FACTORS EFFECTING THE ACOUSTIC PROPERTIES OF DATE PALM FIBER

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To my family, my beloved Mom and Uncle Ahmad,

My lovely sisters Damyaa and Alyaa

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ABSTRACT

This research focuses on factors that affect the acoustic performance of a porous material, namely date palm fiber (DPF). Natural DPF is chosen as a potential replacement to synthetic fibers which raise a lot of health concerns. DPF is considered as abundant material which can be obtained cheaply and easily, particularly in the Middle East region. Analytical approaches, namely Delany-Bazley, Biot-Allard and Johnson-Allard were used to estimate the acoustical performance of DPF with previously tested natural fiber. All of the analytical values were then validated with the experimental results. Two types of tests, namely acoustic absorption coefficient (AAC) and sound transmission loss (STL) were undertaken to investigate the acoustical performance of the DPF. A series of tests were undertaken to evaluate the parameters that influence the acoustical performance of the samples. These include tests on the sample of DPF panel treated with latex; sample treated with Urea Formaldehyde as well as samples backed with porous material such as woven cotton cloth and polyester. The findings showed that the AAC of DPF improved with the increase in thickness and density. It was also found that there were improvements on the AAC for sample panels backed with porous materials, particularly at low frequency ranging from 90 Hz to 1.6 kHz. In addition, the STL of DPF panels treated with Urea Formaldehyde produced higher acoustic insulation (in the range of 30 dB) due to the increase in panel stiffness. In short, the results showed that acoustical performance of the DPF is slightly less than synthetic fibers, but better than other previously tested natural fibers. This is mainly due to the smaller diameter of DPF as compared to other natural fiber counterparts. The good acoustical performance of DPF suggests that it has a very good potential to replace the currently used synthetic fibers for acoustical treatment application.

ABSTRAK

Kajian ini memfokus kepada faktor yang memberi kesan kepada prestasi akustik satu bahan poros tulen baru iaitu fiber pelepah tamar (DPF). DPF semula jadi dipilih sebagai satu bahan berpotensi untuk menggantikan fiber sintetik yang menyebabkan banyak masalah kesihatan. DPF dianggap sebagai bahan buangan yang boleh didapati dengan murah dan mudah, terutamanya di rantau Timur Tengah. Pendekatan analitikal, iaitu Delany-Bazley, Biot-Allard dan Johnson-Allard telah digunakan untuk menganggarkan prestasi akustik daripada DPF berbanding serat semula jadi yang telah diuji sebelum ini. Kesemua nilai-nilai analisis kemudiannya disahkan dengan keputusan eksperimen. Dua jenis ujian, iaitu pekali penyerapan akustik (AAC) dan kehilangan transmisi bunyi (STL) telah dijalankan untuk menyiasat prestasi akustik daripada DPF. Beberapa siri ujian telah dijalankan untuk menilai parameter yang mempengaruhi sampel prestasi akustik. Ini termasuklah ujian ke atas sampel panel DPF yang dirawat dengan latex; sampel yang dirawat dengan Urea Formaldehyde dan juga sampel yang dilapik dengan bahan poros seperti kain kapas tenunan dan poliester. Dapatan kajian menunjukkan bahawa AAC daripada DPF bertambah baik dengan peningkatan ketebalan dan kepadatan. Selain daripada itu terdapat juga peningkatan pada AAC untuk sampel panel yang dilapik dengan bahan poros, terutamanya pada frekuensi rendah dalam lingkungan 90 Hz hingga 1.6 kHz. Di samping itu, STL bagi panel DPF dirawat dengan Urea Formaldehyde menghasilkan penebat akustik yang baik (dalam lingkungan 30 dB) hasil daripada peningkatan kekerasan panel. Secara ringkas, keputusan menunjukkan bahawa prestasi akustik daripada DPF adalah sedikit kurang berbanding serat sintetik, tetapi lebih baik berbanding gentian asli lain yang telah diuji sebelum ini. Ini adalah disebabkan oleh diameter DPF yang lebih kecil berbanding gentian semula jadi yang lain. Prestasi akustik DPF yang baik menunjukkan bahawa ia mempunyai potensi yang sangat baik untuk menggantikan gentian sintetik yang masih banyak digunakan bagi aplikasi rawatan akustik.

