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The Potential of Napier Grass Leaf Fibres as an Acoustic Absorber

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Abstract

Acoustic absorbers are introduced to treat poor acoustic enviroment in rooms. However, many available acoustic absorbers in the market are composed of hazardous materials. Therefore, there are demands for the use of sustainable materials in the production of acoustic absorbers. This research investigated the sound absorption potential of grass leaf fibres, i.e. Napier grass, as material for acoustic absorbers. Various bound Napier grass fibre samples, with and without binder under normal press with different thickness, were prepared and tested by using an impedance tube test for sound absorption coefficient (SAC) determination. Samples with binder under hot press with thickness of 10mm were also prepared. The results revealed that 5mm and 20mm fibres, respectively, when bonded with urea formaldhyde (UF) under normal press and with thickness of 30mm, produced a relatively high SAC for frequencies at 500 Hz, 1000 Hz and 2500 Hz, and thus resulted in a high average NRC value of 0.59. This exceeded the value for synthetic fibre-glass and was similar to rockwool. Moreover, the sound absorption performance of 20 mm fibre size hot pressed samples were better than hot pressed 5mm fibre size at 500 Hz frequency until 1000 Hz, as well as the bulk and fibre bonded with UF samples for all frequencies. This study concluded that non-toxic Napier grass fibres can be used in the production of sustainable acoustic absorbers.

Keywords: Napier grass, Sound absorber, Natural fibre, Sound absorption coefficient

1 Introduction

Acoustic absorbers alter the quality of acoustics inside a room. Absorber materials consist of synthetic fibres like glass wool and rock-wool, which are normaly used due to its good acoustic performance. However, the production of synthetic absorbers have ‘negative’ impacts to the environment due to significant release of CO_2 into the atmosphere. Not only that, but also the disposition of this synthetic absorber is harmful to the environment. Therefore, alternative green materials that can produce comparable sound absorbers are needed and of current interest. Researches had so far explored the capability of natural fibres as an acoustic absorber, such as tea-leaf fibres [1, 2], paddy fibres [4, 5], jute fibres [6], ijuk (*Arenga pinnata*) [7], kapok fibres [8], kenaf fibres [9], sisal-kenaf composite [10], pineapple threads [11] and sugarcane baggasse [12, 13]. However, none of the studies was conducted on grass leaf fibres. One of the grass types that is fast-growing, easily found and abundant in Malaysia is Napier or elephant grass. Napier grass is also easily found in the tropical and subtropical regions across the world [14] (Figure 1). Napier resembles sugarcane in height and in method of propagation [15]. But in terms of value added, sugarcane fibres are not only useful for some new product inventions [16-18] but are also good at absorbing sound [12].

Napier's fibres cellulose content is relatively high and this indicates that the fibres are strong and of good quality and may be suitable for sound absorber. According to Daud et al. [19], the percentage of chemical composition content of Napier fibres is said to be 12.3% of cellulose, 80.4% of holocellulose, 68.2% of hemicellulose, 52.0% of NaOH and 10.7% of lignin. This grass produces a higher dry matter yield of 70 tonnes ha^{-1} yr^{-1} [20]. When noise incident strikes an absorber the sound energy can be dissipated in the form of heat, and thus results in the reduction of sound energy. The absorbed sound energy can be described by sound absorption coefficient (SAC) between 0 and 1 at some frequencies. A value of 0 indicates that the surface of absober has poor absorption while that approaching 1 shows good absorption. According to Mamtaz et al. [21], natural fibres were found to have good (SAC) at mid and high frequencies, provided that the thickness is sufficient to provide the viscous friction through air vibration. Xiang et al. [8] found that kapok fibre with thickness 40mm produced an average noise reduction coefficient higher than that of 20mm, especially at low frequencies. In addition, density of materials also changed the sound absorption performance. Koizumi et al. [22] found that increased sample density could increase acoustic performance in the range of medium to high frequency regions.

