SOUND ABSORPTION STUDY OF THREE-DIMENSIONAL PRINTED MICRO-PERFORATED PANEL

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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Statement 1

This thesis is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF ABBREVIATIONS

a	Sound absorption coefficient
3D	Three-Dimensional
MPP	Micro-perforated panel
Z_s	Micro-perforated panel surface impedance
pc	Characteristic impedance of air
R_p	Resistance of specific acoustic impedance
X_p	Reactance of specific acoustic impedance
Z_p	Specific acoustic impedance
RT	Reverberation time
f	Frequency
p	Density of air
t	Thickness of micro-perforated panel
d	Hole diameter
D	Diameter of micro-perforated panel
c	Speed of sound in air
ω	Angular frequency
η	Coefficient of viscosity
k	Wavenumbers in x-, y- and z-directions
P_{in}	Incidence amplitude
m	Modal indices in x-direction
n	Modal indices in z-direction

A_{mn}	*mn*th modal amplitude
φ_{mn}	*mn*th modal shape
L	Side length of micro-perforated panel
σ	Perforation ratio
θ	Inclination angle
ρ_{in}	Oblique plane wave
w	Micro-perforated panel displacement in y-direction
φ_{mn}	Boundary condition
u_p	Vibration velocity of micro-perforated panel
u_o	Air motion
$\bar{u}_a$	Surrounding air particle velocity in vicinity of micro-perforated panel

KAJIAN PENYERAPAN BUNYI OLEH PANEL BERLUBANG MIKRO YANG DICETAK TIGA DIMENSI

ABSTRAK

Panel berlubang mikro sering digunakan untuk menyerap bunyi dan mengurangkan keamatan bunyi. Ia dipanggil penyerap bunyi ‘generasi baru’ kerana ia lebih mesra alam berbanding bahan penyerap bunyi yang berliang yang terdapat pada masa ini. Kebanyakan panel berlubang mikro ini digunakan di hospital, kemudahan bayi dan makanan. Kaedah baru untuk menghasilkan panel berlubang mikro ini telah diperkenalkan iaitu kaedah pencetakan tiga dimensi. Objektif utama projek ini adalah untuk mengkaji pengkali penyerapan bunyi oleh panel berlubang mikro yang dihasilkan melalui kaedah pencetakan tiga dimensi. Objektif ini boleh diselesaikan melalui cara eksperimenental dan teoritikal. Pengkali penyerapan bunyi oleh panel berlubang mikro ini mampu dikenalpasti dengan menggunakan MATLAB dan ujian tiub impedans. Keputusan eksperimen telah disahkan dengan keputusan berangka dan peratus berbezaan antara keputusan tersebut telah dikira. Pengkali penyerapan bunyi oleh panel berlubang mikro juga telah dikaji dengan kepelbagaian darjah serangan bunyi. Keputusan ini mampu mengenalpasti darjah serangan bunyi yang mampu menghasilkan panel berlubang mikro yang paling efektif berdasarkan pengkali penyerapan bunyi.

SOUND ABSORPTION STUDY OF THREE-DIMENSIONAL PRINTED MICRO-PERFORATED PANEL

ABSTRACT

Micro-perforated panel is widely used to absorb sound and reduce the sound intensity. It is called 'next-generation' sound absorber as it more environmental-friendly the existing porous sound absorbent materials. Micro-perforated panel is commonly used in hospitals, infant and dining facilities. A new method to produce micro-perforated panel is introduced, which is three-dimensional printing method. The main objective of this project is to study the sound absorption coefficient of three-dimensional printed micro-perforated panel. This objective is done theoretically and experimentally. The sound absorption coefficient of micro-perforated panel varies with the sound frequencies is determined by using MATLAB and impedance-tube test. The experimental results are verified with the simulation results and the percent difference of the results are calculated. The sound absorption coefficient of micro-perforated is then studied with the effect of sound incidence angle. The results can determine which sound incidence angle produce the most effective micro-perforated panel based on the sound absorption coefficient measured

CHAPTER 1

1. INTRODUCTION

1.1 Overview

Micro-perforated panel (MPP) is a device used to absorb sound, reducing its intensity. The micro perforated panel absorber was first proposed by Maa[1] in 1975 and it is act as a ‘next-generation’ alternative for porous sound absorbent materials, such as glass wool, mineral wool and urethane foam that can produce unwanted floating dust particles in hospitals, infant facilities and also dining facilities[2]. These unwanted floating dust particles can cause various problems in health, sanitary and environment aspects. Hence, more environmentally-friendly sound absorption systems are needed to upgrade hygienic condition without these hazardous porous sound absorbing materials[3].

A micro-perforated panel, which is shown in Figure 1, consists of a large number of micro-sized Helmholtz resonator holes in front of an acoustically hard backing material[2]. Normally, it has a thickness of 0.5mm – 2mm and the holes typically cover 0.5% - 2% of the plate, depending on the application and the environment in which the micro-perforated panel to be mounted[4]. Damping and sound absorption are produced by the air flow resistance, and the resonance frequency is determined by the dimensions and the number of perforations, the thickness of the air layer between the perforated panel and the backing plate and the porosity[5].

The fundamental absorbing mechanism of the micro-perforated panel absorber, generally backed by a rigid wall and an air cavity is Helmholtz-resonance absorption. This Helmholtz-absorption is mainly due to frictional loss in the air flow of the apertures. Air inside the holes of the micro-perforated panel vibrates like a mass and air inside the backing cavity works like a spring[2]. The system accomplishes a Helmholtz absorption due to the low reactance and high acoustical resistance provided by holes in sub-millimeter size.

