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Effect of Perforation Size on Sound Absorption Characteristics of Membrane Absorber

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Abstract: This paper describes the analysis on the sound absorption characteristics of perforated membrane absorber. This study aimed to investigate the effect of perforation sizes and percentage of perforation areas on the membrane sound absorption characteristic. The effects of physical and material properties of the membranes such as thickness, Young's modulus and density were also investigated. The characteristics of the perforated membrane absorber were measured experimentally in terms of Sound Absorption Coefficient, α and Noise Reduction Coefficient, NRC by utilizing impedance tube method in compliance with ISO 10534-2 standard. The results showed that the peak value of absorption coefficient is determined by the density and thickness of the membranes. The perforation sizes also have a significant effect on the sound absorption coefficient and frequency range width. Optimal perforation size enhances the sound absorption performance of the membrane. Overall, the perforated membranes give better sound absorption coefficient and wider frequency range compared to the unperforated membranes

Keywords: Membrane, Sound absorber, Perforated, Perforation sizes

1. Introduction

In recent years, indoor and outdoor noise pollution has become a global concern, especially in developing countries. Noises from construction activities, traffic, and industrial areas are known to be a major cause of this problem. Many research, methods, regulations, and awareness have been done in order to prevent and reduce this pollution [1-2].

When it comes to the interiors of a space or building, it should not only have to look greats, but it also needs a good acoustic design too. Creating an acoustically pleasing environment is as important as creating a visually appealing environment in order to give a better comfortability in a particular space. Room or spaces with poor acoustic design may cause discomfort, dizziness and continuous exposure to an excessive amount of unwanted sound which will affect human health physically and psychologically [3]. Basically, an enclosed room will have a reflective sound path and direct sound path. The sound usually reflected between the surface such as wall, floor and ceiling and takes a while before it dies out.

Sound absorbers able to prevent and reduce the strength of reflected noise effectively by converting sound energy into heat energy. Porous and fibrous absorbent has been widely used in architecture because of its absorption performance and its inexpensive cost compared to other sound absorbers. However, porous materials need to be thick to be effective and also have a hygiene and health issue where open pore become clogged with dust and spread harmful fibre into the air. Therefore, these negative effects have increased the attention towards natural fibre. Natural fibre has been known to be more environment friendly, safe and also have an ability to absorb sound energy [4-6].

Micro perforated panel (MPP) has been introduced by Maa [7-9] as an alternative to porous materials because of its features and performance in absorbing sound. Lightweight, cheap, fibre free, durable and have an attractive appearance becomes the most significant advantages of MPP absorber. Since that, MPP potential as sound absorbing material has been studied extensively. However, MPP only depends on Helmholtz resonator type of sound absorption. In order to improve this limitation and produce an efficient sound absorbing system with wide range of sound absorption, another absorption mechanism needs to be introduced. Numerous studies have been carried out to broad up the MPP absorption frequency range [10-13].

Basically, MPP is made from a solid thin sheet of impermeable material such as wood, metal plate and plasterboard with drilled submillimeter holes backed by an air cavity and a rigid wall. Membrane absorbers also

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*Corresponding author: hafeez@uthm.edu.my called as panel absorber but with a thin flexible sheet instead of a solid panel and both absorbers share similar sound absorption characteristics. The Membrane is stretched and mounted over rigid support and then converted sound energy into heat energy through the vibration of the membrane. More than a decade, membrane material has been widely used in architecture due to its aesthetic and ergonomic features [14]. Low cost, easy to be constructed, positive aesthetic appeal and energy– efficient are the reason why membranes become popular and attract researchers attention to study its potential as a sound absorber.

Membrane flow resistance, mass density, air gap, surface tension, and thickness are often varied by researchers in order to determine the acoustic properties of the membrane. From previous studies, it has been discovered that the flow resistance and mass density will affect the permeable membrane sound absorption [15-17]. Adjustment of air gap thickness could alter the peak of the sound absorption coefficient of the membrane [17-19]. Membranes with no surface tension have a better sound absorption if compared to applied surface tension membranes [20]. Membranes also have better sound absorption when the thickness of membrane/panel increases [17, 21]. Multi layered absorbers have more absorption and give higher absorptivity in a broad range of frequency compared to a single layer absorber [22, 23]. When different types of absorber are combined together, it produces better absorption [13]. Perforations will turn the absorption of panel/membrane absorber into Helmholtz resonance MPP type absorption [24].

