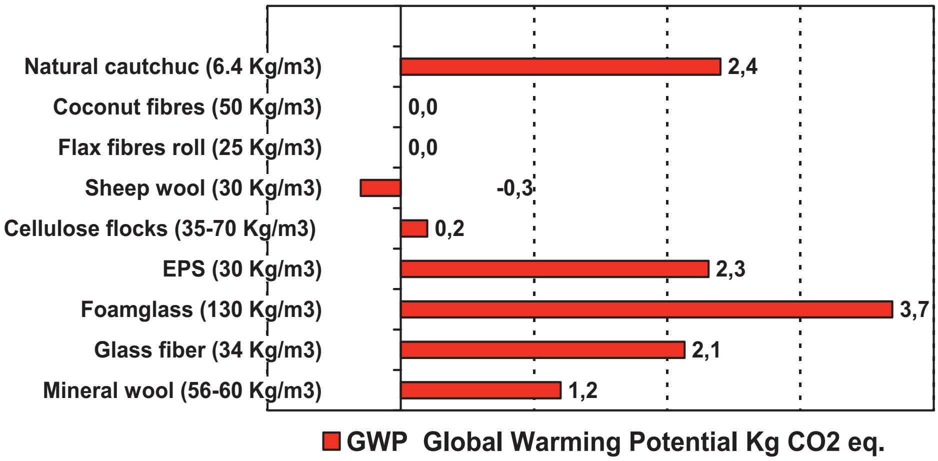

Figure 1.2 Assessment on Global Warming Potential (Desarnaulds *et. al.*, 2005)

contribution of CO_2 release in the atmosphere. The abundance biomass source of this natural fiber is potential to be employed as raw materials for sound absorber panels. Investigation on the ability of the paddy fiber as an acoustic absorber material is therefore of interest.

1.3 Objectives

This study embarks on the following objectives:

1. To fabricate impedance tube and flow resistivity device.

2. To fabricate samples of acoustic absorber from paddy fiber.

3. To determine the acoustic properties of paddy fiber through experiment.

4. To measure the physical properties of paddy fiber.

1.4 Scope

This study is emphasized on the characteristic of the acoustic properties of paddy fibers as sound absorbers. Physical properties are therefore limited, but it was designed so that the

Table 1.1 Comparison between natural and man-made fibers (Wambua *et. al.*, 2003).

Parameter	Natural fiber	Synthetic fiber
Density	Low	Higher than NF
Cost	Low	Slightly higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy Consumption	Low	High
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Non-biodegradable
Environment impact	No	Yes
Greenhouse gas emission	Low	High

trend of the absorption coefficient can be concluded for other properties. This study therefore limits to the following scopes:

1. Samples of the absorber were made for thickness of 10 mm and 20 mm and were limited to weight of 2 grams until 6 grams.

2. Experiment of absorption coefficient was done using impedance tube and thus represents only the absorption performance for normal incidence of sound.

3. The physical test includes the density, porosity, microscopic, water absorption and flammability test. The strength test is not included in this study.

1.5 Thesis Layout

This thesis consists of five chapters. Chapter 1 discusses the problem definition, justification for carrying out the research (background study), objective and the scope of the project.

Chapter 2 briefs a description of fundamental theories of sound absorption. General review on natural fiber properties and some of the previous researches on the natural waste fibers are presented. Natural fiber properties and characteristic of paddy are also reviewed.

Chapter 3 are the details explanation of the methodology of the research. Development and fabrication of instruments used for acoustic properties measurement, namely impedance tube and flow resistivity instrument are presented in this chapter. This also includes the physical property tests, i.e. the density, porosity, water absorption tests as well as the flammability and microscopic tests.

Chapter 4 discusses the results and analysis in details which are the core part of this thesis, particularly for the measured absorption coefficent. The conclusion is written in Chapter 5 followed by the recommendations for the future works.

CHAPTER 2

LITERATURE REVIEW

In this chapter, brief principle of sound absorption and porous absorbers are explained. The properties of general fibers are also described. Established works on sound absorbers from natural materials are reviewed followed by paddy fibers history.

2.1 Sound Absorption

Consider an acoustic material which is uniform and unbounded immersed in air and is impinged by a sound wave. Besides reflected and absorbed, the energy is also transmitted to other side of the material as illustrated in Figure 2.1.

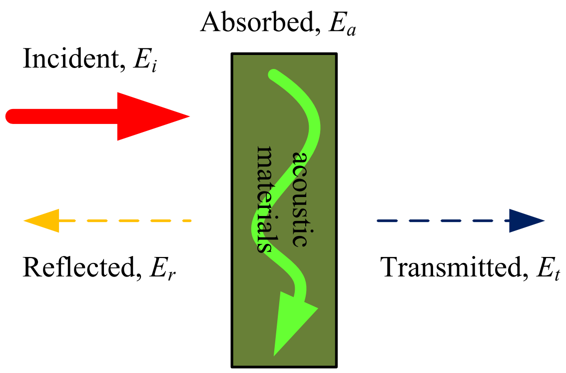

Figure 2.1 Reflection, absorption and transmission of sound energy

The energy balance can be written as

$$E_i = E_r + E_a + E_t \tag{2.1}$$

where E_i is the incident energy, E_r is the reflected energy, E_a is the absorbed energy and E_t is the transmitted energy.

The sound absorption coefficient simply indicates the portion of the sound energy absorbed by the material from the total energy of the incoming wave expressed by

$$\alpha = \frac{E_i - E_r}{E_i} = 1 - \frac{E_r}{E_i} = 1 - r \tag{2.2}$$

where *r* is the power reflection coefficient. From Eq.(2.1), E_i - E_r = E_a + E_t i.e. the sound energy absorbed by the system (seen from incident field) includes the transmission into the other side of the material. If the material is attached on to a rigid surface, then E_t = 0. Whenever the material impedance is equal to the characteristic impedance of the air (medium), maximum sound absorption occurs. Therefore, the amount of the energy being absorbed depends on the material impedance which is determined by the acoustic properties of the material such as porosity, tortuosity and flow resistivity. The absorption varies with frequency as well as with angle of incidence of the sound waves (Everest and Shaw, 2001).

To optimise the acoustics in a rooms, among other techniques is to interrupt the paths of sound propagation towards listener as seen in Figure 2.2. Apart from direct sound, sound is transmitted by reflections from the walls and the ceiling. Depending on the sound absorption coefficient of the ceiling and the walls, part of the incident sound always reverberates resulting in a repercussion of the emitted sound by reflection or scattering.

The sound barrier should have a certain mass per unit area, and their surface should be