DESIGN AND EVALUATION OF MUTILAYER SOUND ABSORBER

CHAW ZHI XIN

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechanical Engineering

Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : 

Name : Chaw Zhi Xin

ID No. : 1701271

Date : 16/04/2021

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DESIGN AND EVALUATION OF MULTILAYER SOUND ABSORBER"** was prepared by **CHAW ZHI XIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineerng (Honours) Mechanical Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : 

Supervisor : Dr. King Yeong Jin

Date : 18/04/2021

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ABSTRACT

Sound pollution has always been a big problem faced by everyone during their daily lives, especially for those who have the special needs to work under quiet environment. There are a lot of research that has been done on experimenting different design of sound absorber since the invention of it from long ago. While on the other hand, as a newly introduced fabrication method, 3D printing has been used frequently for rapid prototyping as it has much more flexibility to produce a prototype with much lower cost and time required. The main aim of this project is to evaluate the effect of the combination of Micro-perforated panel (MPP), Cartesian porous panel and Hexagonal porous panel toward its sound absorption ability. These panels are aligned as 2 layer sound absorber panels with varying inter-layer distance, combination between panels and sequences. Throughout this project, the sound absorption peak varies depending on the combinations of panels as well as its sequence. Generally, the combination panels which include the Hexagonal porous panel would have a better sound absorption ability compared to the other combinations, except when MPP is placed at the second layer. While among this combinations, the combinations between Cartesian and Hexagonal porous panel would have the highest peak of sound absorption coefficient at round $\alpha \approx 1$. However, the frequency range of the absorption peaks would shift slightly toward the higher or low frequency regions when the combination among the 3 printed panel aligned at the 1st and 2nd layer have changed. Based on the study, the current proposal is only effective for the frequency range above 1100Hz. In addition, the varying inter-layer distance has also contribute to the shifting of absorption peak of the combination panels. When the inter-layer distance between each layer increases from 0 mm to 40 mm, the absorption peak would shift slightly towards the lower frequency range while increasing in sound absorption coefficient, reaching its optimum at inter-layer distance = 40 mm. These finding would benefit the tuning the room acoustics to tackle the specific frequency range as a dead room is not healthy to human being when a high absorptive materials across a wide frequency range is used.

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D	Sample diameter, (mm)
t	Thickness, (mm)
d	Hole size, (mm)
b/s	Hole spacing, (mm)
p	Perforation ratio, %
a	Air gap size, (mm)
x	First layer
y	Second layer
f	Frequency, Hz
α	Sound absorption coefficient
MPP	Micro-perforated panel
CP	Cartesian porous panel
HP	Hexagonal porous panel

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Noise pollution is one of the four major pollution categories which include the air pollution, water pollution and solid waste pollution. These pollution has caused a lot of problems to our environment as the pollution problems are becoming more and more serious due to the urbanization and increase in population. At the worst cases, noise pollution could even cause problems such as pathological damage to organs or nervous systems to humans and animals. However, the noise pollution does not attract the attention from most of the people compare to the other 3 pollution.

The source of noise pollution can be from everywhere, from the rumble noise produced by the construction area, to the honk of automobiles, or to the drum sound caused by your neighbour upstairs. These noises would cause great discomfort to the people around the areas. Hence, various types of sound absorbents are introduced to solve the noise problem.

Sound absorber is an important factor to be considered while building a room acoustic control, be it an acoustic dead room or a live room. Background noise control is not always targeting a room with its background sound fully absorbed but to control the background noises to a desirable level, depending on the situation and applications.

Theoretically, sound waves are produced by vibration that travels through a medium. High frequency sounds are made up by short wavelength while low frequency have a longer wavelength. Sometimes, a high frequency sound would cause more discomfort or even physical damages to one around due to its short wavelength. On the other hand, a low frequency sound would travel further due to its long wavelength. It might not cause as much discomfort to one around, but it is still a type of unwanted noise that would cause interruption or stress to one's daily lives. As such, it is important to search for a way to get rid of these unwanted sounds to improve one's living qualities.

Commonly, sound absorbents are materials with pores in it to absorb the unwanted noise. Different types of sound absorption material would contribute to different frequency ranges of sound absorption. Some are good at absorbing high frequency sound wavelength while reflecting back the remaining sound wave, while some were built to absorb lower frequency sound wavelength. When the sound waves pass through these sound absorbents, these sounds would lose their energy and transform into a form of heat energy. Thus reducing the noise around the area. Higher frequency sound would not bend as much as the lower frequency sound does. It would be reflected by a thin sheet of material while a lower frequency sound would pass through the thin sheets. These properties of sound have become fundamental for the research done regarding the effectiveness of sound absorbent on these different frequency ranges of sound waves.

On the other hand, 3D printing technologies are a type of newly introduced technologies as a type of additive manufacturing that have contributed a lot in rapid prototyping as well as manufacturing of products. Unlike the conventional machining method that subtract material from raw material to the desired final product, 3D printing is a process to produce a 3D model from a computer aided program (CAD), by adding layer to layer. The designed drawing can be straightly imported from the CAD software into a slicing software, then printed out according to the instruction given by the g-code produced by the slicing software. There are also tons of materials to be chosen as the filament of 3D printed prototype, mainly plastic material, each having different properties to suit its uses.

The benefit of using 3D printing technology is that it could increase the speed of manufacturing of a relatively complex design. It is best to be used for rapid prototyping due to its flexibility to produce various designs in a short amount of time. Compared to the traditional conventional machining method, it gives more flexibility to design a more complex design with internal pores that are hard to achieve by subtraction manufacturing. While injection molding could also be used to produce a relatively complex design in a short time, 3D printing provides more flexibility to make changes to the design when faults are found on the design as it costs a lot of time and money to make a mold to be used in injection molding.

By applying 3D printing into use, it would give more flexibility to the design of the sound absorption material. Since sound absorbent design tends to contain porous design in its material, 3D printing the model would greatly help in finding the best design for the sound absorbent in the most time and cost efficient way.

1.2 Importance of the Study

Noise pollution has caused a lot of problems to our daily lives and is ought to be paid attention to. These unwanted noises can come from various sources such as construction working, automobile noises, the quarrelling of someone next door, and the echo voices in a packed restaurant, etc.

The effect of unwanted noises can be insignificant compared to the other pollution to our environment. However, sometimes these unwanted noises could potentially obstruct with the activities of our daily lives or even cause physical damages or mental stresses to the one around the area. Thus, sound insulation is very much needed to eliminate these unwanted noise in order to improve the living quality and to be free from the effect of these unwanted noises.

The most important component in sound insulation would be the sound absorbers to be placed on the walls that could absorb those unwanted noise before reaching the people in the area. By implementing 3D printing technology in the design of sound absorbent, it could provide more choices for the design of sound absorption material.

Since 3D printing provides more flexibility of producing a model in a more cost and time efficient manner. This may provide the basics to those in need to customize their own sound absorption material according to their needs on their own by using the 3D printing technology.

The sound absorbers on the market nowadays are usually made to target a certain frequency range depending on the users' applications. They might still have some sound absorption ability outside its targeting sound frequency range, however it would be working at its peak working performance at its targeting range. The users of sound absorber could free select their own type of sound absorber accordingly to their needs. As such, other than improving the sound absorption coefficient of the designs of sound absorber, it is equally important to know the targeting frequency range of each type of absorber so that the users could effective select the right type of sound absorber to be use.

1.3 Problem Statement

The sound absorption rates highly depend on the design of the sound absorbent. Higher frequency sounds have shorter wavelength while lower frequency sound have longer wavelength. The range of the wavelength would greatly affect the travelling properties of the sound vibration.

To accommodate with the travelling behaviour of sound vibration of different frequency, changes are made on the sound absorbent in accordance to the material used, the shapes, perforation ratio, thickness, air gaps size and layers of the sound absorbent (Bucciarelli, 2019), (Jafar, 2020), (King and Teo, 2020). Different designs of the sound absorbent have different effects on the sound absorption coefficient of sound.

Moreover, there is a lack of study that focuses on the hybrid design, such as the combinations of MPP and porous design stacking up in the form of multilayer. The key problem of the study is to study the effects of a hybrid sound absorber combining the designs of MPP and porous structures with the help of the 3D printing technology. It is of interest to compare the sound absorption coefficient between the different designs of sound absorbent printed by 3D printers.

1.4 Aim and Objectives

The aim of this study is to design sound absorber for different ranges of sound frequency by using the 3D printing technology. The objective of the study is to:

1. To develop types of new design for the sound absorption panel using 3D printing technology.
2. To measure the effect to the sound absorption coefficient of different combinations between micro-perforated panels (MPP) and porous by stacking them together in multilayer form.

1.5 Scope and Limitation of the Study

In this work, different designs of MPP and porous panels are aligned together in a multilayer form. By adjusting the combinations and air gap sizes in between each layer, the sound absorption properties of each set of samples were recorded and analysed. The dimensions of each type of sound absorbing material were set at the same standard throughout the experiment. Only the pattern of design, combinations and inter-layer distance in between two layer were manipulated, the perforation ratio and thickness of the samples were not taken into consideration in this study.

The samples that were used in the testing were all fabricated by Fused Deposition Modelling (FDM) of 3D printing technology. The design considerations were made in accordance to the limitations of the 3D printing prototyping method.