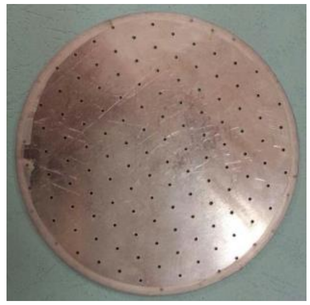


Figure 1: Micro-perforated panel[6]

Sound absorption coefficient of micro-perforated panel is a measure of the ability of a micro-perforated panel to absorb sound. There are several parameters that could affect the sound absorption coefficient of micro-perforated panel including diameter and thickness of micro-perforated panel, diameters of hole, distance between holes and perforation ratio. The general equation to calculate the sound absorption coefficient, *a* is given in Equation (1) below;

$$a = \frac{4Re(\frac{Z_s}{pc})}{[1 + Re\left(\frac{Z_s}{pc}\right)]^2 + [lm\left(\frac{Z_s}{pc}\right)]^2} \qquad (1)$$

Where Z_s = micro-perforated panel surface impedance

pc = characteristic impedance of air

Figure 2 (a) shows the arrangement of micro-perforated panel as sound absorber which is located in front of a rigid wall with an air gap. The system resembles a Helmholtz resonator mechanism where maximum sound absorption can be obtained at resonance. The general trend of the absorption is thus quite narrow in terms of the frequency band and is mainly at low frequencies. Figure 2 (b) presents the analytical simulation of absorption coefficient of micro-perforated panel for different hole diameter, perforation ratios and air gap. From the figure, it can be seen that by adjusting the hole diameter, perforation ratio and the air gap, the peak amplitude and the peak frequency can be controlled.

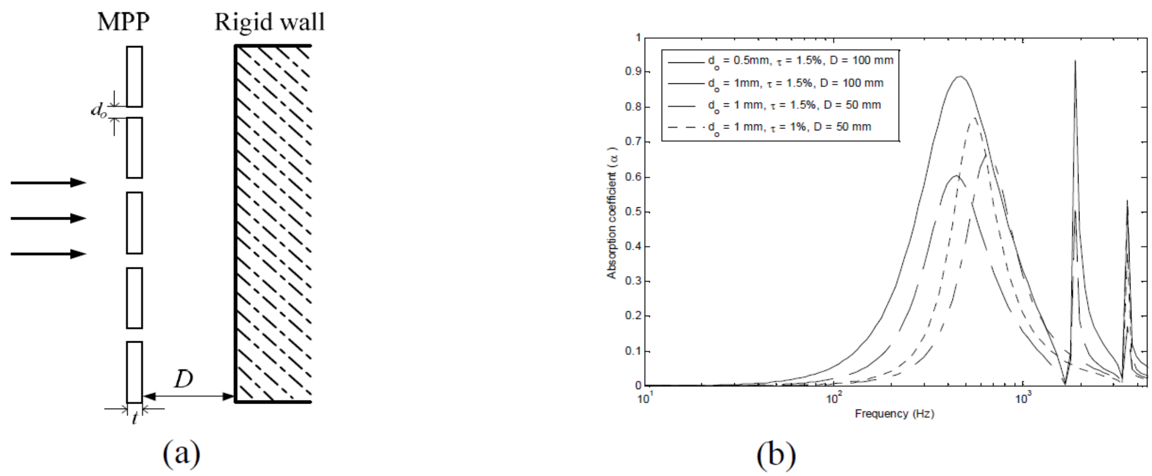


Figure 2: (a) Schematic diagram of MPP in front of rigid wall and (b) its absorption coefficients.[7]

Sound incident angle is an important parameter to the sound absorption coefficient of micro-perforated panel. The difference of sound incidence angle at a constant frequency will produce difference sound absorption coefficient of the panel. Besides, the material of micro-perforated panel also could affect the performance of the panel. 3D Printing method is used in this project to fabricate micro-perforated panels with different parameters and inclination angles. Simulation and experiment are done to measure the sound absorption coefficient of the panels.

1.2 Project Background

General, a micro-perforated panel absorber consists of a micro-perforated panel and a backing air cavity. Sound absorption coefficient is one of the importance character to measure the performance of micro-perforated panel. In this project, the sound absorption coefficient of 3D printed micro-perforated panel is measured by impedance-tube test with different parameters and inclination angles of micro-perforated panel.

Previously, many studies had been done to investigate the performance of micro-perforated panel with difference parameters [3][8][9]. These studies were neglecting the effect of sound incidence angle as one of the parameters of the sound absorption coefficient of micro-perforated panel. This project will be studied the performance of the panel varies with its inclination angle.

Besides that, sound absorption coefficient of micro-perforated panel can be affected by its material. There are a few papers that studied the effect of material of micro-perforated panel to its performance[10][11]. Most materials of the micro-perforated panel are kenaf fibre, polylactic acid (PLA) and polyester. In this project, 3D-Printing technology is used to fabricate micro-perforated panel as it is less time consuming for fabrication and it can print complex design that is uploaded from a CAD model[12][13].

1.3 Problem Statement

The study of sound absorption of micro-perforated panel is important as it is a measure of performance of the panel which can replace most existing porous sound absorbent materials such as mineral wool. Recent papers had studied about the sound absorption coefficient of micro-perforated panel varies with many parameters such as perforation ratio, thickness and diameter of the panel and diameter of holes. But there are some limitations of these studies as the effect of incident angle of sound wave and the material of micro-perforated panel is neglected. Sound incidence angle is one of important parameters as it can bring huge effect to the performance of micro-perforated panel. Besides, different materials of micro-perforated panel also could affect the sound absorption of the panel. In this project, micro-perforated panel is fabricated by using 3D-printing method and the performance is measured experimentally.

1.4 Objectives

1. To study the sound absorption of three-dimensional printed micro-perforated panel.
2. To determine the sound absorption coefficient of micro-perforated panel varies with sound frequencies.
3. To investigate the effect of sound incidence angle to the sound absorption coefficient of micro-perforated panel.

