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Lepironia Articulata as a Sustainable Acoustic Absorber

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Abstract: *Lepironia articulata* is found abundant in a swamp and along streams in West Malaysia and it is commonly used for grey water treatment, numerous traditional craft and now commercialise as an organic straw. However, there is a scarcity of knowledge on the physical and acoustical properties of this natural fibre. Therefore, this study was to determine the potential of *Lepironia articulata* as acoustic absorber. The absorption coefficient was tested using the impedance tube method (ASTM E1050-98) for four different structure arrangements, namely "axial", "horizontal", "crossed" and "combination" made up of *Lepironia articulata* with the diameter ranging from 2 to 4 mm and 4 to 7 mm respectively and the thickness remains at 50 mm. The influence of air gap of 0 to 25 mm, in 5 mm increment was introduced in each sample and other physical properties such as density, porosity and tortuosity were investigated. The results revealed that the *Lepironia articulata* in horizontal, crossed and combination arrangements showed greatest absorption performance especially in the low frequency range compared to the axial arrangement. If compared between samples with the range diameter of 4 to 7 mm and 2 to 4 mm, bigger stalks diameter in axial arrangement exhibits the least NRC value. Next, air gaps have great influence at low frequency range whereby it shifted the peaks and sound absorption coefficient curve toward lower frequency. Sound absorption coefficient increases as porosity increase and decrease as density-tortuosity increase. Overall, *Lepironia articulata* has the potential to be used as a sustainable acoustic absorber as all the samples has the NRC value more than or equal to 0.20.

Keywords: *Lepironia Articulata*, Sound Absorption Coefficient, Sound Absorber.

1. Introduction

Sound control plays an essential role in inventing spaces with good acoustical environment that capable in maximising hearing wanted sounds and thus reducing noise at the same time. By installing an acoustic insulated space by the means of sound proofing, it can increase privacy and confidentiality as well. Apart from that, incorporating acoustic materials in the design of a space will have a direct

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impact in reducing stress level as sound reducing materials are capable to deliver a lower noise volume. Due to the adverse effects of the noise, the researchers have undertaken a significant amount of research to identify the alternative solution minimize noise pollution. The sound absorber is the simplest method to reduce the disturbance into acceptable level to human ears [1]. The sound absorber is the ability of a material to absorb, reflect as minimum waves as possible and transmit the waves concurrently as the sound waves strikes to the surface of the material. The absorbing material is a medium which the incident sound is converted into heat and it can be made up of either synthetic material or natural fibrous material. The natural fibrous material such as coconut fibre, wood, and hemp have been widely used to produce acoustic absorbing material as it holds significant potential for substituting the expensive synthetic fibres due to their abundance and low-cost manufacturing process [2]. Due to the limitation of natural fibres such as low thermal stability, higher water absorption and poor durability, high strength and durable material must be identified to be used as a soundproof panel.

Research on utilising hollow structure as acoustic absorber where the reeds were arranged in three configurations of parallel, perpendicular and crossed concluded that parallel configuration appeared to be the most effective configuration. It exhibits typical SAC curves of porous absorber whereby the SAC increases with an increasing frequency. The absorption performance of the perpendicular and crossed are differ and exhibit definite peak [3]. A deeper analysis was performed by Asdrubali et al., [4] where in this study the reeds (*Phragmites australis*) was cut to obtain stalks of length 3, 5 and 7 cm before brought together using adhesive tape in the vertical configuration and 15 circular panels made of single layer was prepared then stacked in the horizontal and crossed configuration. Result showed that the peak of SAC shifted towards lower frequency with increasing thickness in the vertical tested samples. The higher the thickness, the better the absorption performance. Meanwhile, the trend of sound absorption curves are similar in all the crossed and horizontal tested samples whereby the SAC curves remained steady after a first peak. Lastly, Khair et al., [5] conducted a study on the sound absorption performance hollow tube structures made up of lollipop stick. The results demonstrated that samples with perpendicular and crossed configurations showed greater absorption coefficient. In addition, incorporating air gap in the parallel tested sample moves the peak to a lower frequency but no significant effect was found by introducing the air gap in the perpendicular and crossed tested samples.