1.6 Contribution of the Study

As the sound absorbility of an absorption panel greatly depends on the design specification of the panel, in terms of the porosity, air gap space, number of layer, design structure and material used. In this study, the effect of multilayer sound absorption panel that consist of different types of absorption panels including a Micro-perforation panel (MPP), Hexagonal porous panel and Cartesian porous panel, aligning in the form of 2 layers were studied. The combinations, sequences and inter-layer distance are varied to test out the effect of variance towards the sound absorption of the combination of the sound absorption panels. This would provide a convenience to those in need for constantly varying sound absorption environment. They could tune the sound absorption of the system according to their need without the need of replacing new sound absorber all over again every time changes is needed. One could simply tune the frequency range of the sound absorption accordingly by changing the combinations, sequences of the combinations and inter-layer distance of the multilayer sound absorption panels.

1.7 Outline of the Report

I. Introduction

Sound pollution is an unwanted noise that cause stress/disturbance towards daily lives. On the other hand, 3D printing technique is a new type of additive manufacturing method that are normally used for rapid prototyping, saving cost and time consumption. The factors affecting sound absorption ability of an sound absorption panel are design structure, porosity, air-gap/inter-layer distance, combinations, sequence, and etc.

II. Effect of inter-layer distance

Increasing of inter-layer distance would shift absorption peak frequency region towards the left. Moreover, sound absorption amplitude would reach its optimum when the inter-layer distance is at quarter wavelength.

III. Effect of Combinations

Combination with highest sound absorption coefficient is the combination which containing Hexagonal porous panel. The possible factor that might cause this phenomenal is probably due to its higher complexity structure, hence higher resistivity to airflow.

IV. Effect of Sequences

The poorest combination sequence is when the MPP is at second layer. The possible factor might be due to its non-existence of air-gap space.

V. Fluctuation peaks

The possible factor might be due to its imperfection of the printed prototype (shrinkage, oozing anf rough surface).

VI. Conclusion

Sound absorbility of the absorption panels can be adjusted by altering the inter-layer distance, combination and sequences according to needs.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Commonly, there are a few types of sound absorbent design, that is, the usual porous or fibrous material, perforated panel and micro-perforated panel (MPP). Porous or fibrous material can be found in the normal sound absorbent such as foams and cottons to be used as a sound absorbing perforated panel. These materials contain small spaces in between the structures that aid in absorbing vibration that transfer though the material. As sound is also a type of vibration, a portion of sound vibrations that goes through the material would be absorbed by the porous/fibrous material, making it a good sound absorbent. It is the most usual sound absorbent used since a long time ago.

Perforated panels are usually made out of metal sheets, stamped with a pattern of holes. The perforation ratio, design pattern, hole size, shape and thickness of the metal sheets are adjusted accordingly in order to achieve the desired sound absorption results. It is often used by architects as an exterior cladding to resist the noise from outdoor. Although the sound absorption coefficient of perforated panels are much poorer than the common porous or fibrous material, it can also be used as a barrier of protection from wind, humidity, heat or even as an emergency flame barrier while allowing for air ventilation and light to shine through it.

On the other hand, MPP is a type of special sound absorbent that is used to reduce unwanted noise in severe situations without the needs of the usual porous or fibrous materials (Iwan and Harjana, 2013). It has been recognized as the new generation to replace the perforated sound absorbing materials (Bucciarelli, Malfense and Meo, 2019).

It is first introduced by Maa (1974) in his theory and design guideline of the construction of MPP. He pointed out the problem of the ordinary perforated panels with its added acoustic resistance. In order to obtain a high sound absorbing coefficient, the characteristic acoustic resistance in the free air has to be matched to the resistance of the perforated panels. Moreover, to achieve the absorption of a wide frequency band, the acoustic mass has to be low. These 2 requirements could not be fulfilled by only applying the ordinary perforated panels due its relatively large holes. This has become a limitation of perforated panels as porous materials have to be added to achieve the requirements. However, adding of the porous materials is deemed to be inefficient as the porous material alone can be used to absorb a wide frequency band without the help of the perforated panel.

As such, Maa has introduced the use of MPP, that perforation of the panels to sub-millimeters level, providing a sufficient acoustic resistance to obtain a wide frequency sound absorption without needing the help of porous materials. It improves the ability of perforated panels to absorb a wider frequency sound band while maintaining the properties of a perforated panel.

2.2 Literature Review

Bai, et al. (2019) have done research on the sound absorption performance on compressed and micro-perforated acoustic absorbent. They did test on a few specimens including the normal porous metal, compress porous metal, micro-perforated spring steel panel and compress micro-perforated porous metal, aiming to find out the best acoustic absorber to reduce the noise. The result came out indicating that the compressed micro-perforated porous metal showed a better result in sound absorption than the one that is not compressed or micro-perforated. From the study, it can be known that the specimens that have been compressed show great results in improving the sound absorption coefficient than the ones that are being micro-perforated. The micro-perforated specimens do not affect much compared to the porous metal while only showing improvement when at the spring steel panel. They have also done testing on specimens with different cavities and found out that the absorption frequency does not necessarily increase with the increase or decrease of cavities. The absorption frequency of the specimens would only reach its peak at a certain cavity. Generally, when the cavity increases, the peak of each specimen would shift to the lower end of frequency range until the second peak formed.

On the other hand, Sakagami, et al. (2008) did a research on thick MPP absorber to study if the thickness of the panel would affect the absorption coefficient of the panel. After testing out various MPPs with different micro-perforated diameter as well as tapered holes, they found out that it is not feasible to apply MPP on thick panels as thick panels have higher resistance making it become inefficient.

Sakagami, Morimoto and Yairi (2009) later started another test on MPP and panel/membrane absorber and stated that both of the MPP and panel/membrane-type of absorption can be understood as the same kind of absorption phenomenal and can be transformed into each other depending on the perforation ratio. They have compared the results obtained when only the mass reactance of MPP is considered, when the sound absorption of the wall surface placed at the back is considered and when the losses of panel is considered. When only the mass reactance of MPP is considered, the peak of MPP absorption would be affected by the panel's absorption, when in the other 2 cases, the absorption of the panel/membrane would only occur when the perforation ratio is zero.

Iwan and Harjana (2013) had made a study on a new improvement strategy on sound absorber for quadratic residue diffuser (QRD). They redesigned the MPP into an Array of Constrained Short Tube (ACST), which is coupled by a perforated panel (PP) on each of its perforated holes to form an array of extended orifices. The combinations of the coupled PP forms multiple extended necks Helmholtz resonator with mutual cavity. It gives the structure an advantage of flexibility to tune the frequency and impedance response of the sound absorber by controlling the dimensions of the tube. The result came out great with the improvement of sound absorbing ability as the number of PP attached to the MPP increases until it reaches its optimum state (fully attached). The study stated that this occurrence happened due to the changes in necks reactance of the Helmholtz resonator from the extension of the orifices length. The increase in cumulative reactance shifted the peak of the sound absorption coefficient to the lower frequency region. The study also shows that by increasing the length of the extended orifices, it would further increase the efficiency of sound absorption coefficient of the specimen, especially towards the higher frequency band.

On the other case, Ning, Ren and Zhao (2016) constructed a model testing MPP with different cross section areas such as circular, triangle, square and slit shaped perforation to test out the effect of irregular perforations on the sound absorption of the MPP panels. After testing, they found out that the triangular shaped MPP has the highest sound absorption coefficient along the frequency range of 0 – 2500 Hz among all of the specimens. Thus, they have conclude that by altering the cross sectional areas of the perforations would bring forward the effect of expansion of sound absorption bandwidth, as well as sound absorption coefficient at the higher frequency range.

2.3 Combinations of micro-perforations panels

Sakagami, et al. (2009) have done another test with the combinations of 2 different MPP absorbers. They aligned 2 MPP with different perforations ratio in alternative manner and obtain the average results of 2 respective MPP with wider frequency broadband but lower sound absorption coefficient. They then move on to another test, combining 2 different depth of air cavity aligned in alternative manner. The reading shows a similar results as the previous test, exhibiting the average trend of the 2 types of MPP with lower sound absorption peak but wider frequency broadband.

Multilayer MPP absorber that is made out of 6 layers of micro-perforated panel has been put into test by Bucciarelli and Malfense Fierro and Meo (2019) for low frequency, aiming to increase the sound absorption efficiency of the absorber. They have put together a few layers of MPP absorber form the normal 1 layer to maximum 6 layers. The result shows that as the layer of the MPP absorber increases, there would be an increase in the number of peaks of sound absorption coefficient, optimizing the sound absorption rate throughout the wide broadband of 400Hz to 2000Hz, with absorption level over 90%. They then proceed to test the sound absorption rate between the MPP and micro-slotted panel (MSP) while maintaining the same perforation ratio. The result shows that MPP and MSP have similar sound absorption coefficient with MSP having a slightly lower sound absorption rate while compared to MPP. This indicates that the shape and number of the micro-perforated holes can be adjusted while having the almost similar result, provided the perforation rate is kept constant.