In recent years, membrane and panel absorber application and improvement have been studied extensively. However, there is not much theory and information given about perforated membrane absorption characteristics. Based on this motivation, this study is aimed to investigate the effect of perforation size on membrane sound absorption performance. At the end of this study, the optimal size of perforation for membrane absorber could be determined

In this study, the sizes of perforation were varied and the sound absorption performances in terms of Sound Absorption Coefficient, α and Noise Reduction Coefficient, NRC. Three types of membranes were used to study the effect of material and physical properties of membrane specimens.

2. Theory and Formulation

2.1 Sound Absorption coefficient

Sound absorption coefficient, $\boldsymbol{\alpha}$ is the measure of material efficiency in absorbing sound and could be determined by a formula, expressed as:

$$\boldsymbol{\alpha} = 1 - \frac{I_R}{I_I} \tag{1}$$

Where:

$\boldsymbol{\alpha}$ = Sound absorption coefficient

I_R = Reflected sound intensity

I_I = Incident sound intensity

Sound absorption coefficient, $\boldsymbol{\alpha}$ of materials are varies in between 0 and 1 without unit where $\boldsymbol{\alpha}= 0$ representing perfect reflection with no absorption, meanwhile $\boldsymbol{\alpha}=1$ representing total absorption of all incident sound with no reflection at all. Materials with sound absorption coefficient value greater than 0.5 considered as a good absorber [25].

2.1 Noise Reduction Coefficient

Noise Reduction Coefficient, NRC is the average value of absorption coefficient at 250, 500, 1000 and 2000 Hz. It denotes the sound absorption capability of a material. NRC also similar with $\boldsymbol{\alpha}$, where NRC = 0 represent a total sound reflection and NRC = 1 represent a total sound absorption.

$$\text{NRC} = \frac{\boldsymbol{\alpha}_{250} + \boldsymbol{\alpha}_{500} + \boldsymbol{\alpha}_{1000} + \boldsymbol{\alpha}_{2000}}{4} \tag{2}$$

3. Experimental Work

3.1 Specimen Preparation

The experimental works were divided into three parts. The first part was the measurement of material and physical properties of the specimens. In the second part, the sound absorption coefficients of the un-perforated membrane specimens were measured to be used as standards. In the third part, the effects of perforation size on sound absorption characteristics of membrane specimens were studied.

1st Part: Three types of latex membrane had been chosen to ensure the outcomes of the study are valid for wide range of membrane types. Table 1 shows the physical and material properties of the membranes such as thickness, Young’s modulus and density. These properties were pre-determined by sets of simple laboratory experiment.

2nd Part: The membrane specimens were prepared in two sizes; 28 mm and 100 mm in diameter for the sound absorption tests. The 28 mm and 100 mm specimens are for high and low frequency test respectively. Three specimens were prepared for each size and the obtained sound absorption coefficients were averaged. The membrane specimens are depicted in Figure 1.

Table 1: Physical and material properties

	Membrane		
	A	B	C
Thickness, mm	0.08	0.20	0.58
Density, g/mm^3	9.8x10^{-4}	1.1x10^{-3}	1.14x10^{-3}
Young’s Modulus	1.38	0.4	1.29

3rd Part: Three perforation sizes, *d* were studied; 0.65 mm, 2.70 mm and 5.70 mm. The perforation sizes of Micro perforated and Macro perforated panel were used in this experiment because of its significant effect on absorption performance in the previous research. The size of perforation for micro perforated panel usually less than 1mm and macro perforated panel varies from 1 mm to 1 cm [26-28].