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A	-	Dimensionless Parameter in Delany-Bazley Approach
$\overline{A}$	-	Complex Steady State Pressure or Force
$\overline{B}$	-	Complex Steady State Velocity or Volume Velocity
C	-	Speed of Sound
C_0	-	Sound Speed in the Air
D	-	Distance between Apertures
d	-	Hole Diameter
d_{mix}	-	Diameter of Fibers Mixed with Latex
f	-	Frequency
$G(\omega)$	-	Viscous Correction Factor
k	-	Wave Number in Free Air
K_b	-	Bulk Modulus of the Frame
$K(\omega)$	-	Bulk Modulus of Rigid Framed Porous Material
$K_{m,n}$	-	Wave Number in a Cylinder
l	-	Total Length of Fiber per Unit Volume of Material
l_{mix}	-	Total Length per Unit Volume of Fibers Mixed with Latex
L	-	Thickness of Perforated Plate
I_i	-	Incident Sound Intensity
I_r	-	Incident Sound Intensity
n	-	Compression Ratio
N	-	Shear Modulus of Frame
P	-	Pressure (Pa)
P, Q, and R		Biot's Experiments Elasticity Coefficients
P_0	-	Atmospheric Pressure
P*r*	-	Prandtl Number of air

r	-	Fiber Radius
R	-	Part-Resistance from Impedance (real)
R_S	-	Surface Resistance
$Re(\alpha')$	-	Real Dynamic Tortuosity
S	-	Surface Area of the Sample
$S = \pi R^2$		Cross Section Area of the Perforated Plate
S_p	-	Surface Area of the Pores
T	-	Time Period
[T]	-	Transfer matrix
$[T_1]$ and $[T_2]$		Transfer Matrices of Layer 1and 2
$[T_{1\,2}]$	-	Interface Matrix Relating Stresses and Velocities for the two Adjacent Porous Layers
ν	-	Poisson's coefficient
V	-	Volume of Air
V (A)	-	Acoustic Field Vector at Point A
V (B)	-	Acoustic Field Vectors at Point B
X	-	Imaginary Part of Acoustic Impedance
Z	-	Acoustic Impedance
Z_a	-	Characteristic Impedance of Air
Z_B	-	Normal Surface Impedance of the Backing Layer
Z_f	-	Characteristics Impedance of Fibrous Material
Z_j	-	Characteristics Impedance of jth Layer
Z_0	-	Characteristics Impedance
$\overline{Z}$	-	Complicated impedance
$\|Z\|$	-	Amount of complicated impedance
$Z_i{}^a$	-	Characteristic Impedance Corresponding to Transmission in Air
$Z_i{}^f$	-	Characteristic Impedance Corresponding to Transmission in Frame
α	-	Acoustic Absorption Coefficient
α_∞	-	Tortuosity
β	-	Phase Change Constant (Coefficient)
π	-	Pi parameter
ρ	-	Density

ρ_a	-	Inertial Coupling Term
ρ_0	-	Air Density
ρ_{bulk}	-	Bulk Density of the Porous Media
ρ_f	-	Density of Fiber
σ	-	Flow Resistivity
ζ_e	-	Correction Length
$\rho_{11}{}^{*}$, $\rho_{12}{}^{*}$, and $\rho22^{*}$	}	Inertial Coupling Parameters between the Frame and Fluid
η	-	Air Viscosity
φ	-	Porosity
Φ	-	Perforation Ratio
Λ	-	Viscous Characteristic Length
Λ'	-	Thermal Characteristic Length
γ	-	Ratio of Specific Heat at Constant Pressure to Specific Heat at Constant Volume of air
γ_j	-	Complex Wave Propagation Constant of jth Layer
Γ_f	-	Surface Acoustic Impedance of Material
Γ_j	-	Surface Acoustic Impedance of the jth Layer
ω	-	Angular Frequency
$\delta_1{}^2$, and $\delta_2{}^2$		Squared Wave Numbers of Two Compressional Waves
μ_i (i=1, 2)		Ratio of Velocities for Two Compressional Waves

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CHAPTER 1

INTRODUCTION

1.1 Introduction

A comfortable environment free from unwanted noise is the dream of every person. Unwanted noise can be detrimental to those exposed: negative effects may include hearing loss, sleep loss, and increased stress. Additionally, acoustic radiation may be damaging to sensitive mechanical and electrical systems because excess vibration and fatigue may be induced. For these reasons, noise reduction is of great interest to engineers. Approaches to noise control may be classified as active or passive. Passive noise control widely employs acoustical treatments with porous materials, known to be effective sound absorbers. The sound absorption coefficient provides a quantitative measure of the acoustic energy absorption for rigidly backed porous materials.