The application of *Lepironia articulata* as sound absorption material can be maximized by understanding the physical and acoustical performance. In term of economic sustainability, it holds great benefits in reducing the production cost to manufacture sound absorber and thus assist in decreasing the expenses of buying the dissipative silencer. Besides, it helps to unlock new market and attract investors through the development of *Lepironia articulata* as sustainable materials. In term of social sustainability, the usage of *Lepironia Articulata* as dissipative silencer also possessed the prospect of becoming income generation as well. This will improve the living standards of the locals by creating a stable and secure income.

2. Materials and Methods

2.1 Samples preparation

In this study, four different arrangements of samples, namely “axial”, “horizontal”, “crossed” and “combination” was assessed. The diameter used for each arrangement ranging from 2 to 4 mm and 4 to 7 mm respectively.

In the axial configuration, the stalks with different lengths of 16.7, 25 and 50 mm were cut before bonded together using a minimum amount of Polyvinyl Acetate (PVA) glue. Arrangement 1 consisted of 50 mm of stalks bonded together. Next, arrangement 2 consisted of two overlapping layers of 25 mm stalks, whereas arrangement 3 consisted of three overlapping 16.7 mm stalks. This procedure allowed to fabrication of six samples with two different stalks diameters at a constant thickness. Increasing amount of layer will make the path more intricated as shown in Figure 1.

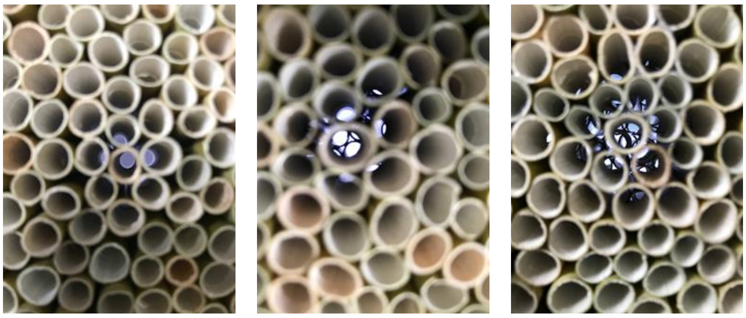


Figure 1: Effect on increasing layer in axial arrangement

For the horizontal configuration, the sample was prepared by stacking several layers until it achieved a thickness of 50 mm. Meanwhile, the sample was arranged the same as horizontal arrangement but each layer was positioned perpendicular to one another for the crossed configuration. Figure 2 illustrated the difference between horizontal and crossed configuration where we can see clearly the visibility of alternate layers in the red circle.

(a) (b)

Figure 2: Samples made up of Lepironia articulata with diameter ranging from 4 to 7 mm for (a) Horizontal arrangement and (b) Crossed arrangement where succession of alternate layers is clearly visible inside the red circle.

Last but not least, the combination configurations consisted of an axial configuration with a length of 25 mm in the center. In the combination of horizontal and axial configuration, several layers stacked in the horizontal direction in both ends until the thickness is 50 mm. This procedure is similar in preparing for the combination of crossed and axial configuration but each layer was positioned perpendicular to one another in both ends until it achieved the constant thickness of 50 mm.

2.2 Experimental Method

Before the acoustical properties were measured using Impedance Tube Method (ITM) based on an international standard of ASTM E1050-98, each sample is crafted into two different diameters of 28 mm for the high frequency (1600 – 5000 Hz) and 100 mm for the low frequency (0 – 1600 Hz). Then, an air gap of 0 to 25 mm, in 5 mm increment is introduced in each sample by adjusting the plunger at the rear end of the sample holder. Measurement was performed three times for each sample. The material and equipment used are illustrated in Figure 3. Noise reduction coefficient is calculated using equation by taking the average value from the sound absorption coefficient, α of the sample at 250Hz, 500Hz, 1000Hz and 2000Hz.

(a)

(b)

Figure 3: Sound Absorption Test
(a) Lepironia articulata fiber, (b) Impedance tube equipment according to ASTM E1050-98