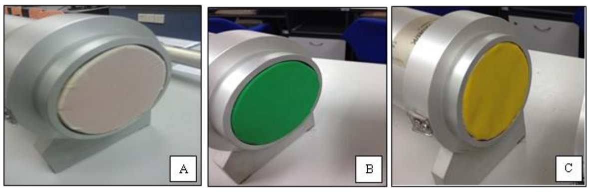


Figure 1: Membrane A, B and C specimens.

For this research, the perforations were set to 0.65 mm, 2.70 mm and 5.70 mm after taking consideration of the available size of the needle to make the perforations. The perforated membrane specimens were also prepared in two sizes; 28 mm and 100 mm in diameter for the sound absorption tests. To ensure the outcomes of the study are also valid for wide range of perforation ratio, three perforation ratios, p were tested in the study; 4%, 8% and 12%. The perforation ratios were obtained by equation:

$$\text{Perforation ratio, } p = \frac{n\pi r_p^2}{n\pi r_s^2} \text{ x } 100 \qquad (3)$$

Where n is the number of perforation, r_p is the radius of the perforation and r_s is the radius of the specimen. The definition of the parameter illustrated in Fig.2. Table 2 show the number of holes for different perforation size obtained from the calculation. The perforations were uniformly distributed onto the specimen surface. Three specimens were prepared for each perforation size and ratio combination and the obtained sound absorption coefficients were averaged. No surface pre-tension was applied to the specimens because the non-stretched surface specimens have better sound absorption if compared to the stretched specimens [19-20].

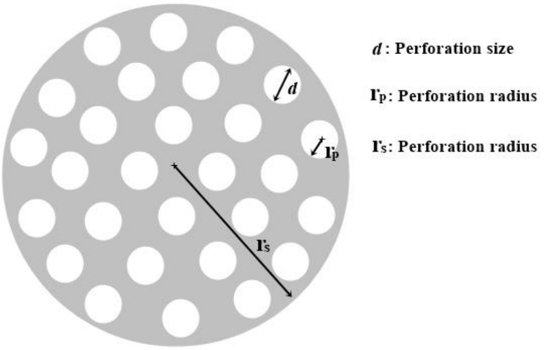


Fig.2: Definition of perforation size,d, perforation radius, r_p and specimen radius, r_s

3.2 Sound Absorption Measurement System

The sound absorption coefficients of the specimens were determined by using the impedance tube method. The impedance tube has two set of tube setup; 28 mm inner diameter is the small tube and was used for high frequency measurement within range of 1600 Hz -7100 Hz and the large tube with 100 mm diameter was used for low frequency measurement within range of 90Hz-1800Hz. Fig.3 shows the impedance tube used in the study. The two microphone transfer function method according to ISO 10534-2 standard was used to measure sound absorption coefficients. The two-microphone method use random noise source and coupled with a pair of microphones positioned at two fixed locations along the tube. The specimens were placed 15 mm from the rigid backed-wall at one end of the tube because the 15 mm air gap gives better sound absorption[19]. The schematic of specimen placement inside the impedance tube is depicted in Fig.4.

Table 2: Number of perforation for different perforation sizes.

Perforation size (mm)		Numbers of perforation, n		
		p = 4%	p = 8%	p=12%
100mm specimen	0.65	952	1904	2855
	2.70	54	110	165
	5.70	12	24	36
28mm specimen	0.65	74	150	224
	2.70	5	9	13
	5.70	1	2	3

Fig.3: Impedance tube: **A** for low frequency and **B** high frequency measurement.

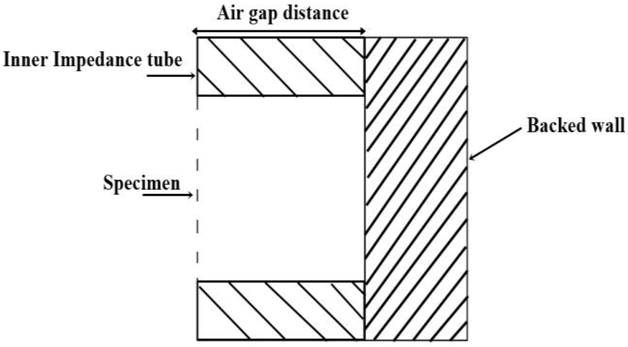


Fig.4: Schematic of specimen placement inside the impedance tube.

