The Potential of Pineapple Leaf Fibre as an Acoustic Absorber

K. Yahya, Z. Haron, S. N. Shaikh Abdul Hamid, N. Mohd Fasli and E. M. Taiwo

Abstract This study discussed an alternative material known as pineapple leaf fibres (PALF) as a replacement of synthetic fibres in sound absorber production. The samples were fabricated from two different sizes of PALF, with and without binder of different thicknesses and densities to determine their effects on the sound absorption coefficient (SAC). The performance of SAC was measured by using an impedance tube instrument according to ISO 10534-2. The resulting frequency peak value of PALF obtained was in the range of 1–2 kHz. The results demonstrated PALF as a new hope for environmentally-friendly sound absorption material in replacing synthetic fibres. The PALF was capable of achieving SAC of more than 0.9 on average above 1 kHz by keeping the densities and thicknesses of the fibres under control. Additionally, the acoustic performance of PALF specimens was better than that of synthetic absorbers available in the market. Therefore, PALF is a promising natural fibre that can be potentially used as a sound absorber material.

Keywords Pineapple leaf fibre · Sound absorber · Acoustic · Sound absorption coefficient

1 Introduction

Generally, synthetic acoustic absorber materials are the primary choice for improving the acoustic quality of rooms such as lecture halls, mosques, broadcasting studios, and more. A sufficient absorber usage makes a speech easily understood and one does not need to raise their voice while speaking. However, the production of such synthetic materials is said to be non-green because, during its

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manufacturing, CO_2 gas is released significantly and causes problems towards the environment and health of the workers. Therefore, alternative green acoustic absorber materials made from natural fibres are now a concern as their manufacturing is bio-degradable and reduces pollution.

Elsewhere, much research have scrutinised the competency and performance of natural fibres as acoustic absorbers, such as tea-leaf fibres [1, 2], paddy fibres [3, 4], jute fibres [5], ijuk or *Arenga pinnata* [6], kapok fibres [7], kenaf fibres [8], sisal-kenaf composite [9] and pineapple threads [10]. These works have underlined these fibres' good sound absorption coefficient (SAC) at either mid or high frequency, as well as sufficient thickness and porosity.

Thickness is a key factor influencing acoustic performance. For example, Xiang et al. [7] have found that kapok fibre with a thickness of 40 mm produces an average noise reduction coefficient that is higher compared to 20 mm thickness. Therefore, thicker samples are thought to produce good sound absorption, especially for low frequencies. Moreover, the density of materials changes the sound absorption performance too. Yahya et al. [11] have indicated that when bamboo fibre densities increase, the number of bamboo fibre per unit area of the sample also increases, as well as the fibre porosity. Due to increased friction between surfaces, a high loss of acoustic energy will occur and this contributes to the increase in the sample's SAC. Koizumi et al. [12] have also noted that the increased sample density can enhance the acoustic performance in the range of medium and high-frequency regions.

In this study, pineapple leaf fibre (PALF) as an agro-waste and its possible usage as sound absorbing material were investigated. Pineapple plants mostly grow in tropical countries, including Malaysia. It has been reported that most pineapples in 2017 totalled to 11.8 million tonne out of all fresh fruits produced in Asia [13]. The leftovers of the pineapple leaves are generally decomposed or burned after the fruits are harvested. Ahmed et al. [14] have further concluded that such practice of decomposition carried out in farm areas do not play any role in improving the plantation yield. Instead, it results in environmental pollution.

Traditionally, threads from PALF have been utilised in the textile industry of many countries. Elsewhere, PALF is used to produce craft products, whereas efforts for PALF utilisation in Malaysia have just begun [15] despite the country being one of the primary pineapple producers in the South East Asia region. Therefore, the aim of this research is to study the potential of PALF as an alternative material for the sound absorber. This includes the acoustic performance capability of the specimens with and without binder, as well as the effect of density and thickness.

2 Methodology

This research consisted of several activities, encompassing the material preparation, mixing of materials, development of sample, experimental testing, data collection, and analysis.