1.5 Scope of Work

In this project, a mathematical model on the effect of the incidence sound angle to the sound absorption coefficient of micro-perforated panel will be done by using MATLAB software. Micro-perforated panel is fabricated by using 3D-print method and the sound absorption coefficient of the panel is then measured by using impedance-tube test. After getting the experimental results from the impedance-tube test, the results are then verified with the mathematical model and the percent difference between the results are calculated.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Fundamental of Micro-Perforated Panel

In 2007, Sung *et al.*[5], made a research about the fundamental of micro-perforated panel. They had discussed about the variation of acoustic impedance models of micro-perforated panel which were proposed by three difference sources, which are Maa[1] in 1975, Beranek and Ver[14] in 1992, and Rao and Munjal[15] in 1986.

In 1975, Maa[1] proposed an acoustic impedance model solution with an error within 5% and the solution was given as,

$$Z_{pM} = \frac{Z}{Z_O} = R_{pM} + jX_{pM}$$

$$R_{pM} = \frac{C_1 t \times 10^{-5}}{pd^2} \left(\sqrt{1 + \frac{X^2}{32}} + \frac{X\sqrt{2}}{8}\frac{d}{t}\right) \qquad (2)$$

$$X_{pM} = 0.0185\frac{tf}{p}\left(1 + \frac{1}{\sqrt{9 + \frac{X^2}{2}}} + 0.85\frac{d}{t}\right)$$

where Z_0 is the acoustic impedance of air, R_{pM} and X_{pM} are the resistance and the reactance of the Z_{pM}, respectively $X = C_2 \times 10^{-3} d\sqrt{f}$, C_1 and C_2 are 0.147 and 0.316 for a non-metal plate and 0.335 and 0.21 for a metal plate, respectively, *f* is frequency, *p* is the density of air, *t* is the thickness of plate, *d* is the hole diameter.

In 1992, Beranek and Ver[14] proposed a different form of the approximate resistance and reactance for the normalized specific acoustic impedance of a perforated panel;

$$R_{pB} = \frac{8.076 \times 10^{-5}\sqrt{f}}{p}\left(1 + \frac{t}{d}\right) \qquad (3)$$

$$X_{pB} = 0.0185\frac{f}{p}[\frac{0.0044}{\sqrt{f}}\left(1 + \frac{t}{d}\right) + t + \delta]$$

where δ = 0.85∅(p) is the function of the porosity and $\emptyset\,(p) = 1 - 1.47\sqrt{p} + 0.47\sqrt{p^3}$.

In 2004, Lee and Kwon[16] proposed another form of the resistance and the reactance based on Rao's and Munjal's empirical model[15];

$$R_{pB} = \frac{8.076 \times 10^{-5}\sqrt{f}}{p}\,(1 + \frac{t}{d})$$

$$X_{pB} = 0.0185\frac{f}{p}[\frac{0.0044}{\sqrt{f}}\left(1 + \frac{t}{d}\right) + t + \delta] \quad (4)$$

The theoretical sound absorption coefficients of the micro-perforated panel were calculated by using acoustic impedance of Equation (2) by Maa[1], Eq. (3) by Beranek and Ver[14] and Equation (4) by Lee and Kwon[16] and are compared in Figure 3. Both panel parameters used in the calculation are shown in Table 1 below;

Table 1: Parameters of micro-perforated panel used to measure sound absorption coefficient using three difference acoustic impedances

Figure	(a)	(b)
Thickness of panel (mm)	0.5	10
Hole diameter (mm)	1	1
Perforation ratio (%)	1	1
Diameter of panel (mm)	30	30

Based from Figure 3(a), both Maa's ad Beranek and Ver's acoustic impedance models yielded similar sound absorption profiles with an absorption peak of 0.75 at 800Hz while Lee and Kwon's model yielded a greater maximum sound absorption coefficient at lower frequency which is 700Hz. For Figure 3(b), the thickness of micro-perforated panel is increased from 0.5mm to 10mm. As a result, the level of the sound absorption coefficients are similar, but the resonant frequencies of Maa and Beranek and Ver are shifted to a lower frequency of 270Hz from 800Hz while Lee and Kwon is shifted to 580Hz from 700Hz. From this 2 figures, it can seen that as the thickness of micro-perforated panel increased, the sound absorption peak remain the same but at lower sound frequency.

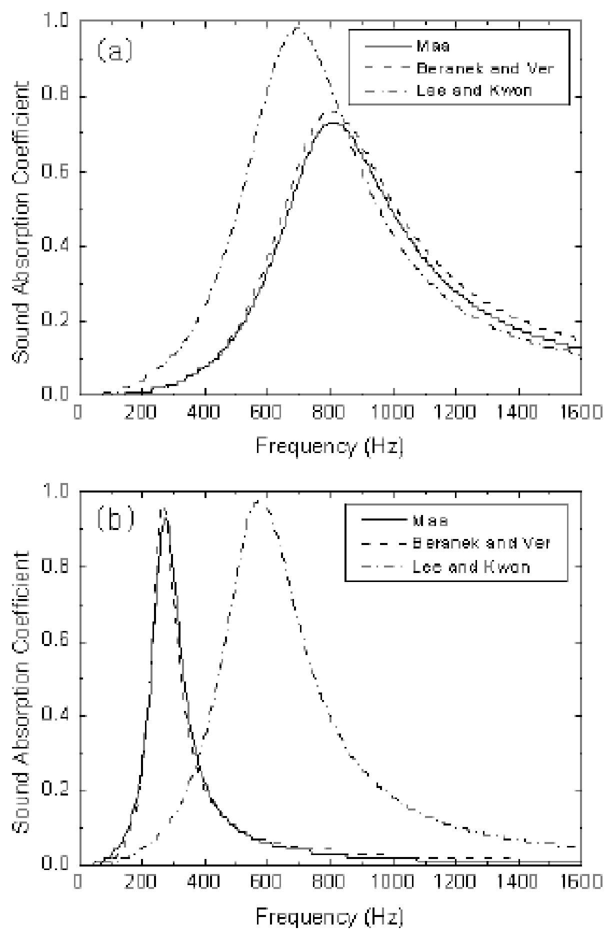


Figure 3: Comparison between simulated sound absorption coefficients of micro-perforated panel by using three difference acoustic impedances with different panel parameters. [5]

The sound absorption coefficients of a micro-perforated panel with the panel parameter as shown in Table 2 below were calculated for each acoustic impedance. The sound absorption profiles were compared in Figure 4(a) and (b) with the values measured by using impedance tube.