4. Results and Discussion

4.1 Correlation between Acoustical, Material and Physical Properties of Membrane Specimens

Fig.5 shows the comparison between absorption coefficients of unperforated Membrane A, B and C. It can be seen that the peak absorption coefficient of all the three membranes are approximately identical. Absorption coefficient of Membrane A reaches 0.84 within the widest range from 1100 Hz to 3300 Hz. Absorption coefficient of Membrane B reaches 0.86 within the frequency range from 800 Hz to 2000 Hz. Meanwhile, Membrane C reaches 0.86 within the frequency range from 500 Hz to 1000 Hz. As can be observed, the peaks of the sound absorption shift to low frequency region with the increasing of the thickness of the membrane. The finding is consistent with [17].

The correlation between the acoustical, material and physical properties is showed in Fig. 6. From the result, the frequency ranges vary with changes in the thickness of the membrane. As the membrane thickness is increased, the frequency range become narrower. This result suggests that the width of frequency ranges is determined by the thickness of the membrane. The peak values of sound absorption coefficient are in good agreement with the densities of the membranes. This result also suggests that the peak value of absorption coefficient is determined by the density of the membrane. This finding is also consistent with [15-17]. Young's modulus does not influence the acoustical properties of the membrane.

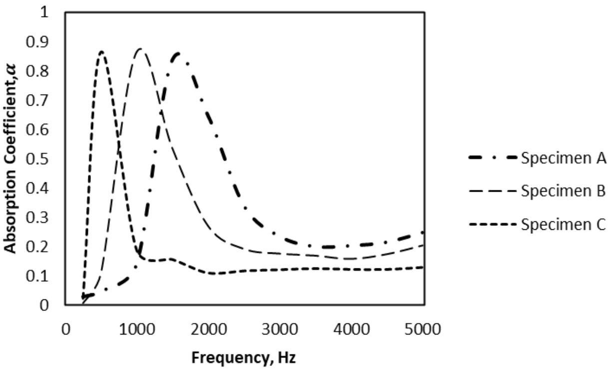


Fig.5: Absorption coefficient of unperforated specimen A, B, and C.

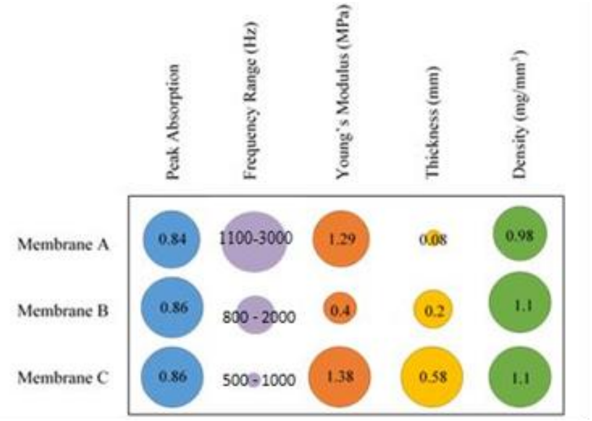
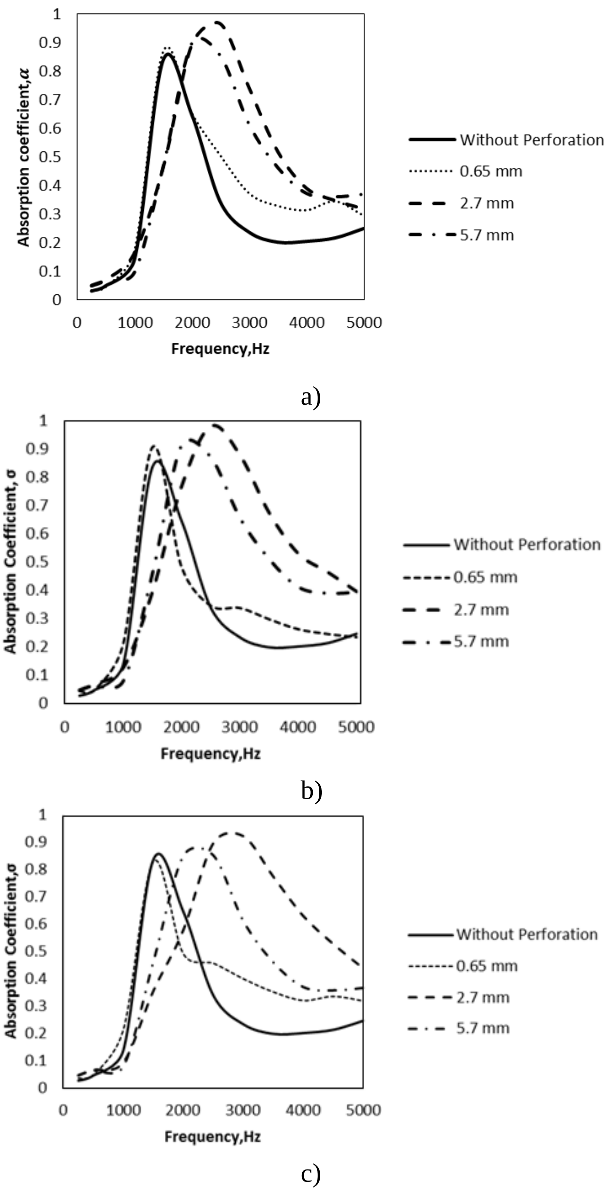