3. Results and Discussion

3.1 Physical Characteristics

Based on Table 1, density of axial arrangement which encompassed arrangement 1, 2 and 3 of sample B showed a steady declination as the number of layer increases from 750 kg/m^3 (B1) followed by 738.10 kg/m^3 (B2) and 729.17 kg/m^3 (B3). In contrast, the density of axial configuration in sample C showed C2 has the highest density of 670.89 kg/m^3, followed by C3 with density of 637.25 kg/m^3 and C1 with density of 620 kg/m^3. This is most probably due to the diameter size of Lepironia articulata used to fabricate in sample C2 is least compared to samples C1 and C3. If compared between samples B and C at the same arrangement, the samples made up of a bigger diameter of stalks demonstrated higher density than the samples made up of smaller stalks. In terms of porosity, samples B4 and B5 showed the highest porosity of 0.215 and sample B2 demonstrated the least porosity with a value of 0.143. The porosity of samples made up of smaller stalks diameter arranged in axial configuration showed significantly higher porosity than the samples made up of bigger stalks diameter. When density increases, the porosity decreases. In a nutshell, porosity had a strong relationship with the arrangement and the diameter of Lepironia articulata. The amount of Lepironia articulata and its diameter size will indirectly influence the porosity of acoustic absorber. Lastly, the tortuosity is inversely proportional with porosity. The highest tortuosity is obtained from sample C1 with the tortuosity of 2.461. Meanwhile, the lowest tortuosity is obtained from samples B4 and B5 with the porosity of 2.157. The samples with horizontal and crossed arrangement shared the same value of weight, volume, density, porosity and tortuosity due to the same layer of stalks are used to fabricate the samples. This goes the same for combination arrangements.

Table 1: The dry weight, density, porosity and tortuosity of the samples

Arrangement	Dry weight (kg)		Density (kg/m^3)		Porosity		Tortuosity	
	B	C	B	C	B	C	B	C
1	0.030	0.062	750.00	620.00	0.150	0.201	2.578	2.233
2	0.031	0.053	738.10	670.89	0.143	0.165	2.642	2.461
3	0.035	0.065	729.17	637.25	0.146	0.187	2.615	2.314
4	0.026	0.051	619.05	607.14	0.215	0.203	2.157	2.220
5	0.026	0.051	619.05	607.14	0.215	0.203	2.157	2.220
6	0.027	0.049	627.91	612.50	0.187	0.188	2.315	2.306
7	0.027	0.049	627.91	612.50	0.187	0.188	2.315	2.306