Based from Figure 4(a), it can be seen that the measured profiles are broader and the resonance is at a higher frequency. To account for the disagreement, the end correction in the acoustic impedance of the theoretical prediction in Equation (2), (3) and (4) were changed from 0.85 to 0.5 which was proposed by Dean[17]. As a result, the sound absorption profiles with 0.5 end correction of Maa's and Beranek and Ver's acoustic impedances exhibit the closest agreement with the experimental profiles obtained by using the impedance tube in the aspect of the level of maximum absorption at 750Hz as shown Figure 4(b). From Figure 4(a) and (b), it can be concluded that the 0.5 end correction that had been proposed by Dean is more accurate than 0.85 end correction compared to the experimental results

Table 2: Parameters of micro-perforated panel used to compare between simulated sound absorption coefficients of micro-perforated panel by using three difference acoustic impedances with difference end corrections

Parameter	
Thickness of panel (mm)	1
Hole diameter (mm)	1
Perforation ratio (%)	1
Diameter of panel (mm)	30

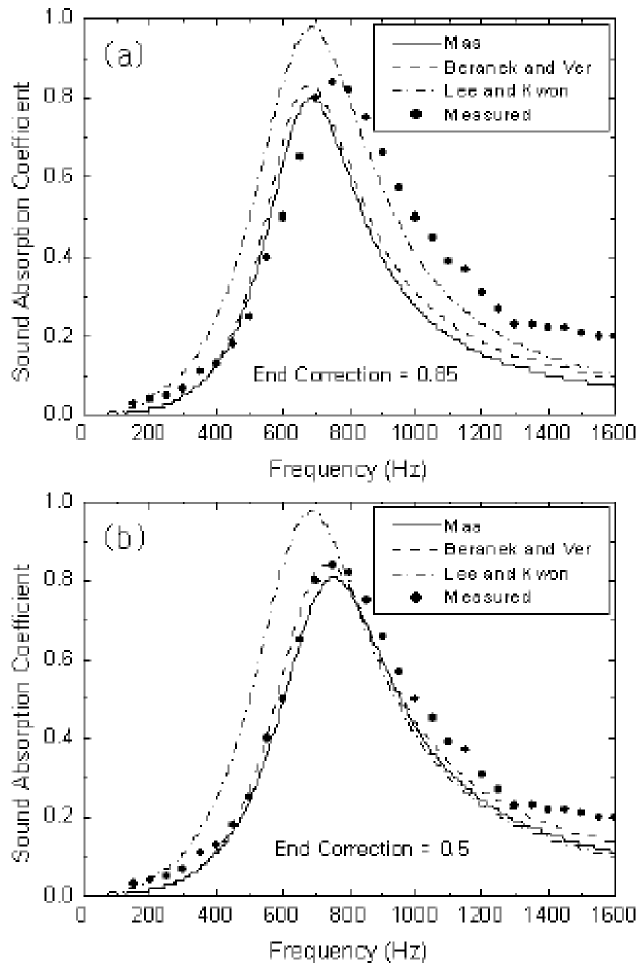


Figure 4: Comparison between simulated sound absorption coefficients of micro-perforated panel by using three difference acoustic impedances with (a) 0.85 end correction and (b) 0.5 end correction.[5]

2.2 Fabrication of Micro-Perforated Panel

The design of a micro-perforated panel acoustic structure to obtain the desired absorption capabilities is relatively easy, but it is difficult and costly to fabricate such submillimeter holes by using the conventional method, such as a micro-punch as shown in Figure 5, or laser technology. Besides that, the punch on the surface of a thin panel may lead to veneer tear out, and partially plugged, tapered, rough walls, which significantly affect the acoustic performance of a sound absorber structure. Some of literature has presented the infiltration method[18], the use of parallel perforated ceramic materials[19] and the use of a perforated plate with micro-filtering mesh[20].

Figure 5 shows a micro-perforator machine that can produce 2.600 holes per minute. Although it has a high hole production rate, the machine has a low accuracy which is 0.762mm hole diameter and it is an expensive method to fabricate micro-perforated panel. An alternative method to fabricate micro-perforated panel need to be studied in order to lower the manufacturing cost and increase the holes accuracy.

Figure 5: Micro-perforator machine[21]

Pedro Cobo *et al.*[18] had made a research on fabrication of micro-perforated panel by using infiltration method. They had proposed a fabrication technique which significantly lowers the manufacturing cost of micro-perorated panel absorber compared to laser technology. This infiltration method consists of mixing common salt grains of controlled size with a commercial epoxy resin. The mixture is introduced into a mould. When the epoxy cures, the sample is released and introduced into a water tank to dissolve the salt grains appearing holes with the shape of the grains. The parameters of the resulting micro-perforated panel are controlled by the size and percentage of salt grains in the initial mixture. The flow process of infiltration method for manufacturing a micro-perforated panel is shown in Figure 6.