Fig.6: Correlation between acoustical, material and physical properties of membrane specimens.

4.2 Effect of Perforation Size on Absorption Coefficient of Membrane A

Fig 7(a)-(c) shows the effects of the perforation sizes, *d* on Sound Absorption Coefficient, $\boldsymbol{\alpha}$ of membrane A, measured with three different perforation ratio: 4%, 8%, and 12%. Referring to the result, it can be seen that the absorption coefficient increases as the *d* increases, however, decreases as *d* increases further. The peak of absorption of 0.65 mm perforation did not change much and mainly positioned at lower frequency range similar to unperforated specimens. Specimens with 2.70 mm perforation have the best value of $\boldsymbol{\alpha}$ which is over 0.90 within the frequency range from 2000 Hz to 3000 Hz. While, the peak of $\boldsymbol{\alpha}$ dropped when the perforation size increased to *d* = 5.70 mm. The increases of *d* also widen the frequency range and shift the peaks toward the high frequency region, but reverted as *d* is getting too large. The maximum $\boldsymbol{\alpha}$ value obtained from 8% of 2.70 mm perforation specimens, reaching 0.98 inside the range of 2500Hz to 2900Hz. As can be seen, the increases of perforation ratio also improve the absorption between 4000 Hz-5000 Hz.



a)