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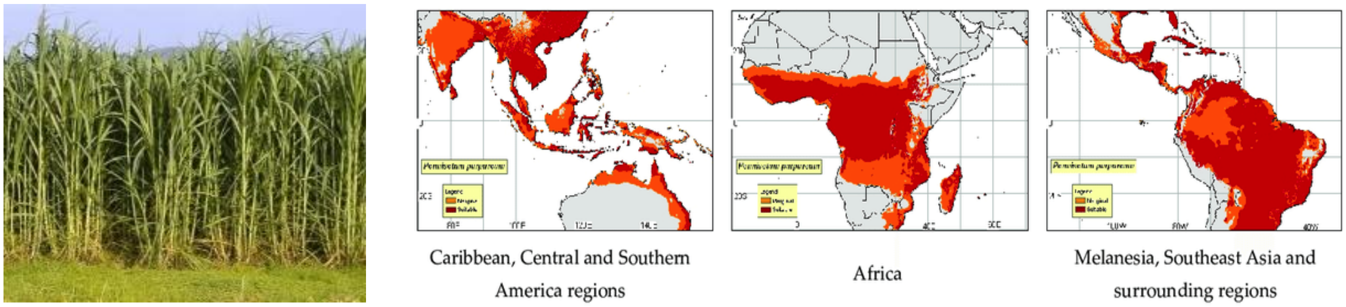


(a) Napier grass/elephant (b) Napier grass distribution arround the world [12]

Figure 1: Napier grass

Density is related to porosity because at high frequency, the higher the density the higher the porosity and sound absorption. Yahya and Desmond [23] found that when bamboo fibre densities increased, the number of bamboo fibre per unit area of the sample will also increase. This would allow increased friction between surfaces, causing the high acoustic energy to be dissipated, and thus increased the SAC of sample.

Resin may change sound absorption performance of natural fibres as it filled the spaces within and between fibres [21](Mamtaz et al.), and thus increased flow resistivity and sound absorption higher than those unbonded. Furthermore, Antonio [24] suggested that a fibrous layer which underwent compression produced high tortuosity behaviour due to decrease in characteristic lengths and porosity. Tortuosity for porous media is the ratio of the characteristic length (L_e) to the sample thickness (L) [25]. Antonio [24] mentioned that passageways for sound travels became small and caused the sound waves to use these available small passageways for their propagation, and thus reducing the SAC at certain frequencies.

Therefore, this paper , demonstrates the acoustic performance of Napier grass leaf fibre (NAF) as a sound absorber. Sound absorber specimens made from two different sizes of fibre, bonded and unbonded with resin were produced. The effects of fibre sizes, density and thickness of absorber specimens on absorption coefficient and noise reduction were investigated. Microstructures and porosity were used to explain the behaviour of acoustical performance. The benefit of study is thedetermination of NAF potential as an alternative material for sound absorber.

2 Materials and Methods

Three types of mixtures were developed to obtain the NAF absorber specimens with specific density. The first and second mixtures were to obtain samples without and with binder,which were fabricated with hand lay up dan normal press method.

(a) Napier grass leaves fiber with 5mm size (b) Shredded Napier grass leaves fiber (size 20mm) (c) Urea formaldehyde (UF)