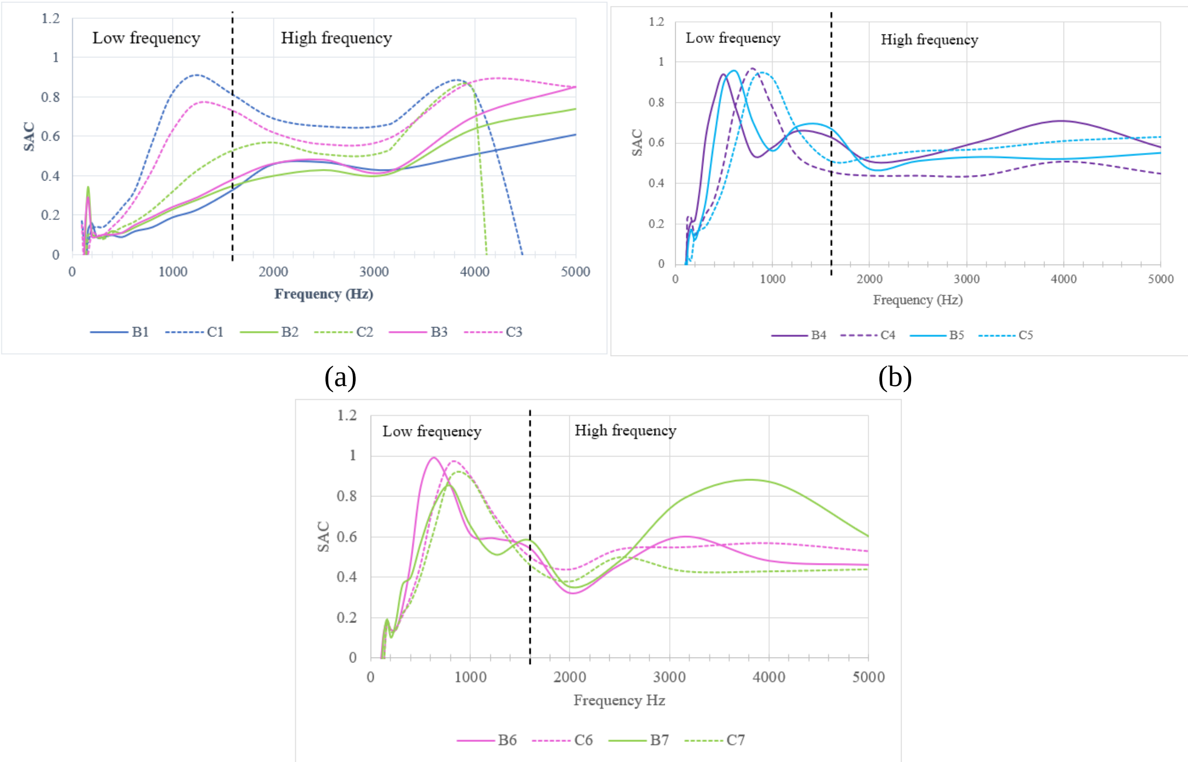
3.1 Acoustical Properties

3.1.1 Sound Absorption Coefficient

The SAC values for axial arrangement samples are illustrated in Figure 4(a). Here, samples of B1, B2 and B3 showed the usual SAC curves of porous absorber whereby the SAC value increases with increasing frequency. If we compared the SAC between the axial arrangement, the sample B3 illustrated higher SAC followed by B2 and B1 especially after 3200 Hz. When the axial layer increases, the material will be able to trap more sound waves. There is high possibility that SAC of the axial arrangement of B1, B2 and B3 samples will continue to increase as the frequency becomes higher. In addition, samples of C1, C2 and C3 demonstrated best SAC curve compared sample B1, B2 and B3. Unfortunately, sample C2 and C3 suffered a severe declination from SAC value of 0.80 at 4000 Hz to zero absorption at 4100 Hz and 4500 Hz respectively. This is probably because the samples are too packed which deteriorates the acoustic absorption performance at certain point. The absorption performance of material is higher for a denser material due to an increase frictional surface between the acoustic wave and the fibres. At certain limit, frictional effect between acoustic wave and fibres less since it is difficult for the acoustic wave to penetrate in material with fewer pores [6][7][8]. Overall, it can be seen clearly that samples when it is fabricated with Lepironia articulata of smaller diameter range demonstrated a good acoustic absorption compared to samples with bigger range of diameter. The performance of sound absorption is higher especially in the middle and high frequency range when there is an increase of fibre content due to a higher airflow resistance and tortuosity [9].

According to Figure 4(b), the SAC results of the horizontal and crossed arrangement demonstrated similar pattern against the frequency whereby it showed definite peak at low frequency range. The peak of SAC curve of samples C4 and C5 were observed to shift towards the higher frequencies compared to the samples B4 and B5. The peak of SAC for sample C4 (0.97) was found higher than sample C5 (0.92) at frequency 800 Hz and we can say both remained steady after it has achieved its highest peak. Meanwhile, the highest SAC peak for samples B4 and B5 were 0.95 at frequency 500 Hz and 630 Hz respectively then it showed fluctuation once it has achieved its highest SAC value. This concluded that smaller stalks of *Lepironia articulata* shows good and stable acoustic absorption performance especially at low frequency range. This might due to higher value of density, porosity and tortuosity of samples that made up of smaller stalks. The declination of SAC values of samples B4 and C4 at frequency range from 4000 to 5000 Hz demonstrated that the steady declination will further continue beyond the frequency of 5000 Hz. However, sample C4 was considered to show poor acoustic absorption at high frequency range as the SAC curve were observed to be the lowest among all. If compared between crossed and horizontal arrangement, crossed arrangements demonstrated higher SAC values compared samples in horizontal arrangements throughout the frequencies.

Result obtained from both combination of horizontal-axial (arrangement 6) and crossed-axial (arrangement 7) configurations was plotted in Figure 4(c), The results indicate the B6 sample has the highest SAC value of 0.99 at low frequency range. Although the C6 and C7 samples did not obtained the highest SAC value at low frequency range, the SAC curve of sample C6 and C7 showed a good absorption performance compared B6 and C7 within the range of 800 Hz to 1400 Hz. Meanwhile, the SAC curve of B7 sample showed a huge gap between 2600 Hz and 5000 Hz compared to others and it demonstrated the highest SAC value of 0.87 at 4000 Hz. After a fluctuation within the frequency of 160 Hz to 3000 Hz, we can say that the SAC of the sample C6 and C7 remain steady at SAC value of 0.55 and 0.44 respectively. The SAC curve of C7 sample appeared to be at the lowest at high frequency range. For combination arrangement, it is best to conclude that samples made up of smaller stalks give an optimum sound absorbing property especially at high frequency range compared to the samples made up of bigger diameter of stalks.