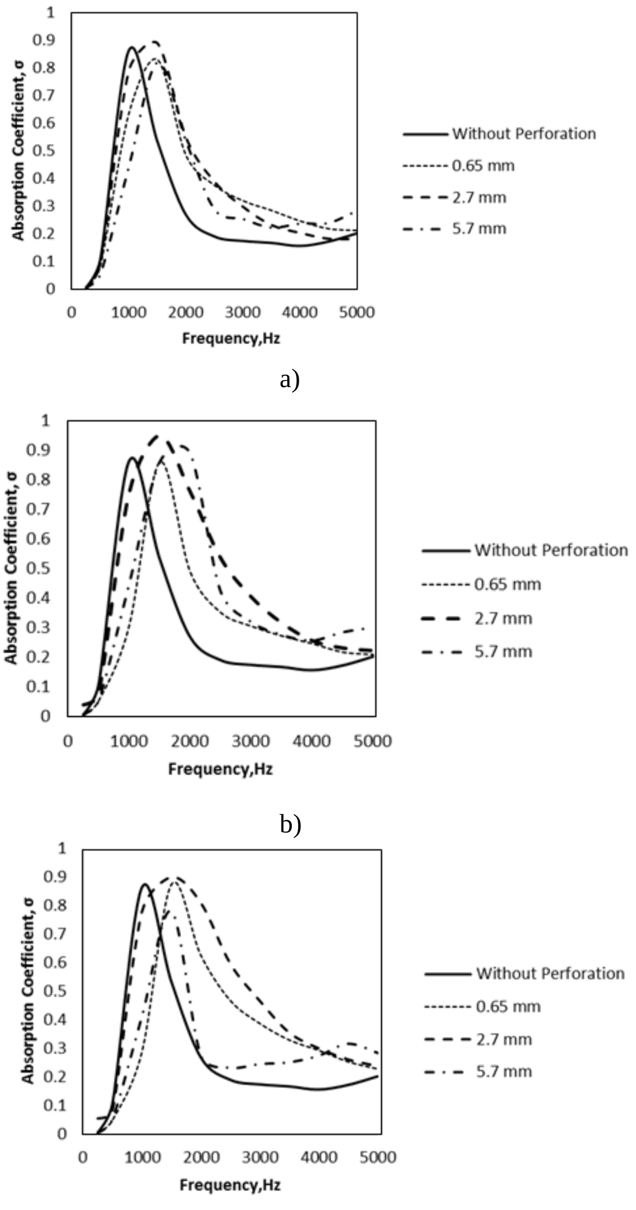
b)

c)

Fig.7: Effect of perforation size on sound absorption coefficient of Membrane A with perforation ratio: (a) 4%, (b) 8%, and (c) 12%.

4.3 Effect of Perforation Size on Absorption Coefficient of Membrane B

The effects of perforation size on Sound Absorption coefficient, α of Membrane B shown in Figure 8(a)-(c). Similar with Membrane A, in which other parameters remained the same, the results show that the perforation size, *d* had some effect on the absorption peaks and frequency range width.



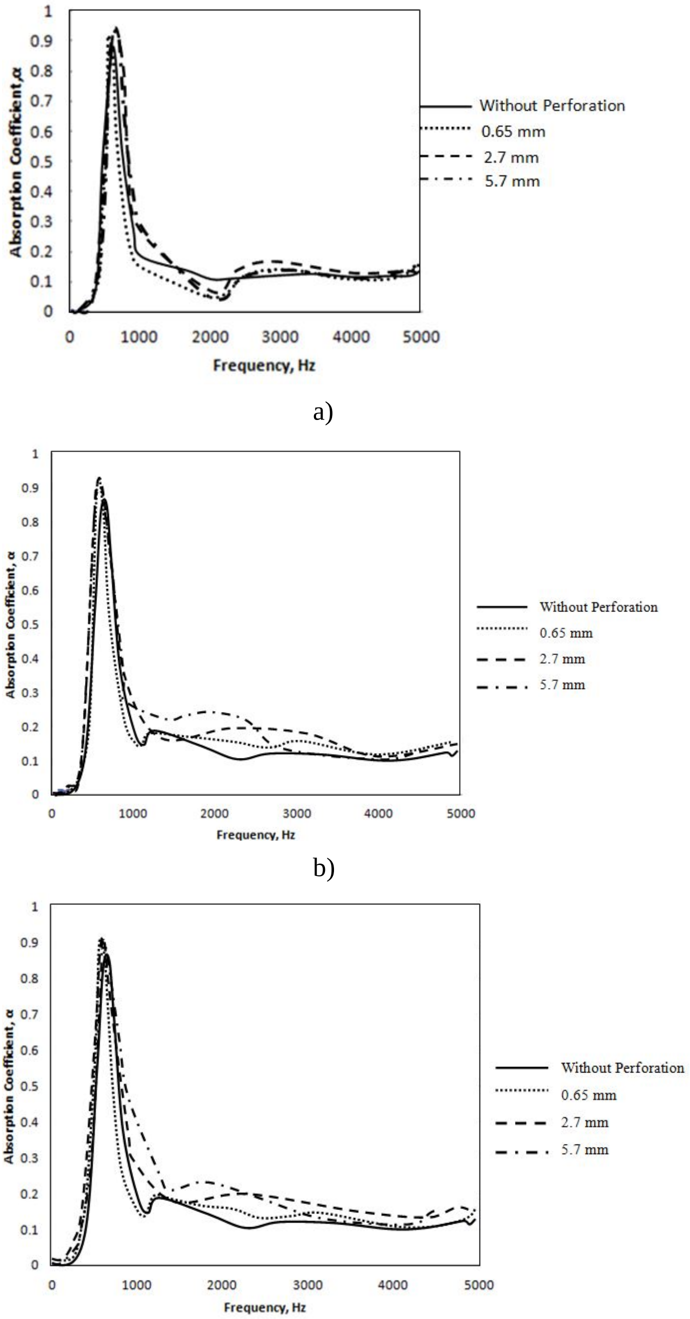
a)