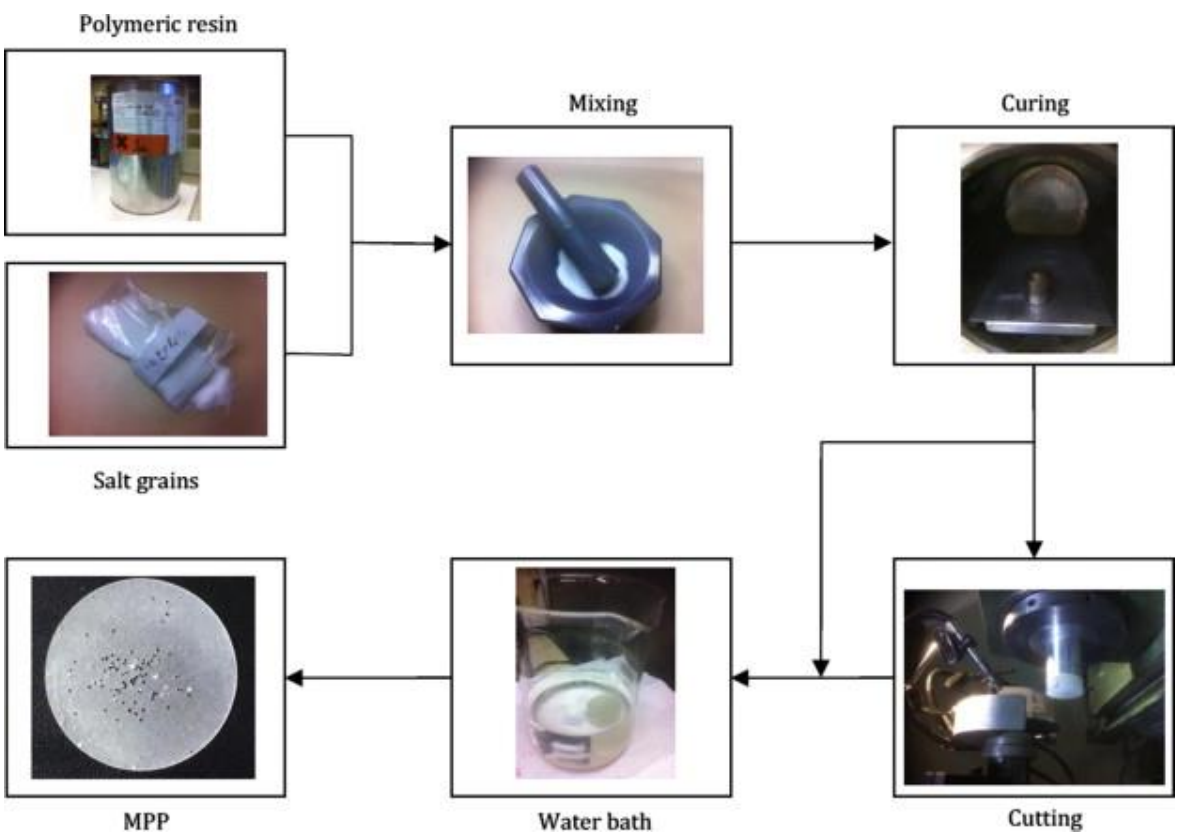


Figure 6: The flow process of infiltration method for manufacturing a micro-perforated panel. [18]

Zhengqing *et al* had made an investigation about the designing of the micro-perforated panel by using 3D-printing method combined with porous material in the year 2017[22][23]. In their discussion, the test micro-perforated panel specimens were made of polymer material, and these specimens were printed with different perforation ratios. Their absorption coefficients were experimentally measured by using the impedance tube method and the results obtain were theoretically validated by using the transfer matrix method.

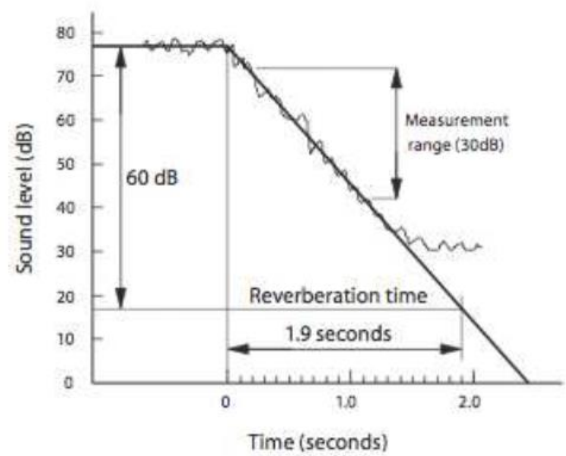
This investigation proved that micro-perforated panel can be produced by 3D printing technology as the experimental results of the sound absorption coefficient of a 3D-printed micro-perforated panel layer backed with porous material are fairly well with the theoretical model. This research will aid this project to produce a 3D printed micro-perforated panel with suitable parameters and precise accuracy. By using 3D printing technology, the time taken to produce a micro-perforated panel specimen can be reduce and the performance of the panel can be guaranteed.

2.3 Application of Micro-Perforated Panel

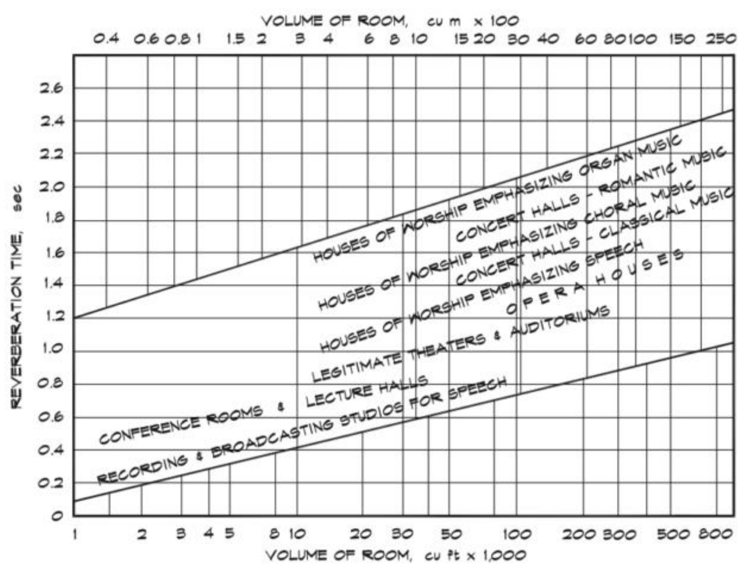
The micro-perforated panel absorber is becoming a good replacement of conventional porous absorbers in building noise control. In Malaysia, a study on the use of micro-perforated panel in mosque to improve its acoustic performance had been done in 2013. Many mosques are built without the attention of its acoustical properties. According to Setiyowati[7], many mosques have reverberation problem and bad sound pressure distribution. By applying the micro-perforated panel to mosques, these problems can easily be solved.