Figure 3: Materials used

In these mixtures, samples of approximately the same density were developed by using 5mm and 20 mm sized fibres that were treated with 5% of NAOH to remove lignin. Meanwhile, for the third mixture hot pressed method was carried out with samples of higher density. In the first mixture, absorber samples which contained 5mm NAF fibres without binder and have bulk density of 160 kg/m^3 with thickness of 10mm, 20mm and 30 mm were obtained, and denoted as Bulk (5mm)_160 kg/m^3. This density was selected after several trials for its workable criteria. Next, with the same density of 160 kg/m^3, absorber samples that contained 20mm NAF combined with 5mm NAF fibres in the ratio of 70:30 were prepared, also with thickness of 10mm, 20mm and 30 mm. These absorber samples were denoted as Bulk (20mm)_160 kg/m^3. The second mixture samples were bonded with UF to achieve slightly higher density samples with thickness of 10mm, 20mm and 30 mm for 5mm and 20mm fibre size, respectively. The series for 5mm NAF bonded with 40% UF by weight was to achieve a density of 186 kg/m^3 (5mm+UF-186 kg/m^3). Meanwhile, the series for 20mm NAF combined with 5mm NAF and bonded with UF in mix ratio of 60:40, was for density of 212 kg/m^3 (20mm+UF-212 kg/m^3). The mix ratio,which was also obtained after several trials, were made to obtain a good intact between fibres and UF. After the fibres were mixed, the mixture of materials was manually pressed in a 98mm diameter cylindrical casing with specified thickness (Figure 4), and then it underwent a drying process.

Figure 4: Specimens with and without binder

Third samples were specimen with UF under the hot press method for high density samples (927 kg/m^3 and 1059 kg/m^3) of 10mm thickness (hot pressed 5 mm +UF and hot pressed 20mm+UF). The mixtures were developed by mix ratio of 50:50 (fibre:UF). The mixture then placed in a 190.5mm x 190.5 mm x 20mm box mould made of woods (Figure 5(a)). This wooden mould was designed for producing a sample that run the compression process in a hot press machine to form the required sample size. The mould was then removed from its position and transferred to a hot press machine and heated up to 130 °C for 2 min (Figure 5). After that, the 'hot press' machine was released and the composite was cooled at room temperature. This resulted in density of 927 kg/m^3 and 1059 kg/m^3 for 5 mm and 20 mm NAF bonded with UF, respectively.

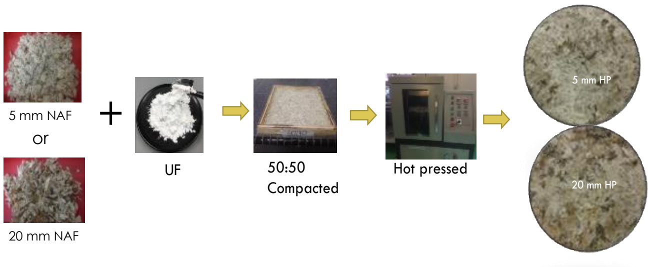


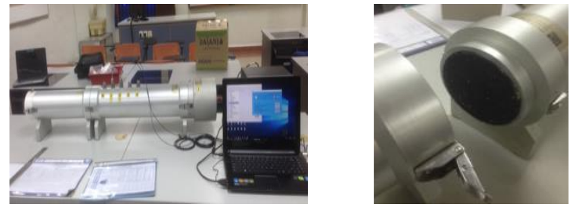
Figure 5: Specimen preparation of hot press NAF: (a) UF binder (b) mixture in wooden mould (c) hot press machine (d) specimens cut after hot press

The acoustic performance of each absorber sample was measured by using an impedance tube in accordance with ASTM E1050-98 [26] (Figure 6). Absorber samples were placed at a sample holder located the end of the impedance tube. The surface of the sample is normally encountered towards incoming sound waves, while the other end of the impedance tube is the location of the sound source. The sound source consists of white noise that is generated from the computer. Two microphones are performed with a loud generator of loud speakers. SAC for one third octave band were meaured and stored in the computer.

Based on the SAC values, noise reduction coefficient (NRC), a scalar quantity to represent the amount of sound energy absorbed when it pounds a surface, were determined. Similar with SAC, NRC can define the nature of a surface based on the value, in which approaching 0 indicates the surface has good reflection, whereas approaching 1 depicts good absorption. NRC is determined by calculating the arithmetic mean of the absorption coefficient at 250 Hz, 500 Hz, 1000 Hz and 2000 Hz. The acoustic performance of rockwool and fibreglass absorber available in the current market were also tested for comparison. A scanning electronic microscope (SEM) was used for specimens' microstructure observation.