b)

c)

Fig.8: Effect of perforation size on sound absorption coefficient of Membrane B with perforation ratio: (a) 4%, (b) 8%, and (c) 12%.

From the results, 0.65 mm perforation does not affect much on absorption peak value if compared to the unperforated specimens, but the peaks shift to the higher frequency region. When the perforation size is 2.70 mm, the peaks becomes higher and wider. The absorption coefficient of 2.70 mm reaches 0.93 within the frequency range from 1000 Hz to 2000 Hz. However, the absorption coefficient becomes low when the perforation size is 5.70 mm. This low absorptivity occurs due to the decreases of acoustic resistance caused by larger perforation diameters. The finding is consistent with [28-30]. The perforation ratios also have a significant influence on the peak of absorption. The maximum sound absorption can be obtained by 2.70 mm size with 8% of perforation at frequency range 1000 Hz to 2000 Hz. From the result, the increases of perforation ratio give better absorption, however larger perforation ratio will reduces its performance.



a)

b)

c)

Fig.9: Effect of perforation size on absorption coefficient of Membrane C with perforation ratio of (a) 4%, (b) 8%, and (c) 12%.

4.4 Effect of Perforation Size on Absorption Coefficient of Membrane C

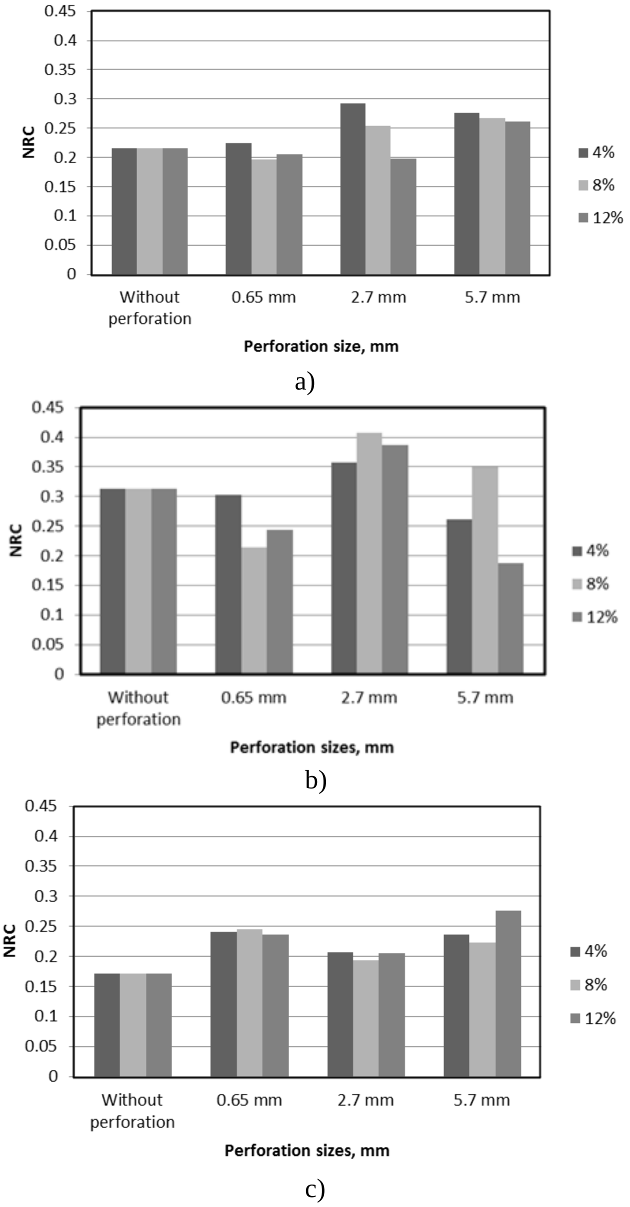
Figure 9(a)-(c) shows the effects of perforation size on Sound Absorption Coefficient, α of Membranes C. The experiment was conducted using same parameters as experiment Membrane A and Membrane B. Referring to Figure 8(a)-(c), it can be seen that the effective sound absorption of membrane C is at low frequency region, from 500 Hz to 1200Hz. The increases of perforation size, *d* affect the peak of absorption while the increases of perforation ratio slightly improve the absorption within the frequency range from 1400 Hz- 2000 Hz. Based on the result, 0.65mm perforation with the increases of perforation ratio does not really improve the absorption since there is no significant change in the graph trend if compared to the unperforated specimens. The absorption coefficient peak is maximized when the size of perforation, *d* is 2.70 mm. The peak reaches 0.9 within the frequency range from 500 Hz to 1000 Hz. However, the increases of perforation size to 5.70 mm slightly dropped the peak values below 0.9. As can be observed, the width and the peaks remain in the low frequency range.