Another study to enhance the sound absorption property of MPP by using mechanical plates is done by Zhao and Fan (2015). The MPP is backed with a layer of mechanical impedance plate (MIP) and the results shows another peak of sound absorption at the lower frequency region while having similar results to the one that only consist of MPP at the other region. They then added one additional MIP and MPP to the structure for further testing. The measured double-leaf MPP and double-leaf MIP shows 2 more additional sound absorption peaks at the lower frequency band. This phenomenon occurs due to the mechanical resonance of the MIP when the acoustics frequency is aligned with the natural frequency of the plate.

2.4 3D printed structure as sound absorption panels

King and Teo (2020) have attempted in applying the Fused Deposition Modelling (FDM) method to 3D print the sound absorption panels. The study had made 2 different types of structure, porous panel and micro-perforated panel with various perforation ratio, air gaps and thickness of the specimens. During their study, they found out that for MPP, the peak of the sound absorption coefficient would shift to a lower frequency range as the perforation ratio decreases. The shifting of the sound absorption coefficient peak could also be noticed when the thickness of the specimens increases. They then increase the hole size and notice a similar trend for the sound absorption rate as the previous one.

As for the porous design, the shifting of the sound absorption coefficient peak to the lower frequency range occurred when the thickness of the specimens increased. Furthermore, it shows a higher sound absorption rate with the smaller perforation ratio.

Generally, porous structures have lower absorption peaks while compared to MPP specimens. The porous structure would also tend to have a better absorption rate at a higher frequency range while compared to the MPP specimens. The study concluded that the MPP structure is better suited to be used at lower frequency at around 4000 Hz and below while porous structures are better suited for higher frequency at above 2500 Hz.

Matlack, et al. (2016) proposed a different approach to study the vibration absorption of the structure for low frequency and broadband using a composite 3D-printed metal structure. The meta-structure of their design consists of a polycarbonate lattice, with steel cubes embedded into the structure as local resonators. It is a printed primitive cubic cell of polycarbonate with metallic inclusions embedded into the matrix.

2.4.1 3D printed Micro-perforated structure

Jafar, et al. (2020) has conducted testing on MPP with 2 different types of material. Two type of absorbent consist of one 3D printed nylon absorber and another laser cut brass absorber with the same MPP design were put into test both theoretically and experimentally. Based on the Maa's MPP theory, both specimens should obtain the same results. However, it is not hard to notice the difference in the theoretical and experiment results for both materials, resulting in two different results.

Comparing two results, the measured results have a lower peak of sound absorption coefficient than the theoretically one. In order to further analyse the reasons behind the difference in results, they scanned the hole for both specimens and found out that the holes at both specimens that were created by 3D printing and laser cutting are not in the perfect circular shape as per used in the theoretical explanation used in Maa's studies. The irregular shape of the 3D printed structure is much worse than the laser cut brass specimens causing it to deviate more from the theoretical obtained result. The shapes of the holes at the 3D printed structures would also vary with circularity results between 0.6 to 0.9, much higher than the laser cut process from 0.9 to 1.0. This indicates that the 3D printed MPP structures have a high rate of design errors that would contribute to inefficiency of sound absorbing.

2.4.2 3D printed Porous panel

On the other hand, the sound absorption of open porous ABS material structures made by 3D printing technology were studied by Vasina, et al. (2020). In their study, different structures and thickness of specimens were 3D printed using the Fused Deposition modelling (FDM) technique. The structure included the Cartesian structure, Starlit structure and Octagonal structure, each tested on different thickness and air gap.

The results show that at a low excited frequency, the structural effect of the specimens are almost negligible, as each of the specimens have obtained nearly similar results. As the excited frequency increased, the results started to deviate with Starlit structure having the best sound absorption rate. This is due to the more complex structure of the Starlit structure, contributing to a higher airflow resistivity that is an important factor in the sound absorption.

They have also found out that as the thickness of the specimens increases, the absorption rate would increase while shifting to the lower frequency range. However, the increase of specimen’s thickness would lead to a higher production cost, which is another undesirable production factor.

The study showed another important factor that would greatly influence the sound absorption coefficient of the structure, that is, the air gap size between the specimens and the solid wall. The increase in the air gap size would shift the peak towards the lower frequency range with the increase of the number of sound absorption coefficient peaks. Each of the specimens would have its maximum and minimum peak over the whole frequency range. The study stated that this phenomena occurs due to the sound reflections from the solid wall.

The effect of excitation frequency would also contribute to each type of the specimen structure. After studying the results obtained from the study, it is observed that different specimens would achieve their optimum sound absorption rate at a different sound excited frequency. It is hard to consider which of the specimens' structure would work the best in sound absorbing material.

2.4.3 MPP with varying perforations cross-sections

Sailesh, et al. (2021) utilised the ability of 3D printer to design a micro-perforated panel with varying cross-section along the y-dimensions. They tested different specimens for their respective sound absorption which includes the usual MPP, convergent type perforated panel (C), divergent type perforated panel (D) and panels with the combinations of the convergent and divergent cross-sections (DC/CD).

After comparing the results obtain from the experiment between the specimens, they found out that the varying perforations cross-sections panels exhibit results close to that of the 1mm diameter MPP which have a much sound absorption coefficient when compared to the 8mm diameter perforated panel with the coefficient rate descending order of DC > D > C > CD. However, the peak frequency of the sound absorption rate of the varying perforations cross-sections panels would shift slightly to the left. Among all of the specimens, the

Divergent-convergent (DC) perforations panel shows the highest sound absorption coefficient that even exceed of that of the normal MPP at 0.9903.

This results show that there are possible improvement of the sound absorption rate by utilising the advantages provided by the 3D printer to produce a more complicated design of the sound absorption panel.

2.4.4 MPP backed with porous material

Liu, et al. (2017) had an experiment on combining MPP and porous material in order to optimize the sound absorbing property of the structure. They had printed out the MPP with the use of a 3D printer with Stereolithography (SLA) technology. The printed MPP was then backed with a piece of non-woven porous sound absorbing material.

The results showed that the introduction of MPP to the porous material had greatly increased the sound absorption coefficient of the specimen from when only porous material was being tested. They had tried to manipulate the perforation ratio of the MPP in order to get different results. As the perforation ratio of MPP increases, the peak of the sound absorption coefficient would shift to the higher frequency band. This proved that the frequency of the absorption bandwidth can be adjusted by adjusting the perforation ratio of the MPP.

2.4.5 Multilayer MPP with varying airspace

Yang, et al. (2020) printed numerous MPP with same dimensions using 3D printer. They then stacked up the printed MPPs in parallel sequence to verify the effect of multilayer MPP on tunning the wideband of the sound absorption of the absorber. After testing on numerous model consisting of a single-layer, double-layer and triple-layer of MPPs, it is noticeable that as the number of MPP layer increase, there is increase in the number of peaks of the absorption coefficient.

On the other hand, while altering the air gap distance behind of MPP models, the sound absorption of each model would exhibit slight difference from another in terms of the frequency broadband or the absorption coefficient of the model. As the air gap distance increases, the peak absorption coefficient would shift slightly to the left, while the lower frequency absorption peak remain almost unmoved. This phenomena is similar to the single-layer one that has been explained by Maa (1974) describing the panels as mass and the airspace behind the panels as an acoustic spring. While increasing the air gaps between the layers, the stiffness of the spring decreases, causing the resonance of both the mass and the spring shifting left towards a lower frequency range.

Next, they continue their testing by changing the interlayer air-spaces of the multilayer MPP models. The result of the experiment indicates a similar reading with the alteration of the air gap distance, showing a shifting of the absorption peaks towards the left while the peak at the lower frequency range remains almost the same. This shows that weather by changing the air gap distance would have the same effect with altering interlayer airspace. And thus, they have concluded that it would be more feasible to adjust the interlayer airspace than to adjust the air gaps between the MPP and the wall in order to tune the absorption frequency broadband as required.

2.5 Summary

Micro-perforated panels were first introduced by Maa (1974) in his own research paper in effort to improve the sound absorbing property of a perforated panel. This has set stone to the foundation of the use of MPP until now. Based on the design, Bucciarelli and Malfense Fierro and Meo (2019) had found out that the sound absorption coefficient will be increased by increasing the layers of MPP for low frequency band. While Liu, et al. (2017) combined MPP and porous material, greatly increased the sound absorption coefficient of the specimen. As they increase the perforation ratio of MPP, the peak of the sound absorption coefficient would shift to the higher frequency band.

Nowadays, 3D printing technologies have started to become a new norm for rapid prototyping. There were also a lot of attempt of using the 3D printing technologies in the sound absorption material. For example, King and Teo (2020) had attempted in applying the Fused Deposition Modelling (FDM) method to 3D print porous panel and MPP with various perforation ratio, air gaps and thickness of the specimens. The study concluded that the MPP structure is better suit to be used at lower frequency at around 4000 Hz and below while porous structures are better suited for higher frequency at above 2500 Hz. On the other hand, Vasina, et al. (2020) had compared the sound absorption coefficient of 3 porous design (Cartesian structure, Starlit structure and Octagonal structure) and found out that the Starlit structure would have a higher absorption rate towards the higher frequency range due to its complex structure.