(c)

Figure 4: Sound absorption coefficient

(a) Axial arrangements (b) Horizontal and crossed arrangements and (c) Combination arrangement

3.1.2 Sound Absorption Coefficient with Air Gap Thickness

It can be seen that the sound absorption performance for all samples made up of *Lepironia articulata* with smaller stalks diameter vary significantly with frequency even with an air gap. When the sample is arranged with a layer of axial arrangement as demonstrated in Figure 5(a), the maximum peaks occur at high frequency range, with the highest value of 0.61 at 5000 Hz when there is no air gap and the lowest value being 0.40 at 4000 Hz for air gap thickness of 25 mm. As compared with the peak of plot without an air gap, all the peaks of the plot decrease with higher thickness of air gaps. The range difference of highest peak between with and without air gap increases and more than 0.05 with increasing air gap. This indicates that absorption performance decreases as the air gap increases when the sample is arranged with a layer of axial arrangement.

This goes the same to double layer of sample arranged in axial direction as showed in Figure 5(b), whereby all the peaks of the plot with air gap decreases with increasing thickness of air gaps. All the plots with air gap show declination when the frequency is more than 4000 Hz after it has achieved its highest peak. This declination will most probably continue after 5000 Hz. The SAC curves shows that maximum absorption occur at high frequency ranges, with the highest value of 0.74 at 5000 Hz when there is no air gap and the lowest value being 0.58 at 4000 Hz for air gap thickness of 25 mm.

In contrast, there is a huge gap at the frequency ranging from 1600 to 4000 Hz when 15mm of air gap is introduced in the triple layer of axial arrangement as demonstrated in Figure 5(c). The SAC curve when there is 15 mm of air gap increased dramatically to 0.82 at 2000 Hz before steadily decline to 0.63 at 4000 Hz and remained constant afterwards. Comparing all the plots, the SAC increased but reached its maximum at 15 mm of air gap and further increasing the air gap will result declination of SAC.