In this study[7], a common controlled acoustical parameter to determine the clarity of speech or quality of sound in room is introduced, which is reverberation time. Reverberation time is defined as the time required for the sound energy to decay 60dB after a sound source is turned off. Other parameters also exist which are equivalent to the reverberation time such as early decay time, clarity and lateral fraction; each provides its own quality of representation with the subjective of listeners to the perceived sound.

The reverberation time required for good room acoustics depends on the function of the room. Figure 7 shows the recommended occupied reverberation time according to the room function and volume[24].



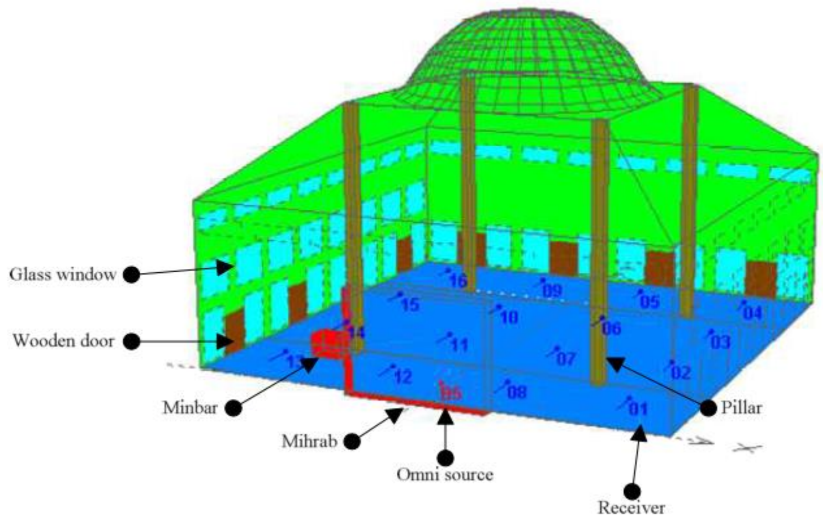
(a)



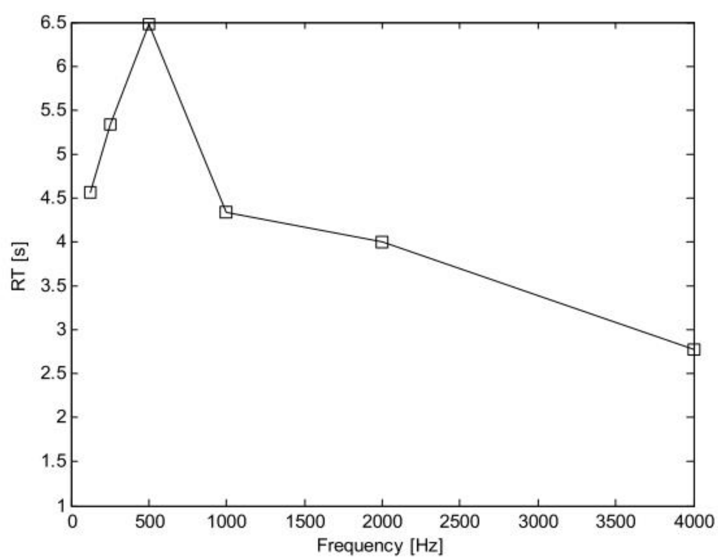
(b)

Figure 7: (a) Reverberation time[25] and (b) recommended reverberation time according to room volume and functions[24]

A typical model of a mosque is developed using CATT room acoustic software as shown in Figure 8(a). Figure 8(b) shows the reverberation time obtained from simulation where at low frequencies below 500Hz, reverberation time can reach up to 605 seconds indicating poor acoustic performance.



(a)

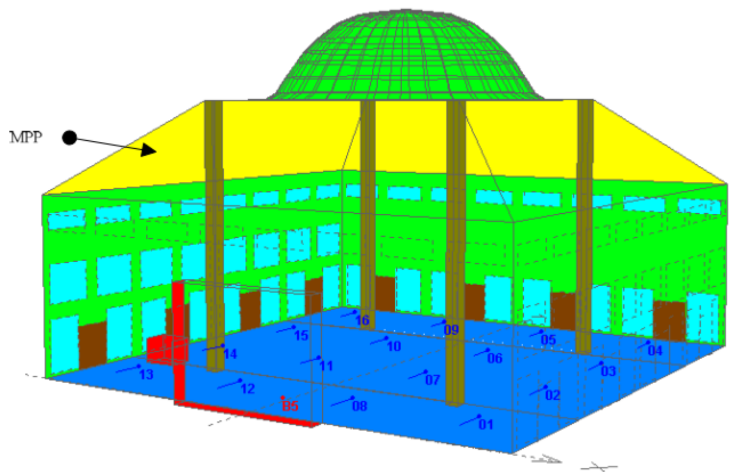


(b)