2.1 Material Preparation

The raw materials used to produce the samples were PALF and the binder, namely urea formaldehyde (UF) (Fig. 1). PALF utilised in this study had different characteristic compared to those of the thread form as investigated by Putra et al. [10]. This study incorporated two different sizes of PALF, namely 5 and 15 mm (Fig. 1), that was obtained from the Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia (UTM). All sample preparation work was carried out at the Structure and Materials Laboratory, D01 Faculty of Civil Engineering, UTM. Meanwhile, the main tests were conducted at the Vibration and Noise Room at Universiti Tun Hussein Onn Malaysia (UTHM).

2.2 Development of Sample

The effect of PALF density on the SAC was investigated using three types of the mixture to obtain the specific density. The first mixture was comprised of samples without a binder to obtain the bulk density of 160 kg/m^3 and thicknesses of 10, 20 and 30 mm (M1). M1-A10-30 was for the 5 mm PALF series, while M1-B10-30 was for 15 mm sized PALF combined with 5 mm PALF with the mixing ratio of 70:30. The second mixture consisted of samples bonded with UF and compressed manually to yield samples of slightly higher density, with thicknesses of 10, 20 and 30 mm for M2 and M3. The other two series i.e. M2-A10-30 were for 5 mm PALF bonded with 40% UF by weight to achieve the density of 172 kg/m^3, while M2-B10-30 was for 15 mm sized PALF combined with 5 mm PALF bonded with the density of 212 kg/m^3. Lastly, the third group of samples were specimens with binder mixture subjected to hot press to produce high-density samples (861 and 927 kg/m^3) with 10 mm thickness (M3). The percentage of PALF and UF used for sample development was in the ratio of 60:40. The mixture proportion is shown in Table 1.

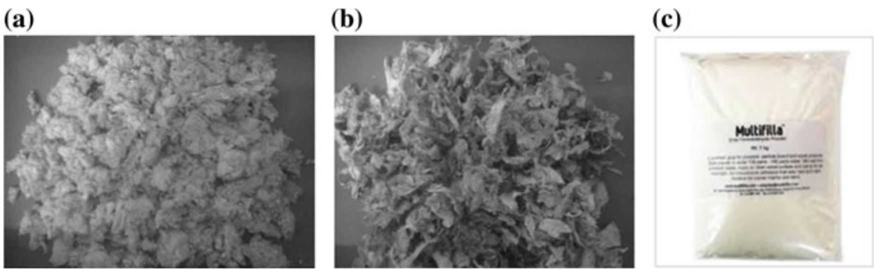

Fig. 1 Materials used, **a** pineapple fibre with 5 mm size, **b** pineapple fibre with 15 mm size, **c** urea formaldehyde

Table 1 Mix proportion of specimen and density

Type of sample	5 mm PALF fraction (%)	15 mm PALF fraction (%)	PALF (%)	UF (%)	Thickness (mm)	Density, ρ (kg/m^3)	Notation
M1-A10	100	–	100	0	10	160	Bulk(5 mm)_160 kg/m^3
M1-A20	100	–	100	0	20	160	Bulk(5 mm)_160 kg/m^3
M1-A30	100	–	100	0	30	160	Bulk(5 mm)_160 kg/m^3
M1-B10	30	70	100	0	10	160	Bulk(15 mm)_160 kg/m^3
M1-B20	30	70	100	0	20	160	Bulk(15 mm)_160 kg/m^3
M1-B30	30	70	100	0	30	160	Bulk(15 mm)_160 kg/m^3
M2-A10	100	–	60	40	10	186	5 mm + UF_186 kg/m^3
M2-A20	100	–	60	40	20	186	5 mm + UF_186 kg/m^3
M2-A30	100	–	60	40	30	186	5 mm + UF_186 kg/m^3
M2-B10	30	70	60	40	10	212	15 mm + UF_222 kg/m^3
M2-B20	30	70	60	40	20	212	15 mm + UF_222 kg/m^3
M2-B30	30	70	60	40	30	212	15 mm + UF_222 kg/m^3
M3-A10	100	–	60	40	10	927	Hot press_5 mm_927 kg/m^3
M3-B10	30	70	60	40	10	861	Hot press_15 mm_861 kg/m^3

