Application of 3D printed structured materials as the sound absorption panels

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Abstract. The human living standard has been increasing day-by-day. Not only the building energy performance has to meet a high expectation, but the noise quality of a building has to be par with it. Sound absorption is one of the key elements in determining the quality of the acoustics performance in a room. A room with high background noise and high reverberant time will affect the comfort level of the occupants in the room. Hence, a well-designed room with acoustics treatment is required. The sound absorptive materials play an important role in reducing the overall sound pressure level in the room. Conventionally sound absorber materials are porous and resonator. With the advancement of the additive technology, the sound insulation materials can be further improved and optimized with 3D printed structured materials. Two 3D printed structured designs have been developed in this study and were printed out by using fused deposited modelling in 3D printing technology. The two designs are micro perforated design (MPP) and porous design. The structured materials have been tested for its sound absorption ability using the sound impedance tube. The frequency range tested is between 100 Hz to 6400 Hz. In conclusion, micro perforated design (MPP) model has a very good sound absorptive behavior at the low frequency at 4000Hz and below, whereas the porous model is effective at high frequency at the 2500Hz and above. Through the study, the perforation ratio is found to be closely related to the peak sound absorption coefficient frequency. The peak frequency is reduced with the increase of the perforation ratio. The gap between the 3D printed structured materials and end wall also play the important role. The larger the gap, the lower the peak absorptive frequency.

1. Introduction
Sound pollution (or noise pollution) refers to the excessive unwanted noise which can cause damage either psychologically or physiologically to human health, such as hypertension, high stress levels, hearing loss, etc. Therefore, sound insulation (also known as soundproofing) or sound absorption is necessary in order to mitigate this issue. Sound insulation can be achieved by improving the sound quality in a room or by preventing the transmission of the sound to the room. Therefore, sound absorbing materials have been found to be very useful for room noise control [1]. On the other hand, sound absorption is a process where material absorbs the sound energy emitted from the sound source. With recent technological advancements, addictive manufacturing has been widely used to produce the sound absorber materials. Addictive manufacturing can also be called as 3D printing. It is mostly used in the application of rapid prototyping. It is able to print the desired design in the shortest possible time with the use of layer-based technology [2]. Set against this background, this study aims to develop two 3D-
printed structured designs for sound absorber by using fused deposited modelling (FDM) and their respective sound absorption performance are assessed and compared. The selection of the sound absorption materials is critical to avoid “dead room” effect. Hence, it is very important to treat the room and controlling the sound absorption at the designated frequencies only.

2. Methodology
In this work, FDM method is used in the 3D printing instead of stereolithography (SLA) owing to its cost effectiveness. The size of the hole in the micro-perforated panel sample is set to be larger than the designated hole size during printing in order to consider possible shrinkage which may occur during the 3D printing process via the FDM method. After a set of samples is selected, the acoustic properties of the 3D printing material are determined using the first sample set. Here, two sample sets are applied, which are micro-perforated panel (MPP) sample and porous sample. For MPP sample, the parameters, as shown in Table 1, are set based on the research values. The MPP sample with labelling is shown in Figure 1(a). The sample is 30mm and 60mm in size. On the other hand, the porous sample is designed based on the porous material that is widely used in the industry. The parameters applied here are depicted in Table 1. Here, hole size of 1mm is not applied as the size is too small which is very prone to shrinkage as compared to others. The perforation ratio of each sample is calculated based on the open area. This means that if the perforation ratio is high, more holes are needed on the sample. The thickness is the same with that of MPP sample so that the results can be compared later. The porous panel sample with labelling is shown in Figure 1(b).

| Parameters                        | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 |
|----------------------------------|----|----|----|----|----|----|----|----|
| Hole spacing, \( b \) (mm)       | 0.6| 0.6| 0.6| 0.6| 0.6| 0.6| 0.6| 0.6|
| Hole size, \( d \) (mm)          | 0.6| 0.6| 0.6| 0.6| 0.6| 0.6| 0.6| 0.6|
| Perforation ratio, \( p \) (%)   | 6.3| 2.7| 1.4| 0.9| 0.9| 0.9| 0.9| 0.9|
| Thickness, \( t \) (mm)          | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 |
| Sample diameter, \( D \) (mm)    | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 33 |

| Parameters                        | P1 | P2 | P3 | P4 |
|----------------------------------|----|----|----|----|
| Hole size, \( d \) (mm)          | 2  | 3  | 4  | 5  |
| Perforation ratio, \( p \) (%)   | 64 | 73 | 80 | 84 |
| Strip, \( s \) (mm)              | 1  | 1  | 1  | 1  |
| Thickness, \( t \) (mm)          | 10 | 20 | 30 | 30 |
| Sample diameter, \( D \) (mm)    | 30 | 60 | 30 | 60 |