Therefore, sound absorbing materials are used to control the sound levels in these sources. It is a well-known subject on which much research has been done already, although much material and absorbing structure design remains empirical. The compromises between the thickness of the materials, their cost, their practicality and their performances are often important. In most cases, rooms, acoustical walls and others have different absorption qualities which depend on the range of frequencies that are produced in their surroundings. A common constraint in design settings is the space (thickness) available for the sound absorbing materials. The sound absorbers must generally be placed adjacent to more rigid walls and surfaces. Good natural material absorption can be the new to obtain.

Furthermore, utilization of agricultural waste materials enhances economics by booming retrieve industry in one hand and reducing the need for non-degradable synthetic matters on the other hand. Studying the acoustical behavior of date palm fiber and analytical method for predicting its characteristics will abate to optimize the performance of absorber panel in various practical usages. Only then can the development of relevant performance be achieved under conditions that are accepted by the market. Additionally, products form date palm fiber will have the benefit of low raw materials and manufacturing cost, at the same time providing a suitable end use for fibers.

1.2 Background

The traditional way for diminishing the undesirable or harmful noise in the noisy places is by using porous materials to block the sound transmission path [1, 2]. These porous materials that reduce the acoustic energy of sound wave passes through it by the phenomenon of absorption are called acoustic absorption materials. Absorption materials consist of various synthetic materials like glass wool minerals and agriculture-based foams and fibers [3-5]. These materials have been widely accepted as acoustic absorption materials for acoustical applications. The ability of these materials absorb at nearly all frequencies, but the performance increasing when increasing the thickness at low frequency [6].

In recent years the interesting investigation has been developed for a wide range of absorber for porous materials where the researchers seek for a new materials and ranking for preparing in order to strengthen noise attenuation techniques. Therefore, the products of sound absorption are mostly synthetic materials because of domination in the market. For this reason many researches has been working in developing a new materials which have a high potential in the acoustical applications [7-11]. The natural materials have interesting advantages such as renewable source and easily available. There is a limited study on alternative materials for acoustical absorber, but during recent years it has increased because of the side effect related to the potential health risks of the synthetic materials which are commonly used in industrial applications such as asbestos, rock wool, glass wool. In USA/ U.E these materials have been banned for nonessential uses especially in risky range due the risk of injury to the workers leading to many diseases especially for lungs and eyes [12]. It is also to give an opportunity for the natural materials to be developed as sound absorbers to be used in applications traditionally occupied by synthetic materials.

Furthermore, nowadays agricultural waste materials has been widely used to replace synthetic fiber for noise absorption purposes [13, 14]. This natural fiber is suitable as a substitute to synthetic fibers and wood-based materials for acoustic absorption purposes. The advantage of this fiber is cheaper, renewable, and non-abrasive which does not give rise to health and safety issues during processing and handling of the materials [15, 16]. The sound absorption attribute of previously natural fiber such as tea leaf fiber, rice straw fiber, coconut coir fiber, oil palm fiber and reed [17, 18] were investigated and the results showed high potential to be used as sound absorption panel. They can be very useful for various usages in many structural and non-structural applications.

In summary, the literature indicates that natural fibers have many advantages such as cheap, non-hazardous, environmentally friendly, and renewable. Moreover, the exploitation of waste materials (natural wealth) boosts the economy by booming the industry through re-cycling technology and diminishes the environmental pollution due waste deposition. Moreover, the synthetic materials are replaced to the natural fibers because less healthy and safety issue during processing.

1.3 Porous Materials

Porous materials are extensively used as sound absorption materials in noise control engineering. There are different kinds of porous materials which are generally categorized as fibrous medium and porous foam. Many researchers have studied the absorption properties of different materials to reduce the influence of noise via sound absorption [19-22]. Most researchers attempted to improve the absorption factor. This research demonstrates that the thickness of a substances' porosity and the depth of the air gap have significant relationships to acoustic attenuation, hereinafter referred to as the 'acoustic absorption factor' (AAF).