For the M2 series, after the fibres were mixed with UF, the mixture of materials was manually pressed in a 98 mm diameter cylindrical casing with a specified thickness. The cylindrical samples then underwent the drying process after mixing. In contrast, the mixtures of M3 series were placed in a box mould of 190.5 mm 190.5 mm × 15 mm dimension made from wood (Fig. 2). The wooden mould was designed for the purpose of producing a sample that could undergo the compression process in a hot press machine and form the required sample size. Next, the mould was removed from its position and transferred to a hot press machine and heated up to 130 °C for 2 min. Following this, the 'hot press' machine was released and the composite obtained was cooled at room temperature. This resulted in 5 and 15 mm PALFs bonded with UF with a density of 927 and 861 kg/m^3, respectively.

2.3 Impedance Test

The acoustic performance of each sample was measured by using an impedance tube instrument according to ASTM E1050-98 [16] (Fig. 3). The sample was placed at the end of the impedance tube and supported by a flat surface. The PALF sample was firmly attached to a sample holder of 98 mm diameter located at the end of the impedance tube. The sample surface was normally directed towards incoming sound waves from the speaker located at the other end of the impedance tube. A computer generated the sound wave in terms of white noise into the impedance tube through a loudspeaker. Two microphones were performed with a loud generator of loudspeaker, which functioned to absorb the sound wave with an indicator value set from 0 to 1. This was thereby known as the sound absorption coefficient (SAC). The process was translated into digital signals using user-friendly software and the output was stored. Based on the SAC values obtained, the noise reduction coefficient (NRC) was generated, which was a scalar quantity representing the amount of sound energy absorbed when it struck a surface. NRC can define the nature of a surface based on its value; values approaching 0 indicate the surface having a good reflection, while those approaching 1 depict good absorption. NRC is generally established via the arithmetic means of the SAC at four different frequencies, namely 250, 500, 1000 and 2000 Hz.

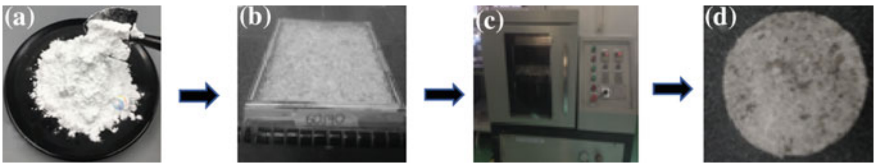

Fig. 2 Specimen preparation, **a** UF, **b** mixture in wooden mold, **c** Hot press machine, **d** specimens cut after hot press machine

(a) (b)

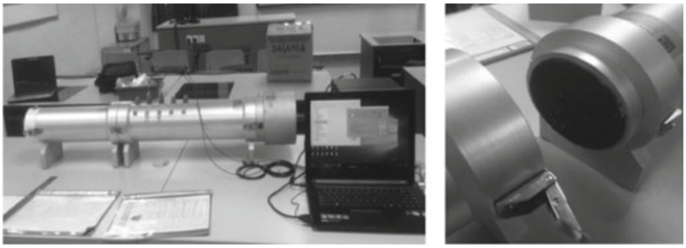

Fig. 3 Sound absorption test, **a** impedance test according to ASTM E1050-98 [16], **b** specimen holder