However, there were some downsides for using a 3D printer in fabricating the MPP sound absorber. Jafar, et al. (2020) compared a 3D printed nylon absorber and another laser cut brass absorber with the same MPP design. They found out that the shrinkage problem caused by 3D printing would increase the circular error of the holes, decreasing the sound absorbing property.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

In this set of work, Fused Deposition Modelling (FDM) of 3D printing technology was used to fabricate the specimens for testing. Polylactic acid (PLA) was selected as the material filament to print out the samples. PLA is a popular 3D printer filament type to be chosen. It is easy to print with relatively lower printing temperature at 180 ℃ - 230 ℃. Thus, it would have a smaller shrinkage problem compared to Acrylonitrile butadiene styrene (ABS) that needed to heat up to a high temperature in order to 3D print it. As mentioned in the study by Jafar, et al. (2020), the shrinkage problem with 3D printed samples would be critical in the sound absorption rate of the MPP samples. It is important to decrease the shrinkage of the sample to a minimum in order to optimize the sound absorption coefficient of the MPP samples. The size of the MPP holes would also be drawn to a bigger hole than the intended dimension to complement the shrinkage problem caused by FDM.

After printing out samples that consist of multiple different designs of porous and MPP, the samples were aligned to a certain set sequence and inter-layer distance. The sequence and inter-layer distance between the samples were manipulated into multiple different combinations in order to obtain different results. The study is to observe and compare the sound absorption coefficient of multilayer sound absorber consisting of different structures of porous and MPP specimens and how would the sequence of the combinations and the inter-layer distance would affect it.

The set parameter of the test samples were tested using the sound impedance tube. The samples will be fixed at a 60mm diameter tube, with frequency range around 125Hz to 2500Hz. Only sound absorption ability of the combination panels would be tested, sound transmission inside the tube would not be tested as it is not a part of the study.

3.2 Sample designs

From the previous research done, it can be known that MPP has a better sound absorption coefficient at lower frequency range while porous structure would have a better absorption rate at higher frequency. This study would like to test the effect of combining both MPP structure and porous structure specimens to the sound absorption coefficient of the sample. The testing parameter includes the types of combinations of the panel, combination sequences and the inter-layer air-gap distance.

3 sample sets are designed as listed in table 1 with designs as shown in figure 1. The test sample consists of 3 different designs including the MPP, Cartesian porous panel and Hexagonal porous panel. These 3 samples will be printed out using FDM to be put into test.

Table 1 : Parameters of 3 samples

Parameters	Micro-perforated panel sample, M1	Cartesian porous sample, C1	Hexagonal porous sample, H1
Sample diameter, D (mm)	60	60	60
Thickness, t (mm)	1	10	10
Hole size, d (mm)	0.6	3	3
Hole spacing, b/s (mm)	3	2	2
Perforation ratio, p %	3.64	36	36

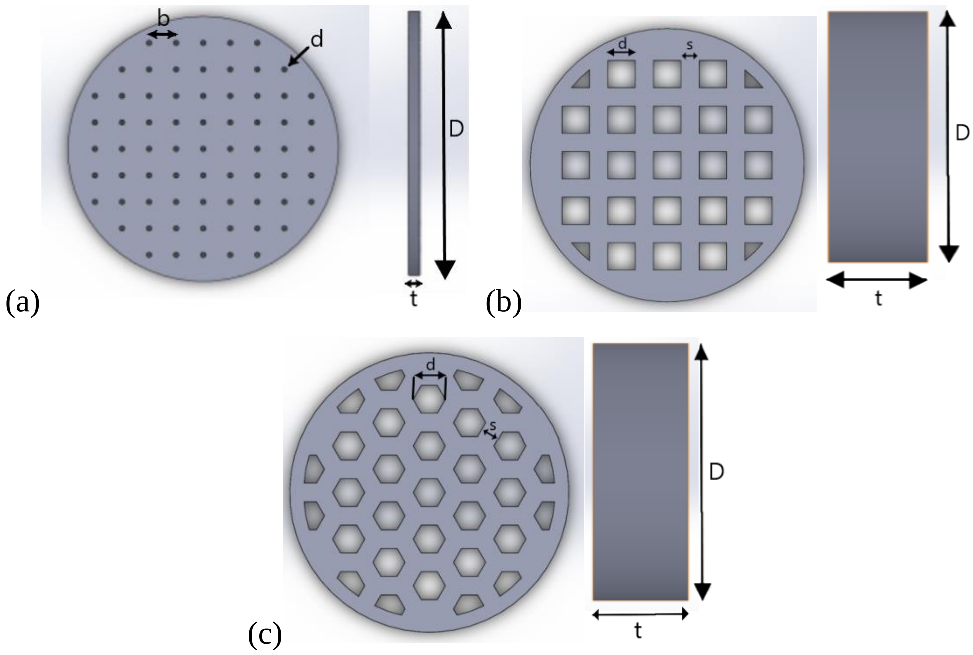


Figure 3.2.1: (a) Micro-perforated panel sample, (b) Cartesian porous sample and (c) Hexagonal porous sample.

Different designs of Cartesian porous and Hexagonal porous samples with the same perforation ratio were used in the study in order to find out the effect of the structure of the model to the sound absorbing quality. As mentioned by Bucciarelli and Malfense Fierro and Meo (2019), the sound absorbing rate is about the same for both MPP and MSP specimens, when maintaining the same perforation ratio. However, in the study by Martin, et al (2020) indicated that the structure of the specimens does affect the sound absorbing quality at the higher frequency range.

The two types of porous structure sample were combined with the MPP samples to see if there are any different effects on each of its sound absorption rate while arranged in the multilayer form.

3.2.1 Printing of specimens

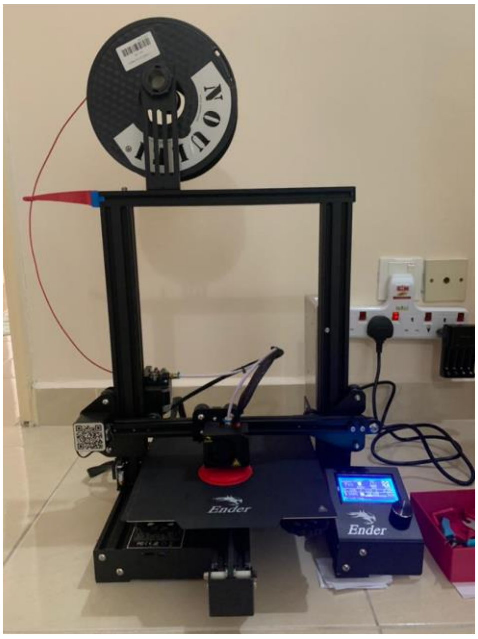


Figure 3.2.2 : 3D printer setup

The model of the FDM 3D printer used in this experiment is Enderpro with the setup as shown in figure 3.2.2. The printing process was done by extruding the PLA filament after melting through the extrusion tip while moving from point to point, layer by layer, as instructed by the inputted G code. The specimens were printed with 0.4 mm extrusion tip and melting temperature of 200℃ with heating bed temperature of 50℃ (figure 3.2.4).

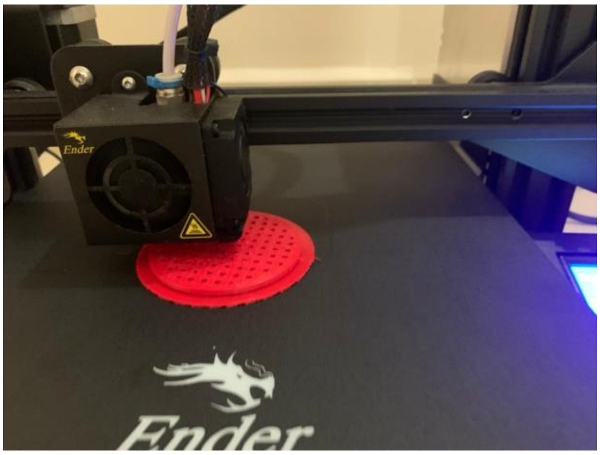


Figure 3.2.3 : Printing process of specimens

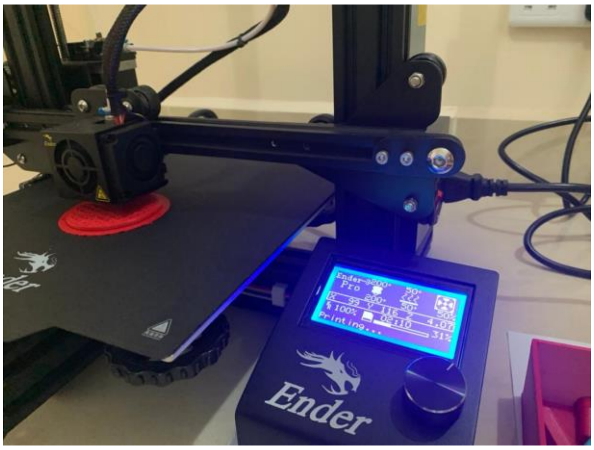


Figure 3.2.4 : 3D printing settings

There are a total of 3 printed specimens (shown in figure 3.2.5) featuring MPP (blue), Cartesian porous panel (red) and hexagonal porous panel (green). The dimension of the CAD drawings were slightly adjusted in order to compensate for the shrinkage problem caused by the heating and cooling during the printing process.