The researchers [23-25] improved the acoustic absorption properties of the materials via multi-layer different forms of flow porosity has been good factors in determining absorbent factor. Gardner [26] studied polyurethane foam to predict acoustic characteristics and suggested a neural network model for polyurethane by gauging multiple parameters such as frequency, the flow of air resistance, and acoustic density from which a model of acoustic characteristics such as an absorption coefficient and surface resistance could be predicted. This model is very accurate and readily expands for the study of different types of materials with different sets of parameters. Hence, the model used for testing foam is also used to derive numerical and other analytical results for other materials.

The problem of noise becomes even more critical the predominant frequencies (low and high) lie within the crucial frequency range of the human ear which is most sensitive to 4 kHz [27]. There is great need for noise reduction by using absorption materials (synthetic materials) such as glass wool, rock wool etc. of various densities. However, glass wool was banned in the USA/E.U. for non-essential uses, especially in this risk range [12]. Furthermore, there is reduction in the transmission of frequencies in nonessential spaces with a double wall. Such hardened building materials have higher absorption coefficients for incidental sound.

1.4 Problem Statement

From the review of reported investigations, it is clear that a synthetic material is harmful to workers. Utilization of agricultural waste materials enhances economics by booming retrieve industry in one hand and reducing the need for non-degradable synthetic materials on the other hand. Two distinct kinds of problem arise of waste natural materials. The first is illustrated the deposition of waste materials (natural fiber) which are renewable annually, due to inevitable imperfections in the accumulation of waste and due to the periodic character of the removal wastes by burning. Therefore, the pollutants are increasing significantly in the environmental directly through the air. Environmental pollution resulting from waste materials deposition and removal of them by burning is one of the biggest problems faced by the human race and a lot of efforts are being put into solving this problem. The second problem is the reduction of acoustic energy by using synthetic materials, namely, asbestos, rock wool, glass wool which have been banned due to potential of injury and risk especially for lungs and eyes.

Furthermore, the use of synthetic materials has always been prohibitive. Therefore, appropriate solutions may offer simpler means for noise reduction. By having absorption natural material with suitable characteristic, engineers can have safer option in tackling acoustical related issue.

1.5 Objectives of the Study

This research focuses on the acoustical properties and development of a new natural material, specifically, date palm fiber (DPF) as acoustic panels. Hence, the three major objectives of this research are as follow:

- To study the capability of date palm fiber (DPF) as a replacement to the synthetic materials for acoustic application.
- To identify major contributor that affect the acoustic properties of date palm fiber (DPF).
- To determine the physical properties that affecting on compression of date palm fiber (DPF).
- To improve the acoustical properties of date palm fiber (DPF).

1.6 Scope of the Research

The scope of this research comprises the following areas:

- Scanning microscopy of the network structure of three types of fiber diameter:
  - Date palm fiber
  - Oil palm fiber
  - Coconut coir fiber
- Develop samples of DPF with different densities and thickness as well as different material combinations, to include:
  - Four thicknesses and densities
  - Three densities of the same thickness
- Develop samples of OPF and CCF with different densities and

thickness as well as material combinations, to include:

  - Two various thicknesses and densities

- Measuring flow resistivity of three types of fiber panels.
- An analytical approach utilized to estimate AAC for three types of investigation:
  - Acoustical properties:
    i) Delany-Bazley
    ii) Biot -Allard
  - Compression effects:
    i) Johnson-Allard
  - Effects of perforated plate:
    i) Allard
    ii) Beranek and Ver
    iii) Atalla and Sgard
    iv) Allard Transfer Function
- An experimental test utilize to measure AAC for two types of investigation:
  - The effect of latex application
  - The effect of porous materials
- An experimental test utilize to measure sound transmission loss (STL) on two types of samples at various densities and thicknesses:
    i) Latex panel
    ii) Urea Formaldehyde panels
    iii) Identify the sound transmission class (STC)
- Comparative study between experimental and analytical.
- Compare results of three types of fibers according to fiber diameter.
- Compare results of DPF with synthetic material fiber glass board.

1.7 Significance of the Study

Natural fiber materials are increasingly being used for different purposes in many specialized applications. Date palm fiber is one of the most important agricultural products harvested in Iraq. The purpose of this study is to make a contribution towards solving the problem of deposition waste material in one hand, reduce pollution and hazards health on the other hand by using natural fibers that are perhaps more suitable as an alternative to synthetic materials such as glass wool (fiberglass) and asbestos which are now widely been used in industrial applications. Secondly, the acoustical performance of natural fiber such as date palm fiber is important in order to be used efficiently in wide range of applications such as transportation sector, building etc. Market demands increases for porous absorbers with the aspirations like lower frequency absorption ability, wide band frequency absorption capability, and thin structure for limited space absorber, specific acoustic absorption spectrum and low cost materials. Another advantage is to be of benefit to the natural wealth of acoustics absorption applications, especially in barrier application because natural fibers are cheaper, non-hazardous and environmentally friendly. To help the greening of technology, wide use is made of manufactured substances derived from agricultural products as materials for industrial fiber and wood based products for the acoustical application. The application of natural fiber may also assist in the preservation of health. Studies conducted on date palm fiber have demonstrated its potential for use in the manufacture of acoustical related application.