3 Results and Discussions

3.1 Effect of Density and Size of Fibres

Figure 4 shows the effect of density on the SAC of PALF. It could be seen that the SAC increased when the densities of the PALF increased. The results demonstrated clearly that increasing the density of PALF for sound absorber purposes by maintaining the thickness of 10 mm would increase the SAC value towards lower frequencies. Furthermore, the density of 5 mm PALF sample size increased from 186 to 927 kg/m^3 at 10 mm thickness, resulting in the peak curve of the SAC of 927 kg/m^3 to shift to 0.77 at 1.25 kHz. The frequency range having SAC greater than 0.4 also shifted from 1.25 kHz for 186 and 927 kg/m^3 densities. It should be noted that for frequencies lower than 800 Hz, the SAC was less than 50% for all samples. When the densities increase, the fibre per unit area of the sample will also increase, thus resulting in increased fibre porosity Yahya et al. [11]. Due to the increased friction between the surfaces, a high loss of acoustic energy occurred and contributed to the increase in sample SAC. At the same specimen thickness, those with 5 mm fibres showed higher SAC for 500, 1000 and 2000 Hz, as more fibres were needed to achieve the same volume (Fig. 5). In the case of the hot press 5 mm specimen, the results showed that the smaller fibres yielded a more tortuous path. As a result, its acoustic performance was enhanced due to the viscous friction through air vibration Mamtaz et al. [17]. It was also observed that the specimen with 5 mm particle and bulk density of 160 kg/m^3 has similar NRC value compared to the hot press of the same thickness of 10 mm, despite their different SAC curves as shown in Fig. 6.

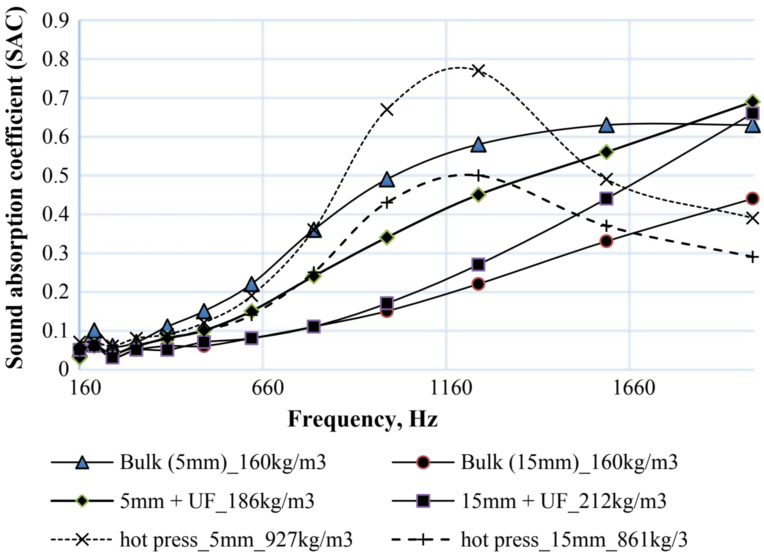

Fig. 4 Effect of density on sound absorption of 10 mm thickness of samples

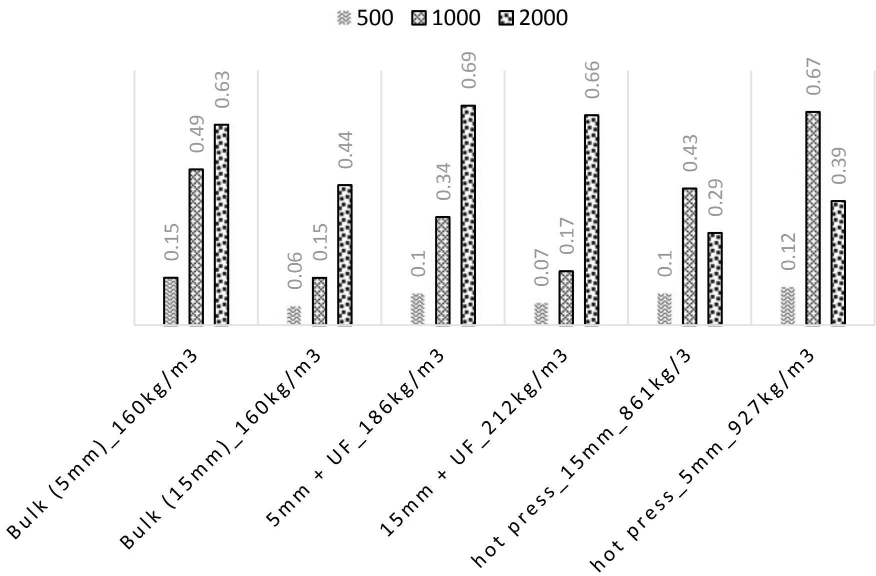

Fig. 5 Effect of density on sound absorption at 500, 1000 and 2000 Hz of 10 mm thickness of samples