Figure 1. (a) Micro-perforated panel sample and (b) porous sample.
Figure 2 shows the set-up for the experiment. The sound impedance tube (model SW260) from the BSWA Technology is used in this experiment. Two inner diameters of the testing tube are applied here, i.e. 30 mm and 60 mm. For the 60-mm tube, two tests are conducted, i.e. one with narrow spacing between microphones which produces frequencies of 400 – 2500 Hz, and another one with wide spacing for the microphone which produces frequencies of 100 – 800 Hz. For the 30-mm tube, wider frequency range of 1000 – 6300 Hz is tested. For all the tests, only sound absorption of the material is tested. Sound transmission will not be considered here. The setting used for the sound impedance tube is based on the ISO format which follows the requirement set on ISO 10534-2:1998. The speaker is located at one end while the other end is the sample. The system needs to be an enclosed system so that no sound can penetrate in to interfere the test. Two microphones are located between them and are mounted with diaphragm to prevent air leakage from the system [3]. For the construction of the impedance tube, the metal wall thickness is about 5% of the circular tube diameter to prevent sound loss during travelling.

![Figure 2. Sound impedance tube][4]

3. Results and Discussion

3.1 MPP Design

Figure 3(a) shows the predicted sound absorption coefficients, α, for the MPP samples with 0.6 mm hole size at constant a of 10 mm. It is observed that the peak level of α varies with different hole spacings, while the shapes of the curve are almost similar to the bell shape which is one of the characteristics that can be found on the MPP design. MI has the highest peak α level as compared to the rest at around 3150 Hz. The peak α is around 0.76 to 0.8 for all the MPP samples at 10mm spacing, except for the M3 sample which has a slightly higher a of 0.87. For frequency lower than 500 Hz, α fluctuates between 0 to 0.3 for all the samples. Same observation is obtained when the frequency is above 4000 Hz. These are deemed inefficient for sound absorption. From Figure 3(b), the a of the samples with a of 20 mm falls between 0.8 and 0.85. The peak α is located at frequency ranges between 1100 – 2500 Hz. Similarly, α fluctuates between 0 to 0.2 for all the samples for frequency lower than 500 Hz and above 3000 Hz, which are also inefficient for sound absorption. In Figure 3(c), the MPP sample with a of 30 mm has a lower peak α frequency ranging from 800 – 2100 Hz with α of 0.85 to 0.95, as compared to a of 20 mm and 10 mm.

From Figures 3(a) to (c), it is noticeable that when the hole spacing increases, the peak frequency will be shifted to the left, resulting in lower α frequency. The increment in hole spacing also changes the perforation ratio at the same time. The perforation ratio is the ratio for the hole over the open area. For the MPP design, it absorbs sound with the concept of resonance where air in the air gap will be compressed and expanded continuously when sound hits onto it. This means that MPP provide the acoustic mass reactance for it to work. The increases in the perforation ratio will result in the decrease of the acoustic mass. This leads to the decrease in the resonance frequency in the air gap for peak α. Therefore, for noise control purpose at a specific frequency range, it will be possible to shift the peak frequency by adjusting the hole spacing. The results obtained here is consistent with the findings of Liu et al. [5] whereby the perforation ratio decreases when the peak frequency decreases.
For hole size of 0.8 mm, the results of $\alpha$ for the MPP samples are demonstrated in Figures 3(d) to (f). Similar trend is observed with those for hole size of 0.6 mm where $\alpha$ frequency reduces with increasing hole spacing. Besides that, when the hole spacing is big, particularly for hole spacings of 4 mm and 5 mm, the peak sound absorption frequencies for the MPP using both hole sizes of 0.6 mm and 0.8 mm are similar. For hole spacings of 2 mm and 3 mm, the peak frequency varies depending on the perforation ratio between them.

Furthermore, based on the results shown in Figure 3, when small perforation ratio sample is used, the peak $\alpha$ frequency will decrease when the air gap becomes smaller. This shows that small perforation ratio is not suitable to be used for small air gap since the peak $\alpha$ will decrease.