1.8 Contribution of the Research

A brief outline of the main contributions of this research is given in this subsection as follows:

- Agricultural waste material is used instead of synthetic materials for acoustical applications to diminish health hazards.
- Date palm fiber has a high potential of acoustical performance to encourage the acoustics engineers for using in various applications such as in buildings, for automotive interior noise reduction, in wall linings and room interior surfacing, transportation sector efficiently and effectively.
- This research is focusing on the use of waste materials (natural fiber) for the purpose of environmental protection against pollution.
- Another contribution of this research is compression ratio simulator approach that can be applied to all thicknesses panels to improve the desired performance as the main goal in the limited space structure.

1.9 Organization of the Thesis

This thesis is divided into seven chapters. A brief outline of the contents of the thesis is as follows:

Chapter 1 presents an introduction to the research problem. It involves the background and significance of the research as well as the problem statement and contributions. The logistical flow and structure of the thesis are also outlined in this chapter.

Chapter 2 is devoted to a literature study on absorption materials for acoustic applications. Firstly, prior works on synthetic materials and natural materials on absorption materials to improve the absorption factor are addressed. In addition, the theoretical background of the study is presented to assist the reader's comprehension of this thesis. Experimental testing is then reviewed and discussed wherein three approaches are described and reviewed prior to the presentation of their application in subsequent chapters. Finally, natural absorption materials that have previously been applied for absorption purposes are reviewed.

Chapter 3 focuses on the three types of natural materials are utilized. The micro-structure of fibers is studied in order to measure physical parameters such as diameter, length and mass to estimate bulk density, flow resistance and so on. Flow resistance is measured to achieve validation via experimental equations. Consequently, average values for physical parameters are then applied in the equations for utilization in all analytical approaches. The experimental setup of the two types of test is clearly introduced.

Chapter 4 presents analytical approaches that were implemented to evaluate the absorption coefficient of date palm fiber. In the first section two approaches modifications of physical parameters using latex are introduced to the equation. In the second section the proposed validated method was implemented within the compression ratio simulation analysis by Johnson-Allard approach. Proposed optimal compression ratio and appropriate thicknesses for improved AAC were based on the simulation which revealed that the compressed DPF considerably improved absorption. Afterwards, presents the effectiveness of perforated plate methodology based on perforation ratio and aperture diameters. This section concentrates on utilizing three types that enhance performance absorbers. The proposed analytical approaches were used as objective functions to improve acoustical properties.

Chapter 5 presents the experimental evaluation of rigid walls for application two type of testing with latex and without. The performances of the two porous materials were selected for enhanced absorption was experimentally investigated. In this chapter also focuses on sound transmission loss (STL) and experimental evaluations. Latex panels with Urea Formaldehyde panels were tested in the impedance tube device. A Urea Formaldehyde panel was employed in the transmission loss studies of rigid panels. The greatest thickness and effectiveness of high density panels were found for optimal insertion losses. Afterwards, sound transmission class (STC) was identified for two types of panels according to STL measure. Finally, the performance of the Urea Formaldehyde panel is suggested for barrier use due to its high potential for transmission.

Chapter 6 is devoted to a comparative between approaches and an experimental result is discussed. Firstly presents the application of the Johnson-Allard approach for the effect of bulk density on the acoustical properties of same thickness panels at various heat compression times during manufacturing. This procedure was utilized for different times of heat compression during manufacturing and the analysis was employed as a valid method to estimate the bulk density required to improve the AAC. Secondly, a suitable perforated plate was selected by the analytical study and the performance of the proposed perforated plates for enhanced absorption was experimentally investigated. In the last section, the effectiveness of each fiber is described and the superiority of DPF compared to OPF, CCF according to fiber diameter and then comparative with synthetic materials discussed.

Chapter 7 sums up the research project and directions for future research works are outlined.

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