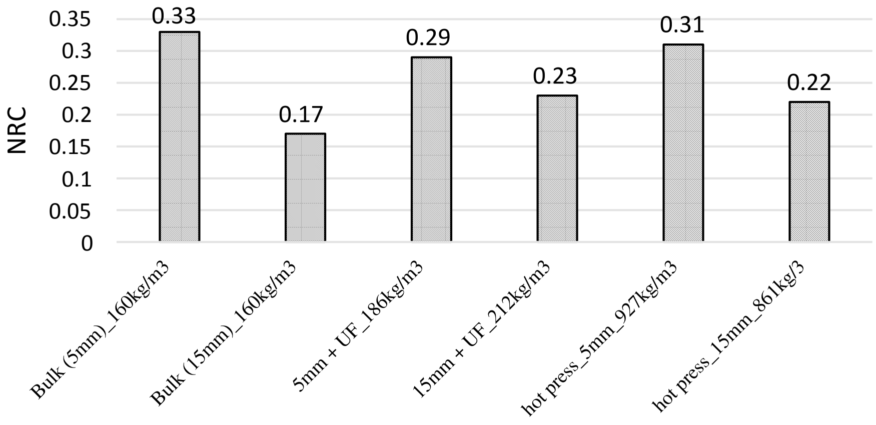

Fig. 6 Effect of density on noise reduction coefficient of 10 mm thickness of samples

3.2 Effect of Thickness

Figure 7 indicates the SAC of PALF for both sizes, which increases by its thickness with and without binder. Generally, as the sample thickness increases, the SAC for all ranges of frequencies are also increased. Based on the results achieved, the variation of thickness alters the curve and peak shape. At 1000 Hz, the sample of 30 mm thickness with binder had a SAC curve of the more tortuous path and reached a high SAC approximation of 0.97, while the 20 mm sample reached 0.65. The maximum SAC obtained was 0.99 at 1600 Hz, whereas the sample of 10 mm thickness only reached 0.17 at the same frequency. Furthermore, the NRC increased as the thickness increased, with the highest value for the specimen with bulk density

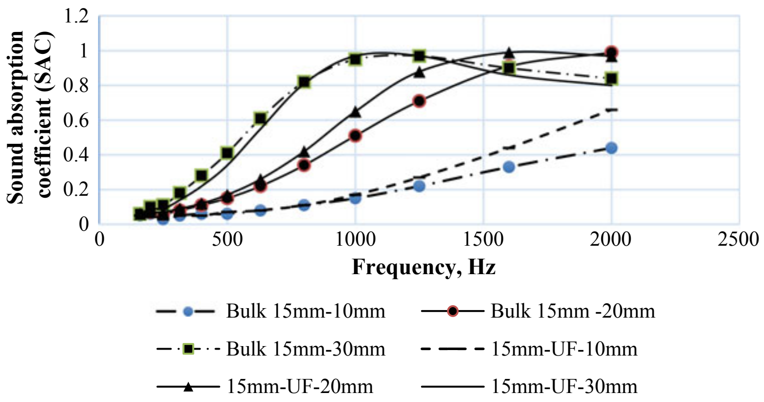

Fig. 7 Sound absorption of PALF 15 mm for thickness of 10, 20 and 30 mm with and without binder

(Fig. 8). Similarly, specimens of 5 mm fibres with UF at 30 and 20 mm thicknesses resulted in more tortuous paths and reached higher SAC values compared to the bulk of samples in between the frequency of 500–2000 Hz. The SAC for the sample of 10 mm bulk sample started to reach a value greater than 0.5 at the range of frequency between 1000–2000 Hz, while the sample with UF reached the value in between 1600–2000 Hz. The trend that NRC showed was that the thicker the sample, the higher the NRC as can be seen in Figs. 9 and 10; this was similar to Xiang et al. [7] finding using kapok fibre.