Table 1: Mix proportion of NAF absorber

Type of Sample	5mm NAF %	20mm NAF, %	NAF %	UF, %	Thickness, mm	Density, ρ(kg/m3)
Bulk – NAF 5mm	100	-	100	0	10,20,30	160
Bulk-NAF 20mm	30	70	100	0	10,20,30	160
NAF 5mm + UF	100	-	60	40	10, 20,30	186
NAF 20mm+ UF	30	70	60	40	10, 20, 30	212
Hot press_NAF 5mm	100	-	50	50	10	927
Hot press_NAF 20mm	30	70	50	50	10	1059



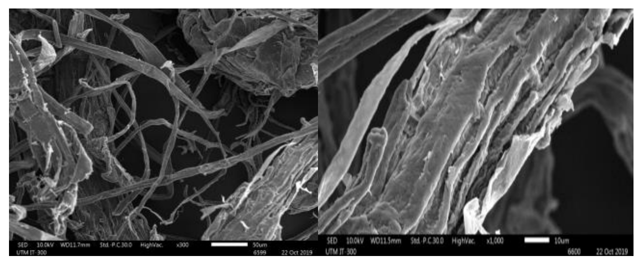
(a) Impedance Test according to ISO 10534-2 (b) Specimen holder

Figure 6: Sound absorption test

3 Result and Discussions

3.1 Microstructures of materials

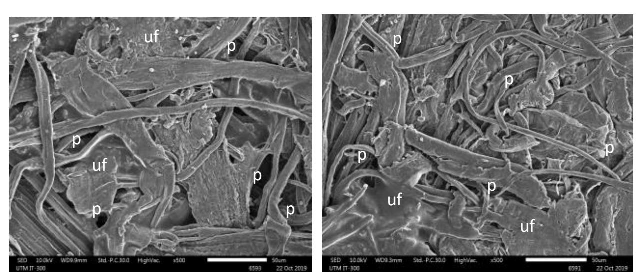
Figures 7(a) depicts SEM micrographs for the magnification of 300x which shows fibrillar structure of NAF while Figure 7(b) for magnification 1000x evidences in a rough surface topography of open cell as well as the porosity existing in fibres. An energy-dispersive X-ray spectroscopy analysis (EDX) analysis shows that the open NAF cells contain Carbon (55.8%), Oxygen (43.8%), Natrium (0.3%) and Calcium (0.1%) (Table 2).



(a) Structure of fibres under magnification 300x (b) Structure of fibres under magnification 1000x

Figure 7: SEM micrographs for Fibres

Figure 8(a) and Figure 8 (b) shows the UF filled in and between fibres (UF) and evidence that some macro pores (p) existed in the hot press sample surfaces. Based on these SEM micrographs, it showed that both fibre sizes were bonded well with UF but there were less pores for the 20mm sized fibre samples as compared to 5mm sized fibre samples. The bonding between fibres and UF matrix for 5mm sized fibre samples were examined by EDX showed that chemical elements of UF matrix (among others carbon, oxygen, silicon, alluminium, and kalium) were present in the fibres bonded with UF, which indicated the penetration of UF in the open cells (Table 2).



(a) Hot pressed 5 mm fibres size bonded with UF (b) Hot pressed 20mm fibres size bonded with UF

Figure 8: SEM micrographs for hot pressed samples

Table 2: Chemical composition detected by using EDX test

Composition	Fibres without UF	UF matrix	Fibres bonded with UF
Carbon (C)	68.5	71.4	56.5
Oxygen (O)	30.9	23.0	41.0
Silicon (Si)	0	2.6	1.0
Aluminum (Al)	0	2.3	0.6
Kalium (K)	0	0.2	0.1
Ferum (Fe)	0	0.1	0
Magnesium (Mg)	0	0.1	0.4
Calsium (Ca)	0.1	0.1	0.2
Natrium (Na)	0.5	0	0.2
Phosphorus (P)	0	0	0.1