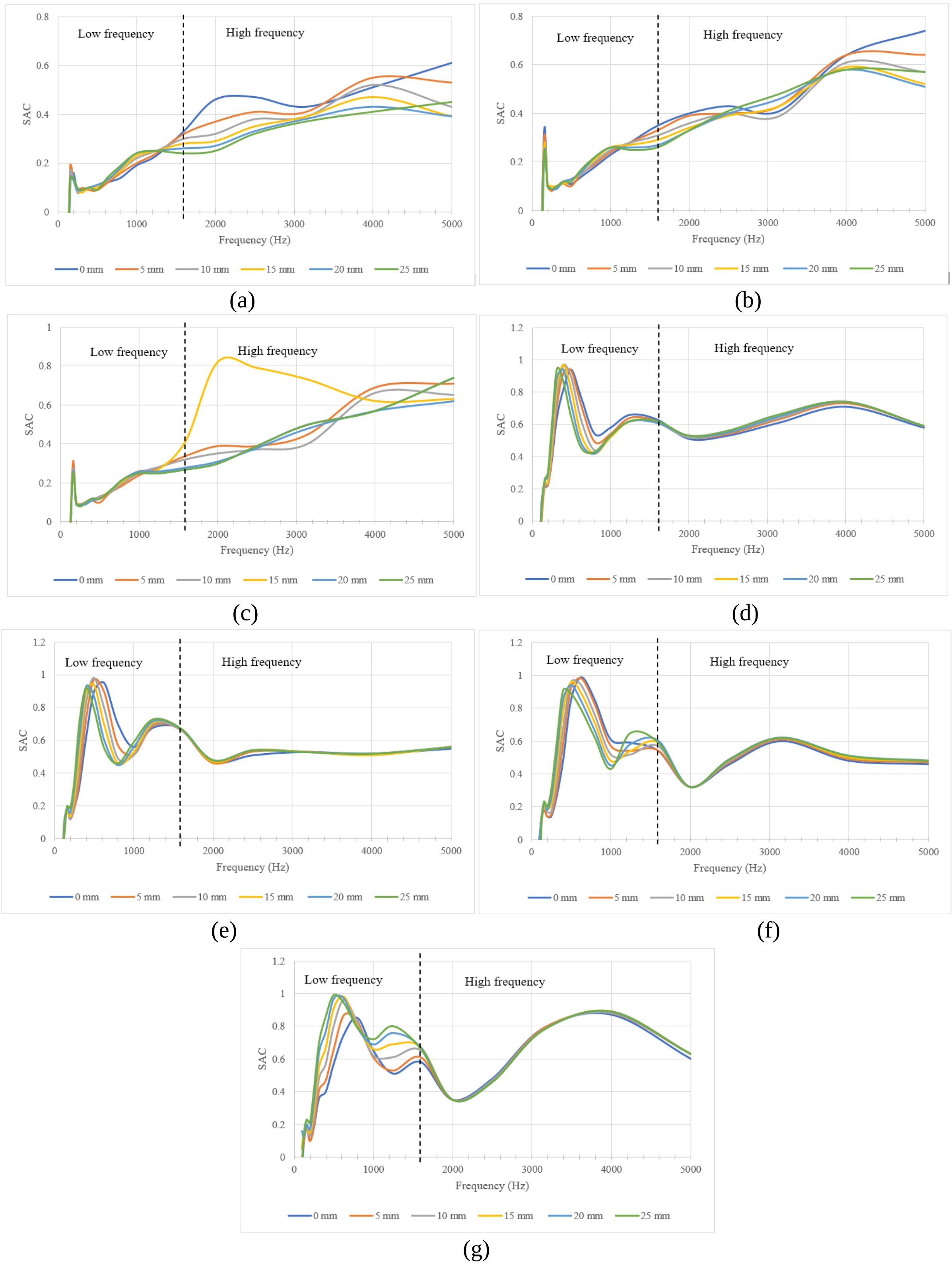


Figure 5: Influence of air gap in samples made up of bigger stalks
(a: B1 sample, b: B2 sample, c: B3 sample, d:B4 sample, e: B5 sample, f:B6 sample, g: B7 sample)

On the other hand, all the SAC curves show the same trend as demonstrated in Figure 5(d), (e) and (f) which all the plots show maximum peak at low frequency range and the peak shifted to lower frequency as the thickness of the air gap increases. For B4 sample, the maximum peak value of SAC of

0.97 at frequency of 400 Hz shown when the air gap is 15 mm. Meanwhile, B5 sample resulted the highest peak of SAC of 0.98 at frequency 500 Hz with 10 mm of air gap. In addition, the highest SAC peak of B6 sample is 0.96 at 500 Hz with 10 mm air gap. However, the range of difference value of the peaks between with and without air gap for the samples of these samples are within the range of 0.05. This low range indicates that the absorption performance for horizontal, crossed and combination of horizontal-axial arrangement is not affected by the thickness of the air gap.

Lastly, the SAC curves of B7 sample as plotted in Figure 5(s) indicates that all the peaks getting higher and reaching to 1 when the thickness of air gap increases. The airgap of 15mm showed maximum absorption as the highest SAC value is 0.98 at 630 Hz. Further increasing the air gap does not significantly demonstrated any much different in the SAC values.

Next, we are going to discuss the relationship between the SAC values with and without air gap when the samples are made up of *Lepironia articulata* with ranging diameter between 2 to 4 mm. It can be seen clearly that there is no dramatic declination in Figure 6(a) and Figure 6(b) when the air gap is introduced to the sample. However, the SAC values decrease as the thickness of the air gap increases in samples C1 and C2 as the range of difference between the SAC values are more than 0.05. This showed that the samples of C1 and C2 demonstrated the optimum absorption performance with highest absorption peak of 0.85 and 0.87 respectively at 4000 Hz and when 5 mm of air gap was introduced to the samples.

On the other hand, the SAC curves of introducing air gap in sample C3 in Figure 6(c) demonstrated more fluctuation trend at the high frequency range as the thickness of the air gap increases. The highest peak also reduces and shifting towards low frequency with an increasing of air gap. According to Mvubu, M. B. et al., [10] this is due to the highest SAC values occurs when the sound waves is in destructive interference and lowest SAC values occurs at constructive interference.