Figure 3.2.5 : Printed specimens

3.3 Testing combination

The samples are tested with different combinations of MPP, Cartesian porous and Hexagonal porous samples arranged in multilayer form. The parameters of the combinations are as listed in table 2 with combinations between MPP and Cartesian porous sample, MPP with Hexagonal porous sample, and the combination of Cartesian and Hexagonal porous sample. The inter-layer distance in between 2 layers was manipulated with the distance of 0 mm, 20 mm and 40mm as indicated in figure 3.3.1. This is to further observe the effect of inter-layer distance to the sound absorption coefficient of the specimens.

Table 2.1: Parameters of the testing combination (2 layer)

Combinations of Micro-perforated panel and Cartesian porous samples						
Parameters	MC(0)	CM(0)	MC(20)	CM(20)	MC(40)	MC(40)
Inter-layer distance, a (mm)	0	0	20	20	40	40
First layer, x	M1	C1	M1	C1	M1	C1
Second layer, y	C1	M1	C1	M1	C1	M1
Combinations of Micro-perforated panel and Hexagonal porous samples						
Parameters	MH(0)	HM(0)	MH(20)	HM(20)	MH(40)	HM(40)
Inter-layer distance, a (mm)	0	0	20	20	40	40
First layer, x	M1	H1	M1	H1	M1	H1
Second layer, y	H1	M1	H1	M1	H1	M1
Combinations of Cartesian and Hexagonal porous samples						
Parameters	CH(0)	HC(0)	CH(20)	HC(20)	CH(40)	HC(40)
Inter-layer distance, a (mm)	0	0	20	20	40	40
First layer, x	C1	H1	C1	H1	C1	H1
Second layer, y	H1	C1	H1	C1	H1	C1

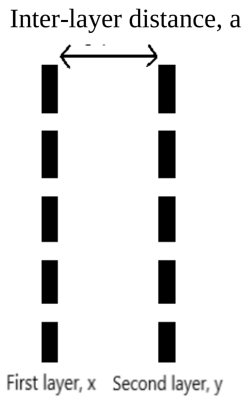


Figure 3.3.1 : Layer combination of testing sample

The air-gap distance behind the combination panels were fix to zero, which means that the second layer of the panel are aligned sticking to the wall. Only the inter-layer distance between the panels were manipulated in this research.

3.4 Testing equipment

Sound Impedance tube model SW260 (figure 3.4.1) is used for the testing of the sound absorption coefficient of the samples. In this experiment, only 2 microphone (as shown in figure 3.4.2) were used to collect the reflected sound from the specimens as only sound absorption is tested in this research.

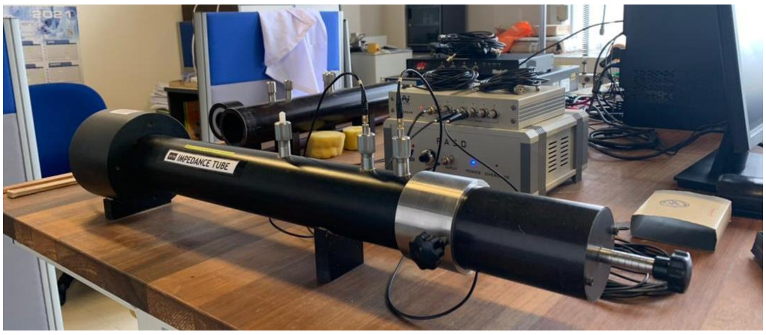


Figure 3.4.1 : Sound Impedance Tube

Figure 3.4.2 : Microphone

The build-in speaker of the sound impedance tube is connected to a sound amplifier (model BSWA PA50), producing sound with different sound frequency range from 125 ~ 2500 Hz. After the sound is transmitted inside the sound impedance tube, the sound in the diameter tube is then recorded by the microphone and sent to channel 1 and channel 2 of the analyser (model

MC3243). The equipment of the amplifier and sound analyser are shown in figure 3.4.3.

Figure 3.4.3 : Amplifier and sound analyser

3.5 Experiment details

Figure 3.5.1 : Panel holder

Figure 3.5.2 : Microphone position

During the testing phase, the samples were held in place with the sample holder as shown in figure 3.5.1. The combinations of the 3 specimens were tested according exactly to the alignment specification listed in table 2.1. The 2 microphones situated in front of the specimens in the tube would acquire pressure produced by the sound source around the sample. The results would then be sent to VA-Lab IMP following the standard of ISO 10534-1 and ISO 10534-2, to separate the incident wave from its reflecting wave to calculate the sound absorption coefficient of the samples. The analysed results from each sample were combined, and tabulated in the frequency-absorption coefficient graphs using excel sheets for further evaluation.

3.6 Summary

In this work, three different samples including a Micro-perforated panel design, a Cartesian porous design and a Hexagonal porous design were printed out using fused deposition modelling of 3D printing technology. The dimensions of the designs such as perforation ratio, thickness and diameter of each panel was fixed to a standard. Only the effect of the panel combinations, combination sequences and inter-layer distance were tested on the sound absorption ability of the combination panels.

The samples were arranged to the set sequence in the form of two layers alternatively with the varying inter-layer distance in between two layers from 0 mm to 40 mm. The samples were fixed into the sound impedance tube (model SW 260) with two microphone input to test for its sound absorption coefficient. The data obtained from the microphone were sent to VA-Lab IMP, separating the reflecting sound wave from the incident sound wave. The test results obtained were tabulated and compared with the result between each combinations.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

It is known that the dimensions and design of a panel would greatly affect the sound absorption of the panel. It is the same goes with the air-gap/inter-layer distance and the alignment of the sound absorption panel.

In this research, various testing has been done on different combinations of panels while alternating the sequence and inter-layer distance between the two panels. Each type of the combination panels were stack up with different types of panels in alternating sequence and varying inter-layer distance. The testing results has shown large difference in sound absorption coefficient based on the set inter-layer distance, panels' combination and sequence.

4.2 Results

Figure 4.2.1 shows the testing results of all 3 types of combinations of the specimens. Throughout the frequency range between 125 ~ 2500 Hz, we can see that the combination of Micro-perforated panel and Cartesian panel as shown in figure 4.2.1 (a) would only exhibits one peak of absorption ranging from 1500 ~2200 Hz. Looking back at the research done various researches for multilayer panels in literature review, there are usually 2 peak of sound absorption coefficient for 2 layer sound absorber testing. However, the combination of MPP with Cartesian panel might have provide variable in the sound absorption of the panels, or the frequency range tested is not enough to completely exhibit the sound absorption range of the combination panels.

On the other hand, the combination of Micro-perforated panel and Hexagonal porous panel in figure 4.2.1 (b) start to exhibit 2 peak of sound absorption coefficient when inter-layer distance is increased to 40 mm. the combination of Cartesian porous panel and Hexagonal porous panel shown in figure 4.2.1 (c) generally exhibit 2 peaks of sound absorption coefficient except for when inter-layer distance = 0 mm.

Moreover, all three graph have shown similar shifting trend of the absorption peak accordingly to the inter-layer distance. While varying the inter-layer distance between the panels, the results shows a shift of the peak towards a lower frequency range when the inter-layer distance is increased. When the panels are aligned tightly together (inter-layer distance = 0 mm), the combination panels has shown a poor sound absorption coefficient within 0.2 for the tested frequency range. The sound absorption rate of the combination panels would then greatly increase when the inter-layer distance increases. As such, by observing the trend of all three different combinations of the panels, it can conclude that the inter-layer distance = 40 mm between the panels is the optimum distance to increase the peak of absorption coefficient, provided with current testing criteria.

The sequence of the combination panels would have an impact on the sound absorption rate of the panels as well. There is not much different when inter-layer distance = 0 mm as the sound absorption coefficient is too low to notice any variable. However, the difference would be starting to show as the inter-layer distance in increase. For both figure 4.2.1 (a) and (b), the combinations would have a better sound absorption rate when the MPP is place at the first layer, compared to the other way round. In addition, for MC/CM combinations, the peak of the sound absorption would slightly shift to the right when MPP is placed first. However, the peak of sound absorption coefficient of the MH/HM combinations would shift to the lower frequency range instead when MPP is placed first unlike how it is at MC/CM combinations.

On the other side of the coin, by looking at the effects of the combination sequences for CH/HC towards the absorption peak, placing Hexagonal porous panel first would contribute to the shifting of the peak of absorption slightly towards the right. During inter-layer distance = 20 mm, HC(20) has shown a better absorption rates than CH(20) while in inter-layer distance = 40 mm shows almost no difference between 2 peaks at the lower frequency range.