3.2 Effect of fibres size and density on sound absorption

Generally, sound incidents were absorbed by the rough surface of topogphy and porosity of fibres (Figure 7). In detail, the effect of fibre sizes and density on the SAC of NAF absorber samples with the same thickness of 10mm can be seen in Figure 9. Bulk sample made of 5 mm sized NAF had a high SAC value as compared to those bulk sample made of 20 mm sized NAF fibres. The finding was similar with a study reported by Mamtaz et al. [21] which found that more subtle fibres absorbed more sound than thick and large-sized fibres. However, the trend was not similar with samples bonded with UF due to slight disparities in density. The binder increased the density of samples and caused uncertain effect on SAC. NAF with sizes of 5mm and 20mm bonded with UF produced a similar SAC with those bulk of 5mm. This implied that the coarser fibre of 20mm bonded with UF sample showed a consistent increase in sound absorption performance. The SAC for the 20mm NAF bonded with UF sample increased at 630 Hz up to 2000 Hz higher than the bulk sample.

The highest SAC was produced by the 20mm fibre size hot pressed sample with value of 0.74 at a frequency of 1000 Hz. Moreover, the sound absorption performance of 20 mm fibre size hot pressed samples was better than the hot pressed 5mm fibre size samples at 500 Hz frequency to 1000 Hz and the bulk and fibre bonded with UF samples for all frequency. This difference was actually related to the density value of the absorber samples, whereby the density value for 20mm fibre size hot pressed absorber samples was the highest, followed by fibre size of 5mm hot pressed samples, 20mm fibre size bonded with UF, 5mm fibre size bonded with UF and all bulk samples.

It could also be seen that the hot press samples had a bell-shaped pattern of SAC. This implied that the SAC curves for hot pressed demonstrated the tortuosity effect (with peak value) and higher SAC for frequency that ranged below 1600 Hz. The denser sample caused the peak of SAC curve to shift to the 1000Hz. It can be seen that the hot pressed sample with coarser fibres yielded a more tortuous path. As the fibres were compressed, the sound that travelled through the fibres decreased and air flow resistivity increased. The sound waves found their way through the small passageways available for their propagation, and thus the viscous losses also decreased [24], reducing the SAC at frequency greater than 1600 Hz. Further, Figure 10 shows the effect of density on sound absorption at 500 Hz, 1000 Hz and 2000 Hz by absorber samples of 10 mm thickness. Generally, with the same sample thickness, hot pressed samples with 20 mm fibres showed higher SAC for 500 Hz, 1000 Hz and 2000 Hz, because hot press the characteristic length increase giving a more tortuous path. Air flow resistivity increased and this caused the incident sound waves energy to decrease due to a longer time taken by sound waves to travel through the sample. This can be seen through the SEM analysis in Figure 8, whereby 20mm sized fibre samples demontrated a denser surface. Therefore, sound energy loss through friction between sound waves and air molecules; hence improved sound absorption, especially at 1000 Hz. It was also observed that the bonded samples with higher density, either compacted manually or hot pressed, had higher NRC despite their different SAC curves.

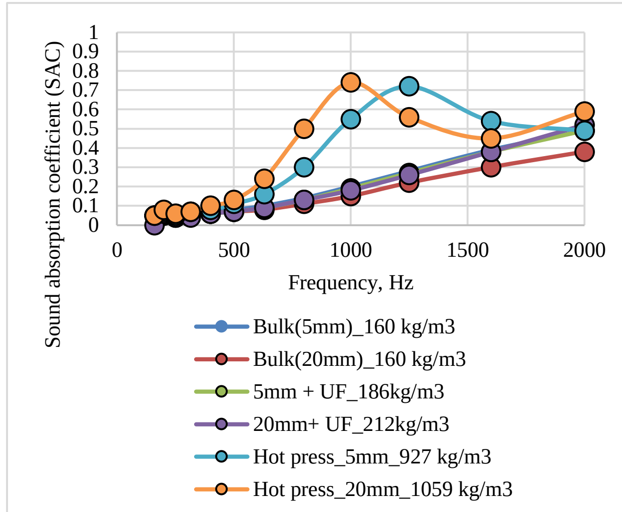


Figure 9: Effect of size of fibres and density on sound absorption of 10 mm thickness of samples