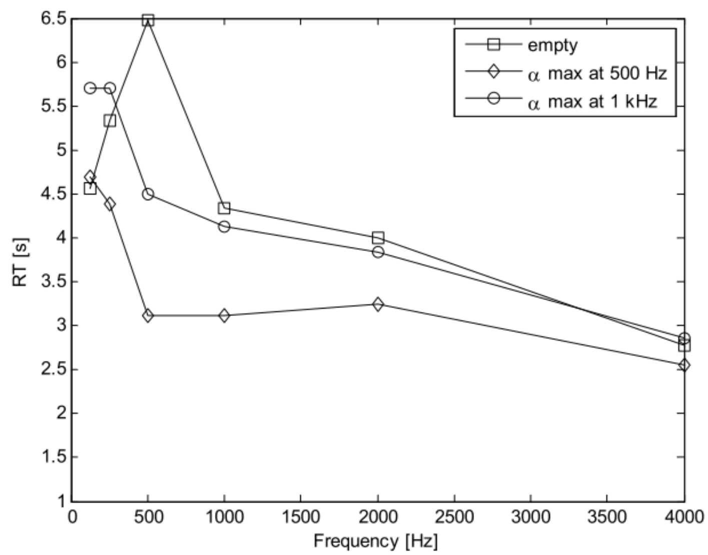
Figure 8: (a) CATT model of an empty mosque and (b) simulated reverberation time[7]

As the reverberation time for speech intelligibility is critical between 500Hz and 1kHz, simulation is conducted to only control the reverberation time at these two frequencies. Figure 9(a) shows the CATT model of the mosque with micro-perforated panel assumed to cover the whole lining roof. The micro-perforated panel parameters used are diameter of hole = 0.4mm, perforation ratio = 1% and diameter of micro-perforated panel = 10mm. Figure 9(b) shows the simulated reverberation time with and without micro-perforated panel.

The results show the designing maximum absorption coefficient of micro-perforated panel at 500Hz is effective to bring down the reverberation time for other frequencies. Reverberation time at 500Hz can be reduced significantly from 6.5s to 3s. Meanwhile for micro-perforated panel with maximum absorption at 1kHz, almost no effect for reverberation time at 1kHz. This can be understood since the frequency band of absorption of micro-perforated panel is broader when the resonance is at lower frequencies and narrower at higher frequencies. Based from the study, it has been shown that micro-perforated panel can control reverberation time at low frequencies



(a)



(b)

Figure 9: (a) CATT model of strips of micro-perforated panel installed in a mosque and (b) simulated reverberation time

CHAPTER 3

3. METHODOLOGY

3.1 Mathematical Modelling

For the simulation of this project, MATLAB software will be used to build the mathematical modelling of the micro-perforated panel. By using MATLAB, a graph sound absorption coefficient against frequency of sound with respect to different sound incidence angles will be generated

The micro-perforated panel impedance is shown below;

$$Z_{resist} = \frac{32\eta t}{\rho_0 c d^2}\ [\left(1+\frac{K^2}{32}\right)^{\frac{1}{2}} + \frac{\sqrt{2}}{32}\ K\frac{d}{t}$$

(5)

$$Z_{react} = i\frac{\omega t}{c}\ [1+\left(1+\frac{K^2}{32}\right)^{-\frac{1}{2}} + 0.85\frac{d}{t}]$$

Where Z_{resist} = resistance of the relative specific acoustic impedance of a hole Z

Z_{react} = reactance of the relative specific acoustic impedance of a hole Z

ρ = air density

c = speed of sound in air

i = $\sqrt{-1}$

ω = angular frequency

t = thickness of the panel

d = hole diameter

η = coefficient of viscosity

K $= d\sqrt{\omega\rho_0/4\eta}$

For an oblique plane wave, ρ_{in} is shown below;

$$\rho_{in} = P_{in}e^{i(\omega t - k\, sin\theta\, sin\beta x + k\ \ cos\theta y + k\, sin\theta\, cos\beta x)} \tag{6}$$

where k = wavenumbers in x-, y- and z-directions

P_{in} = incidence amplitude

θ = inclination angle

panel displacement in the y-direction, *w* in a harmonic regime is expended as

$$w = \sum_{m,n=1}^{MN} A_{mn}\varphi_{mn}e^{i\omega t} \tag{7}$$

where A_{mn} = *mn*th modal amplitude

φ_{mn} = *mn*th modal shape

m and *n* are the modal indices in the x- and z-directions.

A simply supported boundary condition is assumed by equation below;

$$\varphi_{mn} = \sin(m\pi x\ /L_x)\sin(n\pi z\ /L_z) \tag{8}$$

where L = side length of the panel

The vibration velocity of the micro-perforated panel is obtained by using the equation below;

$$u_p = \frac{\delta w}{\delta t} = i\omega\sum_{m,n=1}^{MN} A_{mn}\varphi_{mn}e^{i\omega t} \tag{9}$$

The air motion, u_o in a spatial mean sense is described as

$$\bar{u}_0 = \ \sigma u_0 \tag{10}$$

where σ = perforation ratio (%)

The surrounding air particle velocity in the vicinity of the panel, $\bar{u}_a$ is defined as

$$\bar{u}_a = (1 - \sigma)u_p + \bar{u}_0 \quad (11)$$

The sound absorption coefficient of the micro-perforated absorber is determined by using the following equation

$$\alpha_{\theta,\beta} = \frac{\rho_0 c \int_S Re(\rho_e^* . \bar{u}_a)ds}{|P_{in}|^2 S} \quad (12)$$

Equations (5) – (12) are repeated for different inclination angle.

3.2 Fabrication of micro-perforated panel

Four samples of micro-perforated panel with different parameters, were designed by using SolidWorks as shown in Figure 10 and printed by using 3D-Printing technique. The parameters of the samples are selected from two different papers[2][26] and are shown in Table 1;

Table 3: Parameters of samples of micro-perforated panel

Sample	Diameter of MPP (mm)	Diameter of holes (mm)	Distance between holes (mm)	Thickness of MPP (mm)	Perforation ratio (%)
Sample #1	34.8	1	4	2	4.9
Sample #2	34.8	0.8	4.2	1.8	2.8
Sample #3	34.8	0.9	3.5	1.5	5.2
Sample #4	34.8	1.1	4.4	1.6	4.9

The samples are printed using Objet30 Scholar 3D Printer, which is shown in Figure 11. The material used to fabricate the samples is polypropylene. The printed micro-perforated panel samples are shown in Figure 12.