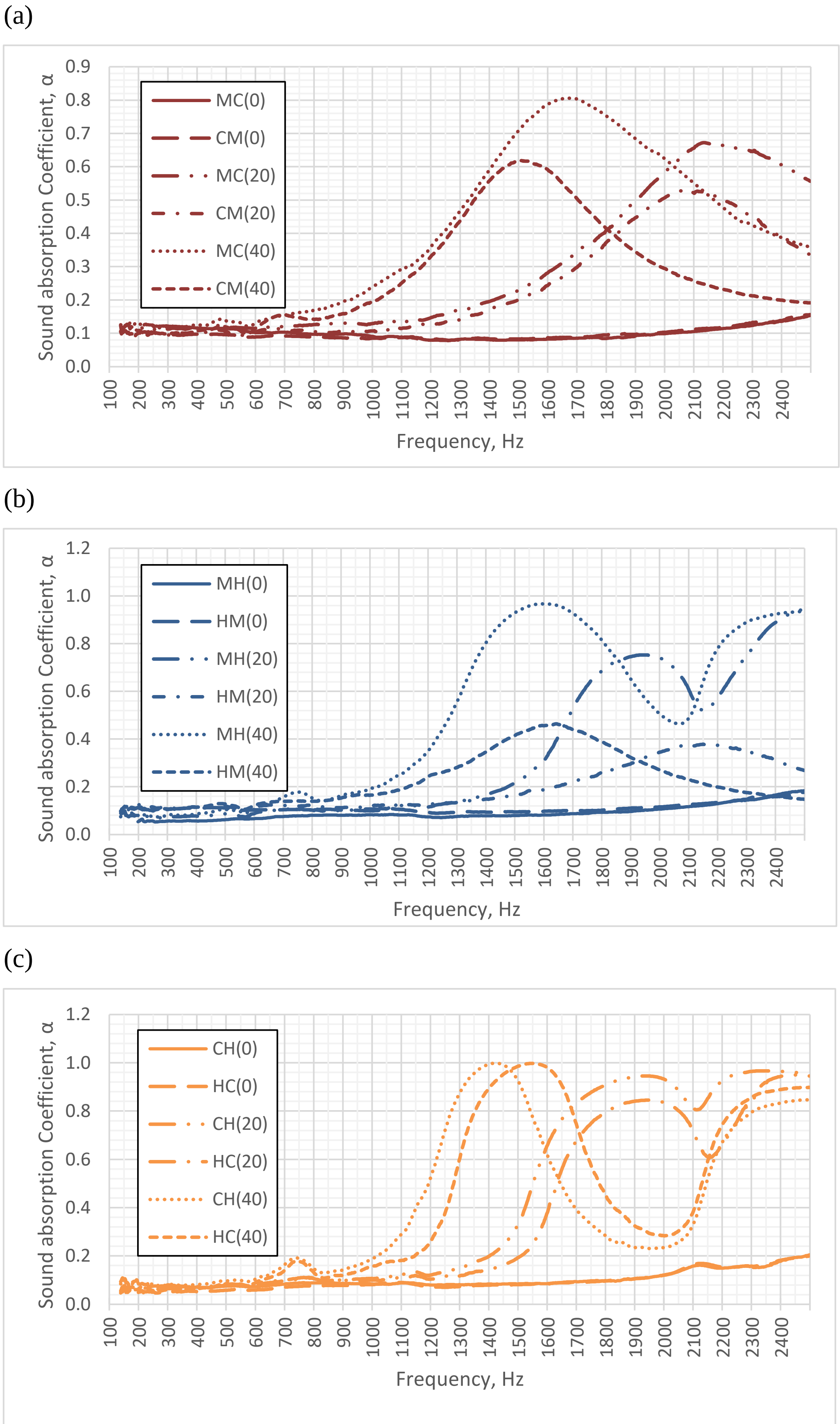


Figure 4.2.1 : Sound absorption coefficient graph of the (a) MC/CM combinations, (b) MH/HM combinations and (c) CH/HC combinations

4.3 Discussions

The ability to sound absorption of a sound absorption panel depends on varies factors. Among the affecting criteria, the most commons factors would be the dimensions of the design, as well as with the perforation ratios of the panels, be it the MPP or porous panels. However, in this research, more important have to be put on the other factors. That is why, the dimension and perforation ratio of the panels are fixed to one dimensions.

This research has put more important at the effect of the combinations of different type of panels and the inter-layer distance between the panels to the sound absorption coefficient of the combination panels.

4.3.1 Effect of inter-layer distance

There have been a lot of research on the effect of air-gaps behind the sound absorption panel towards its sound absorption coefficient. Yang, et al. (2020) have also done similar testing while varying the inter-layer and air-gaps spaces of its multilayer MPPs. They have then concluded that by varying the air-gaps space or inter-layer distance would obtain similar results. As the distance increases, the peak absorption would shift towards the lower frequency range while increasing until a certain optimum distance is achieve.

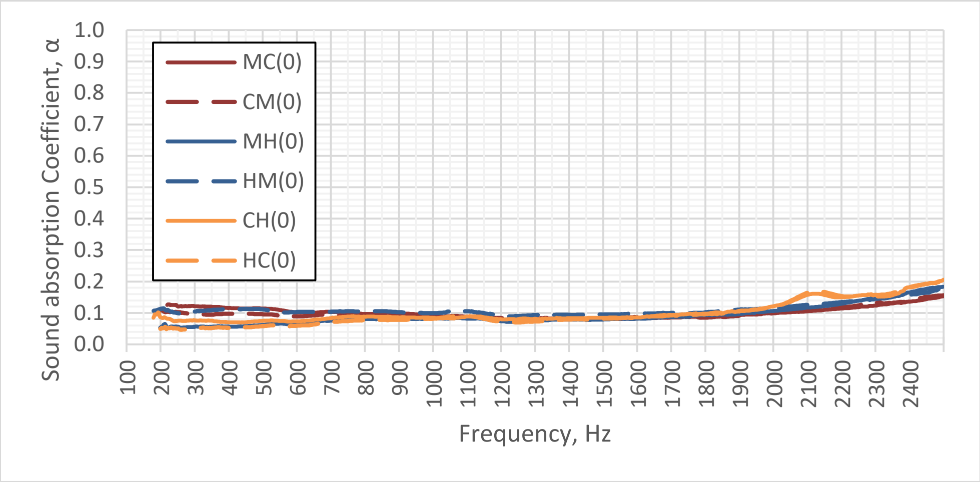
Hence, for this project, it is decided to fix the air-gap size to zero while varying the inter-layer distance between panels as it would be easier than the other way round.

When inter-layer distance = 0 mm, within the testing frequency range of 125 ~ 2500 Hz shown in figure 4.3.1 (a), the sound absorption rate of all of the combinations are very poor (below 0.2). Hence, it is hard to notice the differences between each combinations. The graph indicated that there are an increase in the peak absorption towards the end. From this, it can only be assume that the absorption frequency range of the panels when inter-layer distance = 0 mm is too high to be shown in this experiment as this testing only test on the specimens at the frequency range from 125 to 2500 Hz.

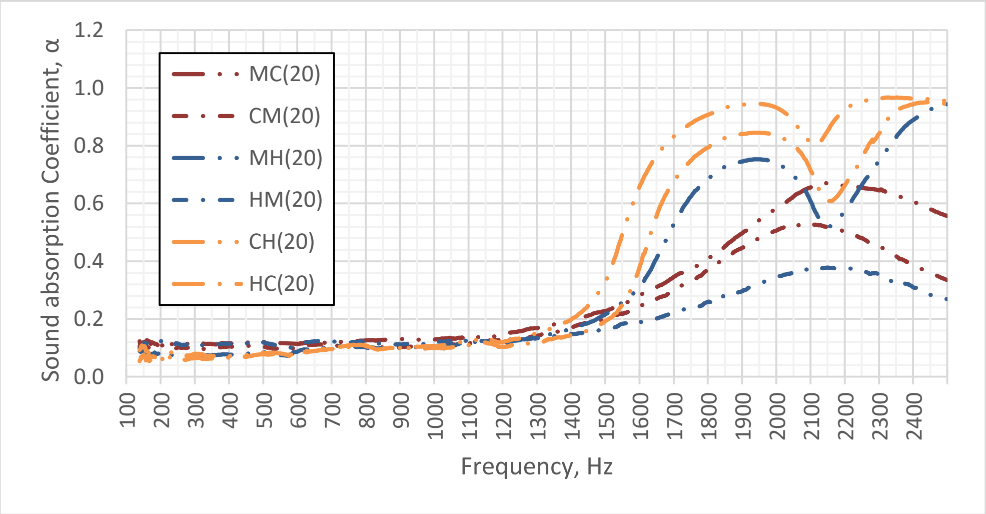
While the inter-layer increase in figure 4.3.1 (b) and (c), it can observe the shifting of the absorption peaks towards the lower frequency range while increase in amplitude. Glancing from the results, the effect of the inter-layer distance in this experiment does indeed exhibit similar result as concluded by Yang, et al. (2020). The shifting of the absorption peak towards the lower frequency range can be explain by considering the air space as an acoustics spring while the panel as the mass. By increasing the air-gap/inter-layer distance would reduce the stiffness of the acoustics spring. Thus, shifting the mass systems and resonance of the spring towards the lower frequency range.

On the other hand, the increase of the amplitude of the absorption peak is explain by the theory of the wavelength of the sound. When the inter-layer distance = 0 mm, the acoustic pressure is at its maximum while the air particle velocity is at zero. Hence, exhibits poor sound absorption quality. Oppositely, when the inter-layer distance is at a quarter wavelength of the sound, the acoustic pressure is at zero, while the air particle velocity is at its maximum value. Thus, to achieve maximum sound absorption coefficient of each panel, an optimum inter-layer distance has to be calculated based on the quarter wavelength distance. Through this experiment, it have found out that the optimum inter-layer distance for the provided criteria would be at 40 mm.