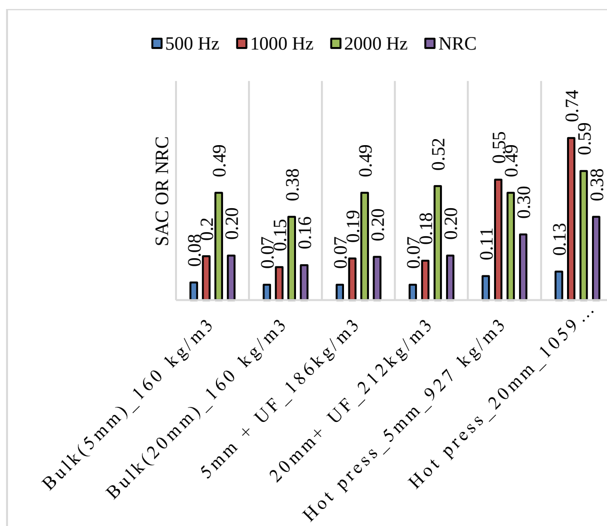


Figure 10: Effect of absorbers samples density on sound absorption at 500 Hz, 1000 Hz, 2000 Hz and NRC of 10 mm thickness of samples

3.3 Effect of thickness on sound absorption

Figure 11 indicates the SAC of NAF 20mm sized fibre absorber samples, which increases by thickness, with and without binder. Generally, as the sample thickness increases, the SAC for all frequency ranges are also increased. Based on the achieved results, the variation in thickness altered the SAC curve and peak shape. The sample of 30 mm thickness, with binder and without binder, and manually compacted had a bell-shaped SAC curve, denoting the more tortuous path and reached a peak SAC approximation of more than 0.99 at 1250 Hz. The SAC for 20mm and 10mm thicknesses samples reached 0.99 and 0.52, respectively, at frequency 2000Hz. For low frequency at 500 Hz the bonded samples with UF reached a higher SAC of 0.60 as compared to those unbonded samples.

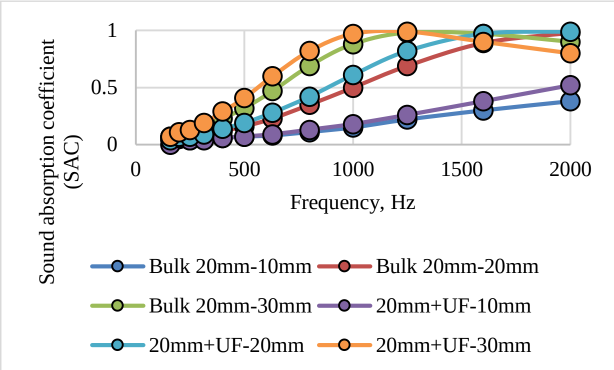


Figure 11: Sound absorption of absorber with NAF fibre size of 20mm for thickness of 10mm, 20mm, and 30mm with and without binder.

Similarly, absorber samples of 5 mm sized fibres with UF and bulk at 30 mm thicknesses resulted in more tortuous paths and reached similar values of SAC (Figure 12). Moreover, both have higher SAC values as compared to the other thickness. The thicker samples demonstrated a higher SAC at lower frequency. Furthermore, the NRC increased as the thickness increased, for both samples with bulk density and bonded with UF (Figure 11). The trend that NRC showed was that the thicker the sample, the higher the NRC; this was similar to Xiang et al. [8] finding which used kapok fibre. This showed that sample thickness caused the incident sound waves energy to decrease due to the longer time taken by sound waves to travel through the sample. UF filled the spaces within and between fibres and in the fibre samples. It increased flow resistivity and increased sound absorption higher than those unbonded. This was in agreement with Mamtaz et al. [21] who concluded that resin may achieve effective sound absorption performance. Also, NRC is average absorption, and thus it showed that finer fibre samples, both bonded and unbonded, demonstrated higher noise reduction capability, whereas the coarser fibre samples showed a higher peak SAC curve. This finding was similar with a study reported by Mamtaz et al. [21], in which more subtle fibres absorbed more sound than the thick and large-sized fibres.