4.5 Effect of Perforation Size on Noise Reduction Coefficient, NRC

Noise Reduction Coefficient, (NRC) is an average absorption coefficient and its characteristics are affected by the peak value and the width of sound absorption coefficient against frequency graph. Figure 10 shows membrane B has the highest NRC value if compared to the other membrane. The maximum NRC value reaches 0.41 at 2.70 mm size with 8% perforation. Membrane A also has a good NRC value at 2.70 mm size. However, NRC value for membrane C only reaches 0.26 at 5.70 mm size. The NCR values of Membrane C become lower due to the narrow frequency range of the sound absorption coefficient peak, α, even though it has very good α value. The NRC values not more than 0.45 for all specimens because most of the width of the membrane sound absorption coefficient is relatively small.

5. Conclusion

Based on the experiment results, the peak value of absorption coefficient is determined by the density and thickness of the membranes. The increases in the density and thickness also move the peaks of absorption to low frequency region. The effects of perforation sizes and perforation ratios on the sound absorption coefficient also have been studied. The results show that the perforation sizes affect the sound absorption coefficient and the width of the frequency range. The increases of perforation size improve the sound absorption coefficient and move the sound absorption peaks toward high frequency region. However, the peaks become low as the perforation size increases further. The maximum α value reaches approximately 0.98 obtained by Membrane B with 8% of 2.70 mm holes. It can be observed that moderate perforation size with optimal ratio will significantly improve the sound absorption of the membrane. Small perforation sizes will makes the sound waves difficult to penetrate into the holes. As a result, most of sounds waves are reflected on the surface thus indicate less absorption similar with unperforated specimens. Meanwhile, when the size is too large, the acoustic resistance and reactance become smaller thus reduces the sound absorption. The NRC values for all specimens not more than 0.45 because of the width of the membrane sound absorption coefficient is relatively small.



a)

b)

c)

Fig. 10: Noise Reduction Coefficient for (a) Membrane A, (b) Membrane B and (c) Membrane C.

Overall, the perforated membranes give better sound absorption coefficient and wider frequency range compared to the unperforated membranes. Combination of membrane and Helmholtz type absorption seem to have better sound absorption coefficient, α and Noise Reduction Coefficient, NRC values over the unperforated membrane. From the experiment, it can be conclude that the perforated surface of the membrane with optimal size and ratio produced better sound absorption.

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