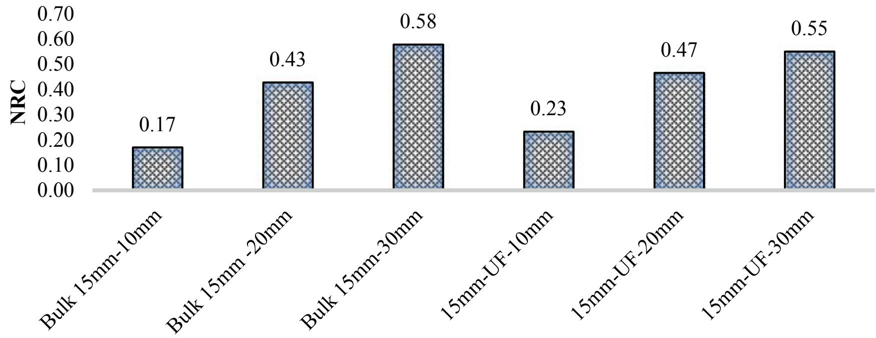

Fig. 8 NRC for PALF 15 mm and thickness of 10, 20 and 30 mm with and without binder

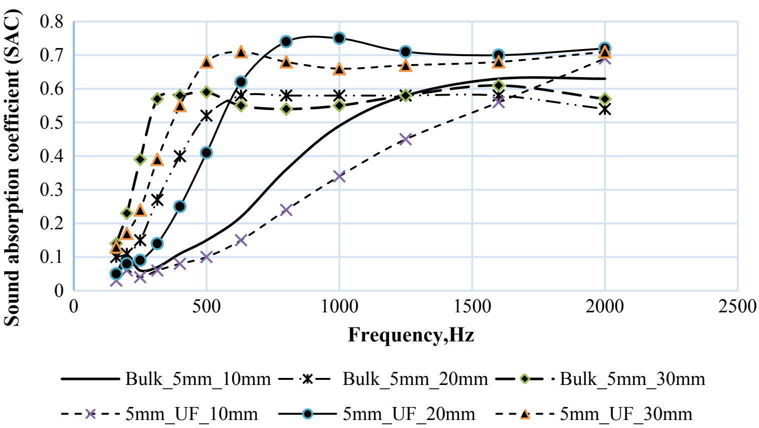

Fig. 9 SAC of PALF of 5 mm for thickness of 10, 20 and 30 mm with and without binder

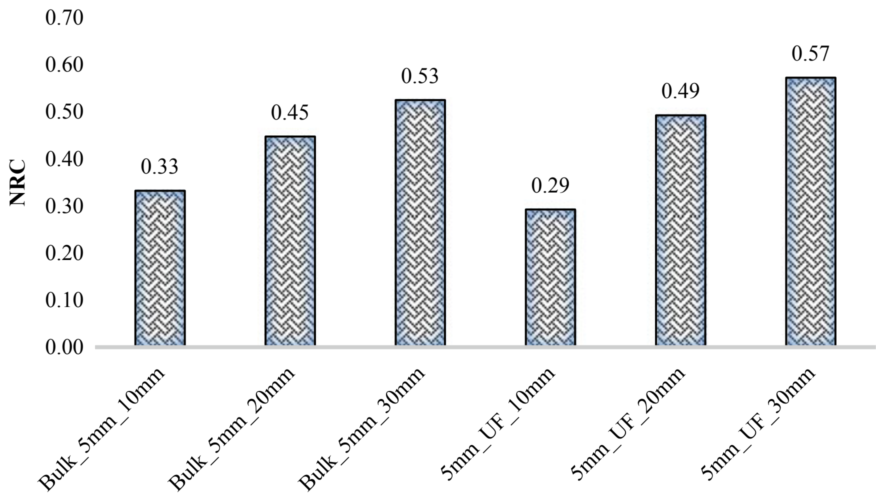

Fig. 10 NRC for PALF 5 mm and thickness of 10, 20 and 30 mm with and without binder

3.3 Comparison with Current Synthetic Fibres

Figures 11 and 12 compare the acoustic performance of PALF absorber of the 30 mm thickness with the samples of rockwool and fibreglass absorber available in the current market. The specimen with 5 mm fibre of either bulk or bonded with UF demonstrated better SAC at low frequency compared to the 15 mm-sized PALF