3.4 Comparison with current synthetic fibres

Figure 14 and Figure 15 compare the acoustic performance of absorber samples with the samples of rockwool and fibreglass absorber available in the current market of about the same range of thickness. It can be seen that except for bulk 5mm sample, all Napier fibres were able to achieve a high SAC value of greater than 0.8 as compared to the SAC value of synthetic fibres at a frequency range of 1000 Hz and above.

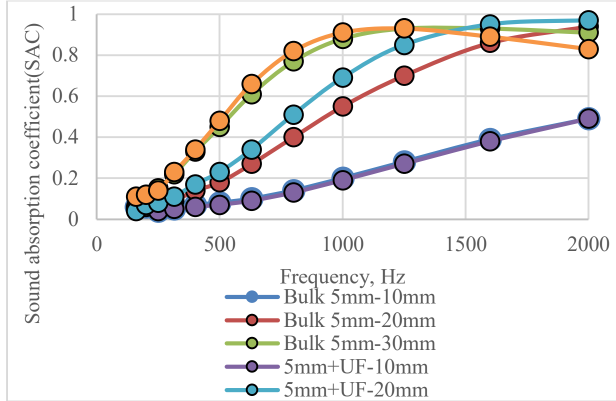


Figure. 12: SAC of absorber samples with fibre size of 5mm for thickness of 10mm, 20mm, and 30mm with and without binder.

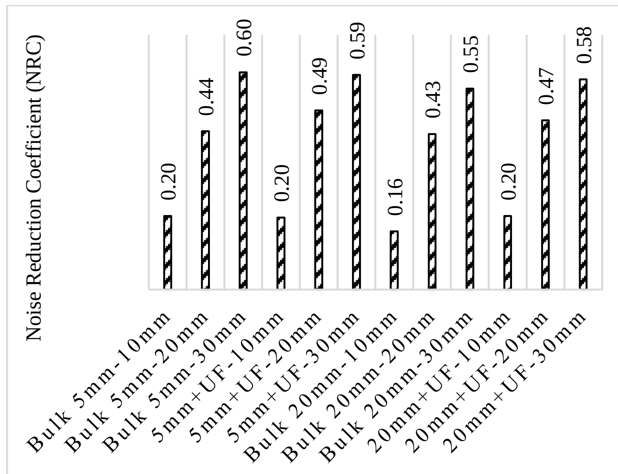


Figure 13: NRC of absorber samples with fiber size of 5 and 20mm for thickness of 10mm, 20mm, and 30mm with and without binder.

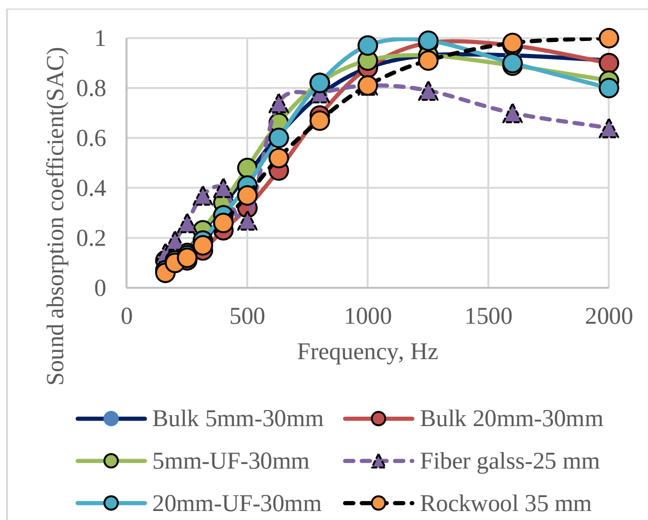


Figure 14: Comparison of sound absorption of NAF absorber samples with rockwool and fibreglass.