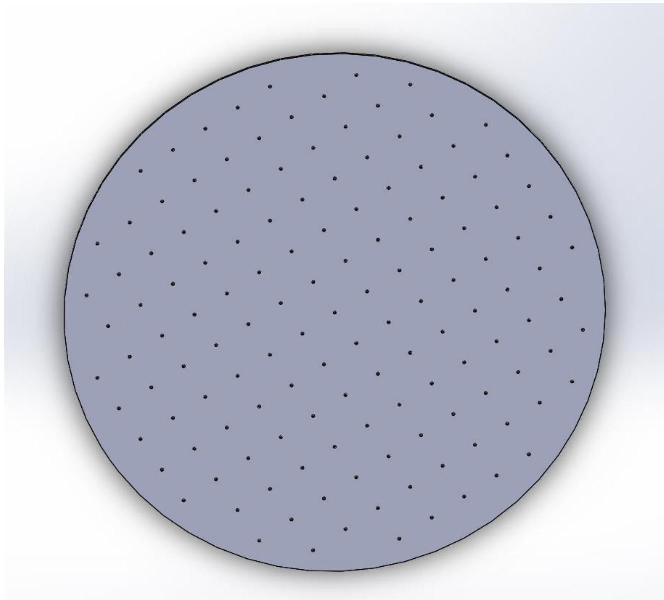


Figure 10: Designed micro-perforated panel with inclination angle θ = 0°

Figure 11: Objet30 Scholar 3D Printer

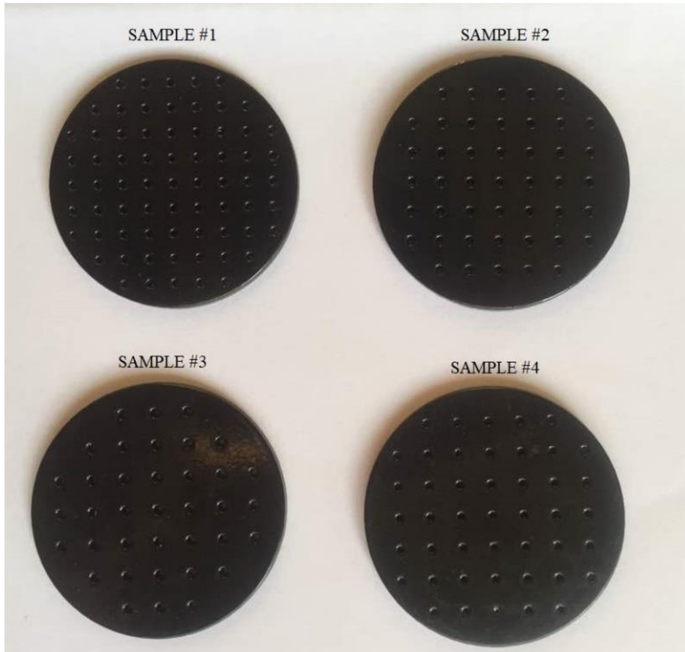


Figure 12: Four samples of micro-perforated panels with inclination angle θ = 0°

3.3 Experimental Setup

The sound absorption coefficient was experimentally measured according to the ASTM E1050-12 standard[27] by using the two-microphone impedance tube method. The impedance tube used in this project is shown in Figure 13 and the experimental setup is shown in Figure 14. The experimental solution is divided into two parts, which is at inclination angle θ = 0° and θ = 45°.

Figure 13: Impedance-tube

Figure 14: Experimental Setup

3.3.1 Inclination Angle θ = 0°

Impedance-tube is used to measure the sound absorption coefficient of 4 samples of microperforated panel in Figure 12. The samples are inserted in the impedance tube as shown in Figure 15. The sound frequencies are set in range of 0Hz – 2000Hz. The results taken from the impedance-tube test method are recorded for further verifications.

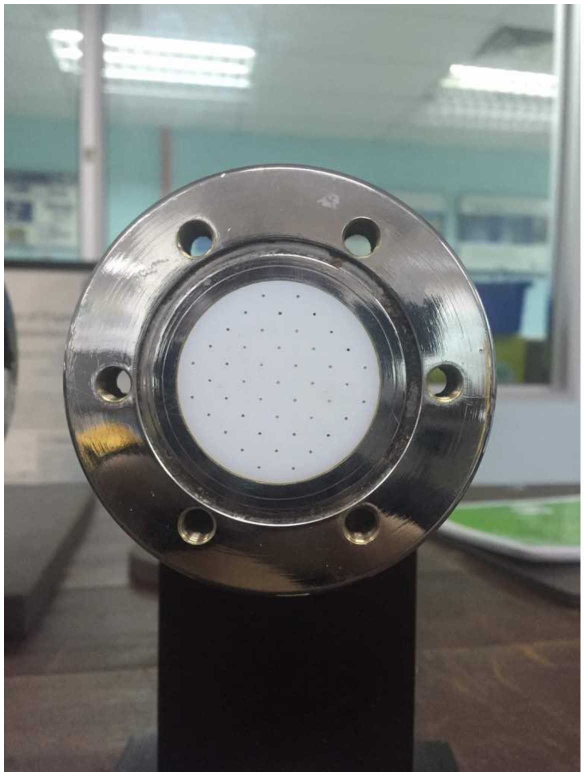


Figure 15: Sample of micro-perforated panel with inclination angle θ = 0° inserted in impedance tube

3.3.2 Inclination Angle θ = 45°

A micro-perforated panel is designed as shown in Figure 16. This is to ensure that the inclination angle is set to 45° when the micro-perforated panel is inserted in the impedance tube as shown in Figure 17. The parameters of the micro-perforated panel are chosen from one of the 4 samples in Table 3 based from their percent difference between