(a)



(b)



(c)

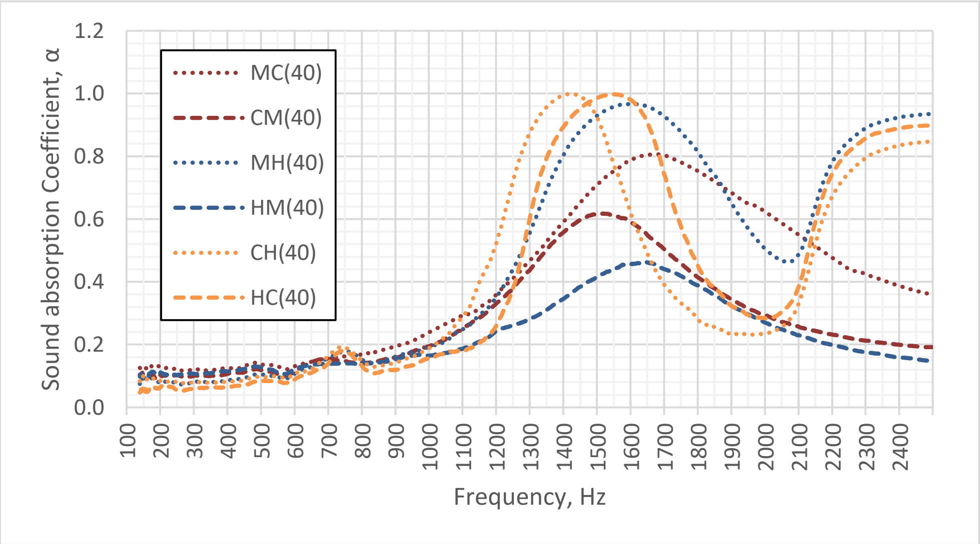


Figure 4.3.1 : Sound absorption graph when inter-layer distance = (a) 0 mm, (b) 20 mm and (c) 40 mm.

4.3.2 Effect of MPP as second layer

Figure 4.3.2 indicates that whenever MPP is aligned at the second layer, it would have a poor sound absorption panel. This is due to the non-existence of air-gap behind the panels. Maa (1974) has mentioned that MPP is constructed by combining a thin piece of micro-perforated panel and an airspace behind it. As the air-gap size have been fixed as zero in this experiment, the MPP where were placed at the back sticking to the back of wall would not have any air space to act as its acoustic spring, hence not being able to perform as it should be. . Thus, it can be concluded that the alignment where the MPP is place at the back with on existence of air gap is not feasible as it does not enhance the sound absorption of the panel in any way.

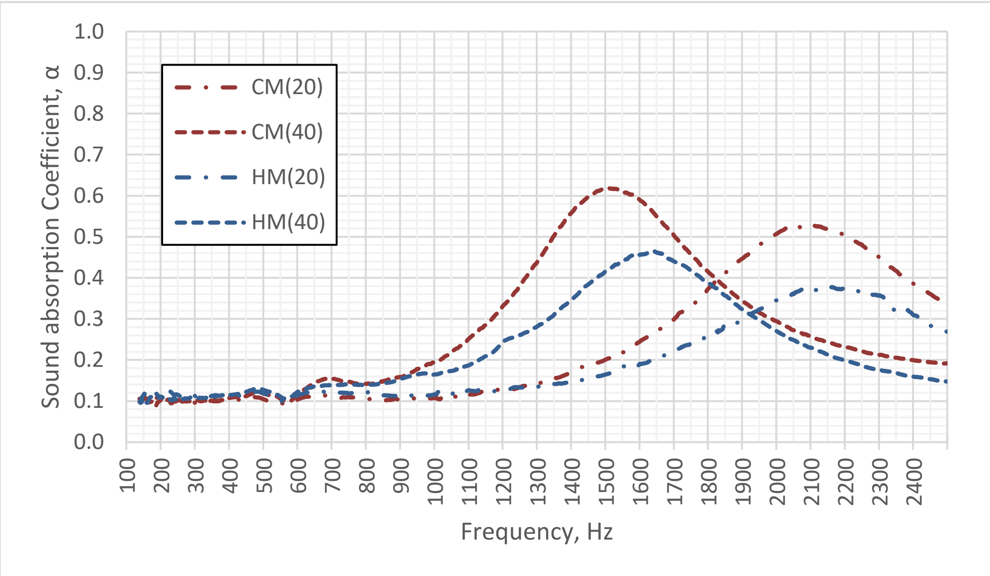


Figure 4.3.2 : Sound absorption coefficient of combinations with MPP aligned at the second layer.

The effect is even more noticeable when it is paired up with the hexagonal panel (shown in figure 4.3.3). As throughout the 3 combinations, the combinations which involve with the Hexagonal porous panel would always exhibit a better absorption ability, with only one exception, where MPP is placed as the second layer of the combination panel.

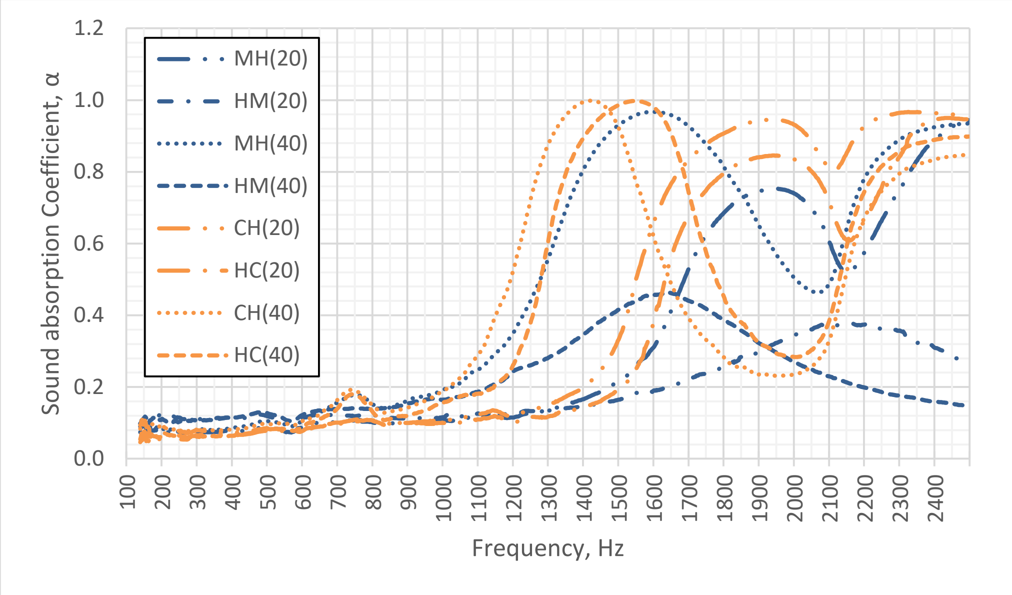


Figure 4.3.3 : Sound absorption coefficient with Hexagonal porous panel combinations.

4.3.3 Effect of types of combinations

Based on previous research done by the other researches, it is said that MPP have a better sound absorption efficiency towards the lower frequency range, while porous structure sound absorption panel would have a better sound absorption coefficient towards the higher frequency range. However, in this experiment, by combining different types of sound absorption panels, it is possible to achieve a good sound absorption efficiency at a relatively lower frequency region.

As mentioned at 4.3.2, the combination which involve a Hexagonal porous panel in the combination would exhibit an excellent sound absorption ability, except for those with MPP as second layer. While looking at overall performance of each combinations, the combinations that consist of 2 porous panel (Hexagonal and Cartesian) would exhibits better sound absorption ability with a slightly lower frequency range.

Vasina, et al. (2020) have mentioned that a porous sound absorption panel with a more complex structure would contribute to a higher airflow resistivity, which in the other way provide a better sound absorption ability to panel. However, when the airflow resistivity of the panel when beyond a certain range of the value, the sound absorption ability of the panel would start to drop as well. In this case, Hexagonal porous panel has a relatively more complex structure as to compare with the other 2 panels, it has provided a higher airflow resistivity, hence exhibiting a higher sound absorption rate among all of the combination panels.

4.3.4 Effect of combination sequence

To the surprise, the sequences of the combination panels have affected the sound absorption peak of the specimens by quite a bit, in terms of both of the amplitude and frequency range. For the MC/CM combinations, the combination panel has shown a better sound absorption ability while shifting slightly towards the higher frequency region when the MPP is placed at the first layer compared to the other way. While on the other hand, for the CH/HC combinations, the combination panels tend to show a better sound absorption rate when the Cartesian porous panel is aligned at the first layer instead of the Hexagonal porous panel and the frequency range of peak absorption would shift slightly towards the left. As for the MH/HM combination panels, the frequency range for both sequence are almost the same, except that when MPP is placed at the second layer, it would exhibits a much poorer sound absorption quality.