![Figure 3. Graph of $\alpha$ against frequency for MPP with 0.6 mm hole size at $a$ of (a) 10 mm, (b) 20 mm, and (c) 30 mm, as well as MPP with 0.8 mm hole size at $a$ of (d) 10 mm, (e) 20 mm, and (f) 30 mm.](image)

### 3.2 Porous Design

Figure 4 shows the result for the porous samples with a constant thickness ranging from 10 – 30 mm. It is observed that the $\alpha$ of the samples of 10 mm air gaps remains almost constant from 0 – 4000 Hz. This is the part where the sound absorption is the most insufficient. The design parameter in this range cannot be used. When the frequency exceeds 4000 Hz, the peak $\alpha$ frequency has not been reached yet. This shows that the peak $\alpha$ frequency should be above 6400 Hz and this cannot be completed in this test due to the limitation of the sound impedance tube.

Furthermore, it is found that $\alpha$ of the samples with 20 mm thickness falls between 0.34 and 0.61. The peak $\alpha$ is located at a frequency range of 4100 – 5100 Hz. For frequency lower than 3200 Hz, the porous
samples have a very low $\alpha$, i.e. around 0 to 0.25. This indicates that the samples are not suitable to be used in that frequency range since $\alpha$ is too small. P1 has the lowest peak $\alpha$ frequency of 4100 Hz with $\alpha$ of 0.61, follows by P2 which has a peak $\alpha$ frequency of 4800 Hz with $\alpha$ of 0.55, and P3 which falls into 5000 Hz with $\alpha$ of 0.45. P4 has the highest peak $\alpha$ frequency of 5100 Hz and the lowest $\alpha$ of 0.34. However, the trends obtained by Jiang et al. [6] are in opposite. It is claimed that when size of the hole increases, the peak $\alpha$ frequency will be lower. It is noted that several parameters applied in this study are different with those in [6]. The holes that they used are all sub-millimetre hole ranging between 0.6 mm to 1 mm. This may attribute to the difference in the results obtained.

Additionally, referring to the results in Figure 4, it is observed that when the thickness of the sample increases, the peak $\alpha$ frequency tend to shift towards the smaller frequency. This is more evident when a smaller hole size (e.g. P1) is used, which is around 1600 Hz. For bigger hole size, it appears to be in opposite. The shift is smaller, which is around 100 Hz. This proves that perforation ratio is closely related to the sound absorption. When the perforation ratio is smaller, the peak $\alpha$ frequency will be reduced. Besides that, based on the design of the porous sample, the number of strips presented in the porous sample with smaller holes is greater than that with bigger holes. The viscous effect and material damping will then occur more frequently for the smaller holes. This gives rise to higher $\alpha$ in P1 as compared to the others. Apart from these, peak $\alpha$ frequency will increase with the decrease in the air gap. In this study, sample with 10 mm thickness has the highest peak $\alpha$ frequency which is greater than 6400 Hz. The peak $\alpha$ frequency is reduced when sample with thickness of 20 mm is used. It is reported that sample with 30 mm thickness has the lowest peak $\alpha$ frequency of 2500 Hz with $\alpha$ of 0.62. This shows that the volume of air gap can affect the shifting of the peak $\alpha$ frequency, in which it acts as the acoustic spring. With the decrease in the mass, the stiffness of the acoustic spring will increase. So, the resultant resonance frequency is higher.

4. Conclusions

According to the current work, it was found that the MPP design is suitable to be used at lower frequency ranging 4000Hz and below, whereas the porous model is suitable to be used for higher frequency at 2500 Hz and above. It is found that the perforation ratio is closely related to the peak sound absorption frequency. The peak decreases with increasing perforation ratio. The gap between the sample and wall also plays an important role. The bigger the gap, the lower the resultant frequency. For the porous design,
smaller perforation ratio tends to shift more when the thickness increases. This is important for the design of the sound absorption material as a targeted range of absorption materials can be developed for specific noise treatment in a room.

References
[1] Azimi, M., 2017. Noise reduction in buildings using sound absorbing materials. Journal of Architectural Engineering and Technology, 6, p.198.
[2] Andreas Gebhardt, 2011. Understanding Additive Manufacturing, Hanser Publishers, Munich.
[3] ISO 10534-2:1998 Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 2: Transfer-function method. International Organization for Standardization.
[4] User’s Manual - Impedance Tube Test System, BSWA Technology Co. Ltd, 2010.
[5] Liu, Z., Zhan, J., Fard, M. and Davy, J.L., 2017. Acoustic properties of multilayer sound absorbers with a 3D printed micro-perforated panel. Applied Acoustics, 121, pp.25-32.
[6] Jiang, C., Moreau, D. and Doolan, D., 2017. Acoustic absorption of porous materials produced by additive manufacturing with varying geometries.