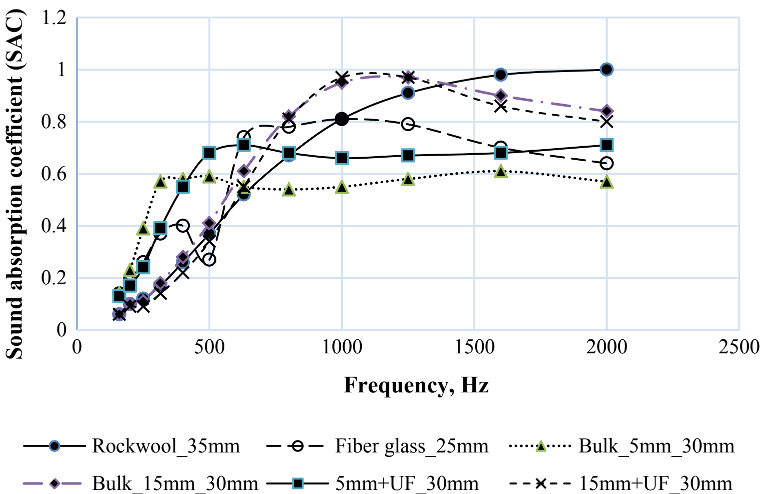

Fig. 11 Comparison of sound absorption of PALF absorber with rockwool and fibreglass

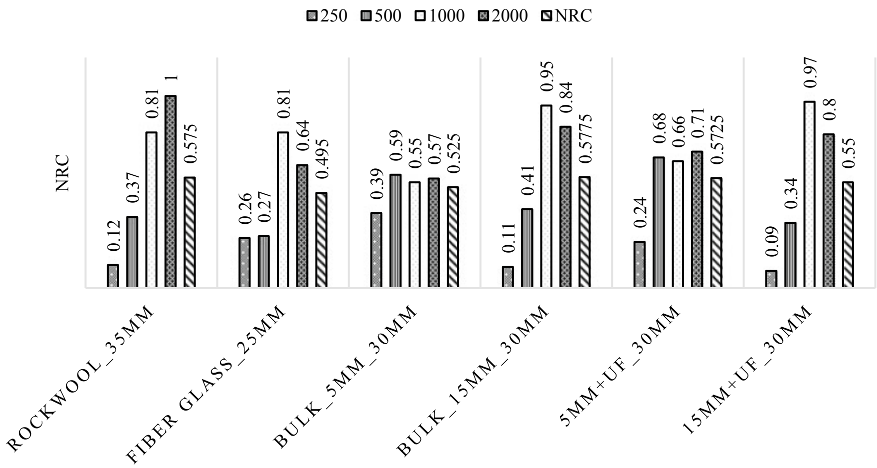

Fig. 12 Comparison of NRC for PALF with thickness of 30 mm with and without binder with synthetic absorber

samples and synthetic fibre. This acoustic performance is important since most sound absorbers have high SAC at a high frequency. In addition, PALF absorber yielded good performance despite its thickness is 5 mm less than rockwool. In terms of the NRC, the PALF specimen demonstrated acoustic performance as good as rockwool, while it was better than 25 mm fibreglass.

4 Conclusion

In this paper, the acoustic performance of PALF with and without binder was evaluated. It is found that:

i. Specimen with a higher density has a higher sound absorption performance;
ii. The thicker the specimen, the higher the SAC;
iii. For the same thickness of 10 mm, specimen made with hot press has higher density and SAC, and is more tortuous compared to those bulk or bonded with UF;
iv. 5 mm PALF has higher acoustic performance compared to the 15 mm PALF;
v. 5 mm PALF with UF binder has higher acoustic performance compared to the bulk sample;
vi. The maximum SAC of PALF mixed with UF is 0.99 at 1600 Hz; and
vii. The performance of sound absorption shows that PALF specimens of 30 mm thickness with and without binder are greater than the fibreglass specimen.

It can be inferred that PALF poses vastly significant potential to be utilised as raw material for the production of acoustic absorber. Therefore, this may overcome the environmental problems that arise due to the production of synthetic acoustic absorber.

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