Glancing back at all the results from the combination sequences, although the difference are not that big, there are common trends shifting the sound absorption peak frequency range when the sequence of the combination changes. When the Hexagonal porous panel is aligned at the first layer, the sound absorption peak of the combination panels tend to shift towards the higher frequency region while on the alternative sequence, the peak would shift towards the lower frequency range when it is placed at the second layer. On the other hand, when the Cartesian porous panel are placed at the first layer, the sound absorption peak would shift to the right. When it is placed at the second layer, the sound absorption peak would shift to the higher frequency region.

4.3.5 Fluctuation peaks

There are a few fluctuation of the amplitude of the combination panels' sound absorption coefficient throughout the range, especially those in the lower frequency range. The possible cause of the fluctuation might be because of the imperfections and flaws of the printed specimens. After having a close look at the printed specimens in figure 4.3.4, it can be seen that there are a lot of imperfections and flaws on the panels, different from the ‘perfect’ model drawn from the drawing CAD. The surface of the specimens are relatively rough, and there are also leftover stringing inside of the pores. Moreover, the shrinkages of the dimension of the panels during the printing has also contributed to the fluctuation of the sound absorption peaks. Although adjustments have been made to compensate to the shrinkage problems, the dimension cannot still be the exact with the set dimensions. Thus, some strays of the experimental data are to be expected.

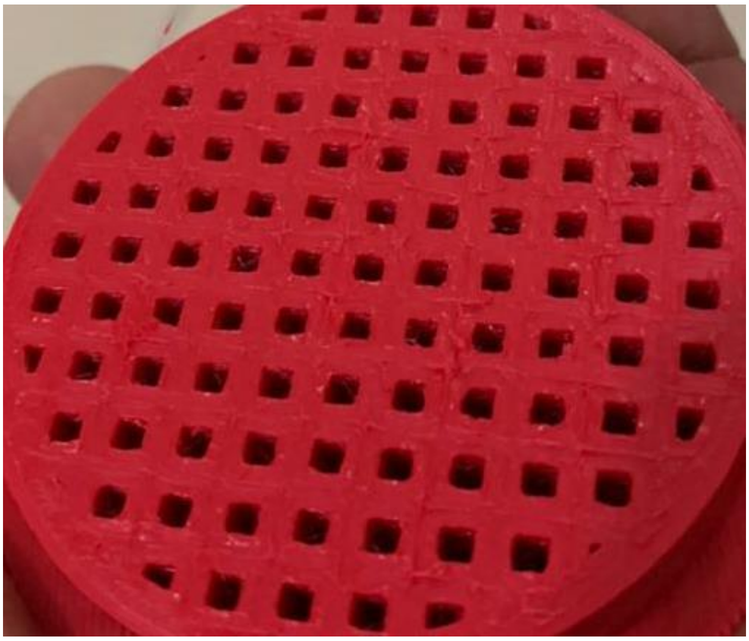


Figure 4.3.4 : Printed Cartesian panel.

4.4 Summary

From the experiments, it is known that different alignment and combinations of panels would produce different sound absorption quality. As a lot of researches shown, the increase of inter-layer distance or air-gap sizes would greatly influence the sound absorption ability of the panels. There should always be an air-gap/inter-layer distance available to be acted as an acoustic spring for the sound absorption panels to perform well, especially for the MPPs. The result of this research has shown that it is not feasible to place a MPP without any airspace behind the panel. This does not only provide enhancement for the sound absorption of the combination panels, but even worsen it.

Form the observation from this experiments, the specimens with 0 mm inter-layer distance would always exhibits a poor sound absorption performance.

By increasing the inter-layer distance, the sound absorption performance would gradually increase with 40 mm as its optimum distance in the case of this experiment criteria. The increasement of the inter-layer distance would also shift the absorption peaks towards the low frequency range. This is due to the shifting of the mass systems and resonance of the spring towards the lower frequency region when the inter-layer distance is increased.

Furthermore, the sound absorption performance would varies based on the combinations and sequence of the panels. Generally, the combinations of a Cartesian porous panel and Hexagonal porous panel indicates a better results than the others while the combinations with MPP aligned at the second layer exhibiting poor sound absorption coefficient. The effect of MPP as second layer are even more noticeable when combined with a Hexagonal porous panel as the combinations which includes the Hexagonal porous panel would show a higher amplitude of the sound absorption coefficient except when the time when the MPP is aligned at the second layer in the combinations. The reason behind of the better sound absorption ability shown by the combination panels which include the Hexagonal porous panel might be due to its relatively higher complexity of its structure, providing a higher airflow resistivity, thus exhibiting a better sound absorption ability than the other combination panels.

At the optimum inter-layer distance of 40 mm, all 3 of the combinations of MH(40), HC(40), and CH(40) indicates similar amplitude of sound absorption peaks while shifting to the lower frequency range correspondingly (for the first peak). The results had also indicated that when the Hexagonal porous panel is placed at the front, the sound absorption peak would shift to the right, and when placed at the back, the sound absorption peak shift to the other direction. On the same time, the sequence of alignment for the Cartesian porous panel would have a totally different effect from the Hexagonal porous panel, in terms on the shifting of the frequency range of the sound absorption peaks. These indications have shown that the sequence of the combination does in fact alter the frequency range of the sound frequency.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the experiment done, it can be conclude that it is possible to alter the sound absorption performance of the absorption panels by stacking 2 types of different panels together and by varying the inter-layer distance, combinations and combination's sequences according to needs. Hence, the objectives of this study have been fulfilled.

This research might help for situations where varying of the target sound absorption frequency range is needed frequently. There would be no need to produce a lot of different panel to be substituted as most of the research done indicating the change of the perforation ratio in order to achieve the desirable sound absorption performance. The panels can be simply taken down and arrange in a set alignment either by altering the inter-layer distance, or changing of combinations and sequences.

The combination panels would only start to exhibit sound absorption properties after the sound frequency reached 1100 Hz and above. For the range below 1100 Hz, the sound absorption ability of the combination panels tested in this study are negligible (sound absorption coefficient below 0.3).

The frequency range of the combination panels' sound absorption peak would shift towards the lower region when the inter-layer distances between the 2 panel increases due to the increase of stiffness of the acoustic spring. Moreover, the sound absorption peak would reach its optimum when the air-gap distance is at the quarter wavelength, while zero when the air-gap is at zero/half wavelength.

Among the tested combinations, it have been found that the combinations that include a Hexagonal porous panel would generally show a better sound absorption ability due to its relatively complex structure that resist airflow through the panel. The sound absorption coefficient peak of combination panels consist of one Hexagonal porous panel are mostly above 0.5, except for those with 0 inter-layer distance and those with MPP aligned as the second layer.

While among all of the combination panels, the combinations between a Cartesian and Hexagonal panels would exhibits a better sound absorption ability, exhibiting sound absorption coefficient peak above 0.8, with exception of inter-layer distance = 0 mm. On the other hand, the combinations with MPP placed behind would have the poorest sound absorption ability, with sound absorption coefficient peak all below 0.65. As stated by Maa (1974), MPP need a certain air gap distance in order for the application of MPP to work properly. This effect is even more noticeable for those combinations that contain a Hexagonal porous panel.

Thus, it is safe to conclude that the combination with MPP placed at the second layer is not feasible as it not only does not enhance the sound absorption properties of the panels, but downgrade its ability to absorb sound, provided with the set condition in this research. Moreover, it is also a must to provide a certain air-gap or inter-layer space while aligning the sound.

Furthermore, the sound absorption peak would have a shifting towards the lower sound frequency region when the Cartesian porous panel is placed at the first layer, or the Hexagonal porous panel is placed at the second layer, or both. While on the opposite side, the sound absorption peak would move right to the higher frequency region when the Hexagonal porous panel is aligned at the first layer, or the Cartesian porous panel is aligned at the second layer, or both.

The results have not only shown difference in the frequency range of the sound absorption peak but also in term of its amplitude. Certain combination sequences have shown a better sound absorption ability when the inter-layer distance is not at its optimum than the others. As the sequence of the combination panel does indeed exhibits a certain trend over the shifting of the amplitude of the sound absorption peak. However, the data that have been obtained are still not sufficient to make any conclusion regarding the phenomenal.

5.2 Recommendations for future work

Due to the difficulty of accessing the lab equipment for the testing due to the MCO restriction, a simple testing can only be done. Hence, the data collected in this research are not perfect and more testing would need to be done to fully show the potential of the effect of panel combinations towards its sound absorption abilities. Testing of the specimens on higher frequency range would need to be done in order to further explore the sound absorption performance of the combinations at the high frequency range. As mentioned, porous structure panel normally work at a higher frequency region and there are quite a lot of cut off of the sound absorption peak of the combination panel towards 2500 Hz.

It is now known that the amplitude and frequency region of the peak absorption of the combination panels varies with the change of sequences of the combinations from this testing results. However, since there are still lack of research about this topic, the reason behind this phenomenal is still unsure. There is possibility that it is affect by the airflow and sound reflection between the panel that contribute to this result. Thus, more study have to be done in order to find out the real reason behind the occurrence of this phenomenal.

Last but not least, since there are also not much research done on combining the 3D printed MPP and porous panels, the data on hand are still lacking to conclude the trend of the effect of each combination towards the peak absorption’s frequency range. More data have to be collected while varying the combination panel criteria before a conclude statement can be made about the effect of combinations of multilayer panels towards the sound absorption affected frequency range and amplitude.

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