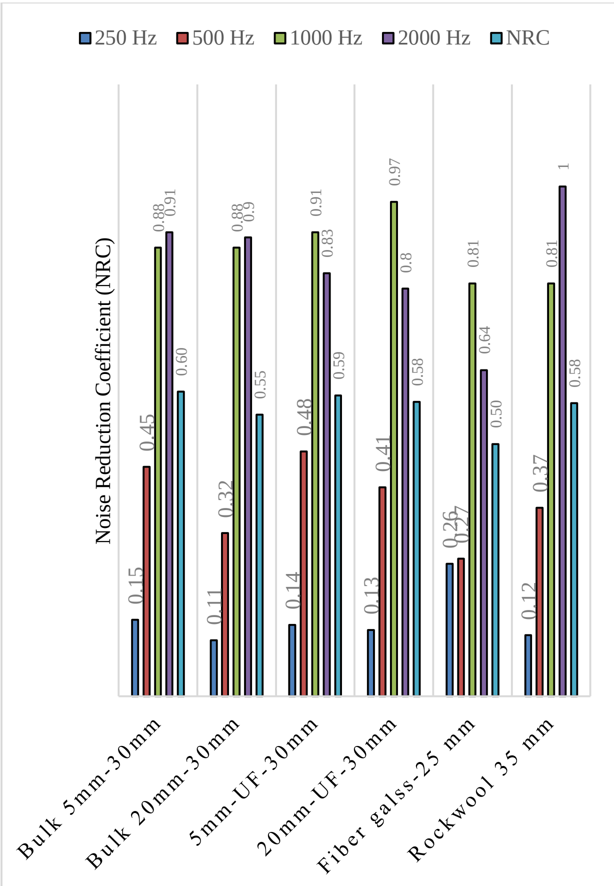


Figure 15: Comparison of NRC for NAF absorber samples with thickness of 30mm with and without binder with synthetic absorber.

At frequency 500 Hz and below, all NAF absorber samples, except unbonded with fibre size of 20mm, were satisfactory and more than the synthetic rockwool samples, which were 5 mm thicker. Meanwhile, all samples exceeded the SAC of synthetic fibreglass of 25mm. Obviously, the 5mm bonded with UF had SAC of more than 0.5 at frequency 500 Hz and above, which was better than than the fibreglass and rockwool absorbers. As shown in Figure 14, the 5mm fibre bonded with UF and unbonded samples of thickness 20mm–30mm, produced relatively high SAC for frequencies 500 Hz, 1000 Hz and 2500 Hz, and thus resulting in high NRC values of 0.55 to 0.6, which exceeded the synthetic fibreglass and similar to those of rockwool. However, when considering the higher SAC at 500 Hz and the sample condition which was more solid and bound together, the 5mm bonded with UF with 30mm thickness sample indeed has potential to replace synthetic fibres in the manufacture of acoustic panels.

4 Conclusions

In this paper, the acoustic performance of NAF absorber samples with and without binder was evaluated. It was found that:

i. Bulk samples of 5 mm size of fibre has higher acoustic performance as compared to those samples with 20 mm fibre size;
ii. NAF with UF binder has higher acoustic performance as compared to the bulk sample
iii. Under the hot press condition, the 20mm fibres size has higher acoustic performance than those 5 mm fibre size hot press. SAC curves are more tortuous as compared to those bulk or bound with UF
iv. Generally, the thicker the sample, the higher the acoustic performance
v. The best sound absorption performance by considering the low and high frequencies is given by 5mm fibre size bound with UF. It is better than the 25 mm thick fibreglass and 35 mm thick rockwool samples.

It can be inferred that NAF poses great significant potential to be utilised as raw material for acoustic absorber production. Therefore, this may overcome the environmental problem caused by the production of synthetic acoustic absorbers.

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