Last but not least, the plotted graph shown in Figure 6(d) to Figure 6(g) showed that introducing air gap in samples C4, C5, C6 and C7 only influenced the SAC values at low frequency range whereby the highest peak of SAC is shifting towards more low frequency. Besides, it creates new peak within frequency of 1000 Hz to 2000 Hz as the thickness of the air gap increased. If compared with and without air gap, the value of SAC with air gap is lower at the same frequency. For instance, the SAC of sample B7 with 25 mm air gap is 0.52 whereas the SAC without air gap is 0.89 at frequency 1000 Hz. However, the range difference of the highest peak between with or without air gap is less than 0.05. This indicates that air gap does not influence the SAC values of sample C4, C5, C6 and C7 although new peak is introduced.

In a nutshell, more acoustic energy at long wavelengths (low frequency) can be absorbed with an increased or air gap. In addition, the highest peak of the SAC curve tends to shift the resonance frequencies towards lower frequencies (to the left of the axis) but does not significantly improve the absorption performance at high frequencies. Incorporating an air gap is equivalent to increasing the material's thickness, but it saves a large number of fibres used in the sample. Overall, a sample will demonstrate the degradation of absorption performance once it has achieved its optimum thickness.

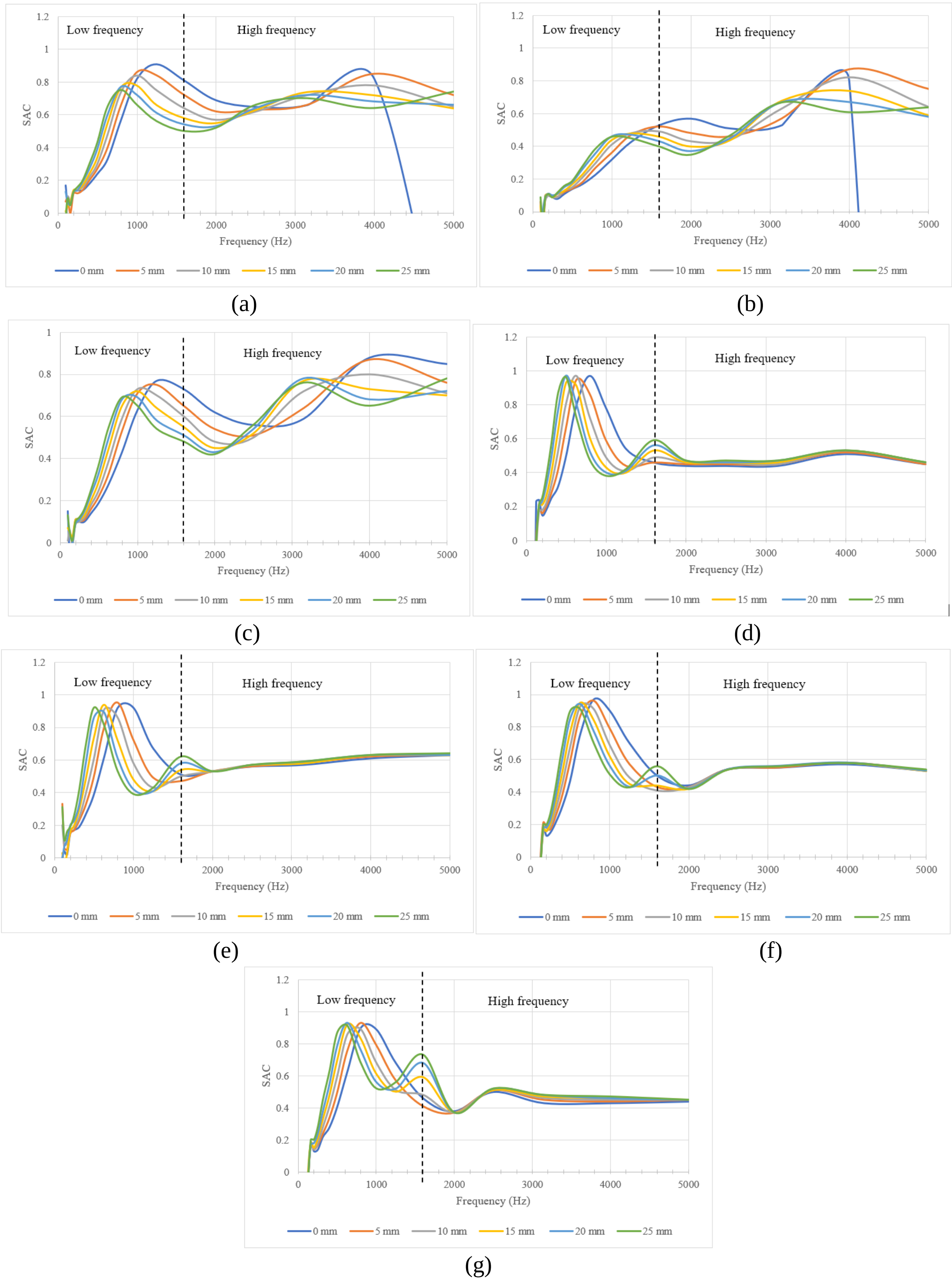


Figure 6: Influence of air gap in samples made up of smaller stalks
(a: C1 sample, b: C2 sample, c: C3 sample, d:C4 sample, e: C5 sample, f:C6 sample, g: C7 sample)

3.1.3 Noise Reduction Coefficient (NRC)

The NRC values must be rounded off to the nearest multiple of 0.05 and ranging only from 0 to 1. Higher value of NRC indicated that the sample has better acoustic absorption. As shown in Table 4.6, it can be seen that the minimum NRC value are given by the samples of B1 and B2 which is 0.21. Meanwhile, the highest NRC (0.60) is obtained by sample B4. If we compared between *Lepironia articulata* with diameter ranging 2 to 4 mm and 4 to 7 mm, huge difference is found for the axial arrangements whereby the NRC value of samples C is higher than samples B. Overall, the NRC for all samples are greater than or equal to 0.2. Hence, *Lepironia articulata* has the potential to become acoustic absorber. NRC values less than 0.20 are considered to be a reflective while NRC values greater than 0.40 are considered to be absorptive [11][12].

Table 2: Noise reduction coefficient (NRC) of samples

Stalks Diameter (mm)	Sample Code	Frequency (Hz)				
		250	500	1000	2000	NRC
4 - 7	B1	0.09	0.09	0.19	0.46	0.20
	B2	0.09	0.11	0.23	0.40	0.20
	B3	0.09	0.11	0.24	0.46	0.25
	B4	0.37	0.94	0.58	0.51	0.60
	B5	0.19	0.90	0.56	0.47	0.55
	B6	0.14	0.85	0.61	0.32	0.50
	B7	0.18	0.57	0.65	0.35	0.45
2 - 4	C1	0.14	0.24	0.82	0.69	0.45
	C2	0.09	0.14	0.32	0.57	0.30
	C3	0.10	0.19	0.63	0.62	0.40
	C4	0.18	0.50	0.78	0.44	0.50
	C5	0.17	0.39	0.92	0.53	0.50
	C6	0.15	0.47	0.90	0.44	0.50
	C7	0.14	0.41	0.89	0.38	0.45

4. Conclusion

The smaller the diameter of *Lepironia articulata*, there will be more fibers in the sample. Hence, the porosity increases with decreasing amount of density. Higher porosity demonstrated good absorption performance as more pores increase surface friction as the sound wave flows through the material. The increase in porosity will reduce the tortuosity. Most of the samples show good absorption performance at low-frequency range except for B1, B2 and B3 samples. In terms of incorporating air gap, further increasing the air gap will reduce the absorption performance once the sample has achieved its maximum absorption at a certain thickness. In this research, the sample made up of smaller stalks with horizontal configurations showed the highest NRC value of 0.6. If we compared smaller and bigger stalks diameter of *Lepironia articulata*, we could say that the fabricated samples with smaller diameters demonstrated good sound absorption performance. Lastly, the result obtained illustrated that *Lepironia articulata* can be used as a sustainable acoustic absorber as all the samples have the NRC value more than or equal to 0.20.

Initially, alkaline treatment with 4% sodium hydroxide solution for 4 hours was done but the fibers were degraded, shrink and twisted. The researchers recommend that the effect of soaking time and concentration of NaOH solution should be investigated to determine the optimum fibre treatment parameters and improve absorption performance. Next, further investigation on the dimension of structure using Scanning Electron Microscope (SEM), flow resistivity, water content and alkaline treatment should be done. Last but not least, the experiment to determine the density and porosity in this research was done alternatively using the home apparatus due to the pandemic. Hence, it is also necessary to extend this research using laboratory apparatus in a controlled environment to determine the physical characteristics in the future to reduce uncertainties and errors.

Acknowledgement

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