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Technical note

Oil palm empty fruit bunch fibres as sustainable acoustic absorber

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ABSTRACT

This paper discusses the utilisation of fibres from the oil palm empty fruit bunch (OPEFB) to be an alternative natural acoustic material. The study was carried out by fabricating samples from raw OPEFB fibres with different densities and thicknesses to observe their effects on the sound absorption performance. It has been demonstrated that the sound absorption performance can be improved by increasing the thickness of the sample and also by having optimum densities of fibres. In particular for lower frequencies, this can be achieved by introducing air cavity gap behind the fibre samples. Measurement of the normal incidence absorption coefficient in an impedance tube based on ISO 10534-2 found that the OPEFB fibres can have absorption coefficient of 0.9 on average above 1 kHz. The sound absorption performance of OPEFB fibres is also shown to be comparable to that of the commercial synthetic rock wools.

1. Introduction

1.1. Acoustic absorbers from natural materials

The acoustic absorber has been widely known for its applications for noise control in industries and especially for realising good acoustic quality in buildings. The acoustic absorbers in the market such as glass wool, stone wool and foam plastics are still mostly derived from synthetic materials. These substances not only cause pollution and global warming, but are also harmful to health [1]. Studies thus keep on progressing to find alternative substances from natural materials, which are 'green' to environment (biodegradable) and are also sustainable for future generation.

Numerous research works, particularly on natural fibres have been published, which present findings on the performance of the fibres as acoustic absorbers. These include bamboo fibres [2], tea-leaf-fibres [3], coir fibres [4], sugarcane fibres [5], paddy fibres [6], *Arenga Pinnata* fibres [7], orange tree pruning fibres [8], date palm fibres [9] and various vegetable fibres [10]. The fibres generally have a nature of good sound absorption coefficient at mid to high frequencies ($\alpha > 0.5$, above 1 kHz). Performance at lower frequencies can be improved by increasing the thickness of the panel or by introducing the air gap behind the panel. It has also been demonstrated that adding a fabric cover on the front surface of the panel improves the frequency bandwidth and the level of absorption [3,6].

Chemical treatments can be introduced to bind the fibres together (to maintain the shape and to increase structural stiffness), to enhance the fire retardant properties, to change the fibre from hydrophilic (attract to water) to hydrophobic (resist water absorption), to prevent or to slow down the formation of fungus and to prevent the attack from microorganism and insects. For the first case as highlighted by Wassilieff [11], the increase stiffness of the skeleton fibres due to the binder could shift the resonance to higher frequency and thus could lower the absorption performance at lower frequencies. The absorption coefficient of a 13 mm thick wood fibre sample treated with PVA adhesive was presented, but no comparison with the untreated fibres was discussed in the paper. However in another work, Fatima and Mohanty [12] showed that jute fibres treated with 1% and 3% alkali had no significant effect on the sound absorption performance compared with the untreated one. The effect was found with 2% alkali where the absorption coefficient is lower than that of the untreated fibres by 0.1–0.2 above 1 kHz. As suggested, the effect of chemical binder on sound absorption depends on the formation of porosity during the treatment and may also depend on the type of the binder.

Apart from fibrous type absorbers, works on foam-type absorbers utilising natural materials have also been presented. Yeon et al. [13] utilised cellulose from recycled papers to construct a foam absorber. The experimental results show that the absorber has noise reduction coefficient of 0.75. Foam absorber using extract of natural quebracho wood tannin and maritime pine bark tannin was presented by Lacoste et al. [14]. The measurement shows average absorption coefficient of 0.9 between 1 to 4 kHz.

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Asdrubali et al. [15] demonstrated that tropical plants used for the decorative purpose in the living buildings can also serve as good sound absorbers. Tropical plants, namely baby tears and fern shown to have average sound absorption coefficient of 0.9 from 900 to 1600 Hz. At low frequencies, the substrate soil is shown to be the main contributor for absorbing great amount of sound energy between 500 to 600 Hz.

Efforts on developing bio-based composites for acoustic absorbers as well as for thermal insulation materials in buildings have also been initiated. Among established works are flax-tows composite [16], sunflower's stalk-chitosan composite [17] and cellular poly matrix-ramie fabrics composites [18]. However the challenge with the nature of 'hard' structure of the composite materials is that the samples should have good porosity and tortuosity to effectively absorb the sound energy. High 'inner' porosity usually becomes difficult to develop, especially when compression process is involved in the composite fabrication. As presented by Mati-Baouche et al. [17] and Zhou et al. [18], the proposed composites were shown to have good thermal insulation, but had poor acoustic performance.

This paper discusses the potential of fibres originated from the oil palm empty fruit bunch to be the alternative, natural acoustic material. Conventionally, the oil palm empty fruit bunch (OPEFB) is mainly used as the burning fuel in boilers to supply electricity for the plantation mills. The fibres are also used for fertilisers, mulching material and reinforcement materials in polymer composites [19–21]. Until recently, early development of research has been done on oil palm fibre on its potential as thermal insulating material in construction of buildings [22]. As one of the agricultural by-products with abundant quantity, the OPEFB also causes environmental problem due to its disposal issues [19]. With the existence of technology to extract the fibres [21], it is therefore feasible to study the waste materials on its performance as green and sustainable sound absorber. According to the author's knowledge, the use of OPEFB fibres for acoustic materials has not been discussed by other researchers.

1.2. Oil palm empty fruit bunch fibres

The oil palm in Malaysia is from the species *Elaeis guineensis* Jacq. which originates from West Africa and was introduced in Malaysia in 1860s [19]. Palm oil has been well known to be one of the major commodities in Malaysia. Being the second largest producer in the world, palm oil plantation is vital to Malaysia's economy. According to Malaysian Palm Oil Board, the oil palm plantations in Malaysia have increased rapidly from 400 hectares planted in 1920 to five million hectares in 2011 [23]. The increasing demand for palm oil is due to the rapid population growth and economic development around the globe. In 2013, Indonesia and Malaysia were the two major palm oil producing countries in the world with the former produced approximately 31 million tonnes and the latter produced approximately 19.4 million tonnes [24]. The average amount of oil palm fruits produced worldwide from 1993 to 2013 were about 159 million tonnes, where more than 83% of the fruits were produced in Asia [25].

Fresh oil palm fruit bunch consists of 22–25% of empty fruit bunch [26]. In the production of palm oil, one hectare of plantation can produce 5.5 tonnes of oil, at the same time it also produces 55 tonnes of total dry fibrous biomass as by-product annually. Among the various dry fibrous biomass from oil palm tree, empty fruit bunch occupied up to 73% of fibres. The empty fruit bunch is the by-product of the steam sterilisation process where the oil palm fruits are separated from the fresh fruit bunches. The fibres can be obtained from the empty fruit bunch through retting process. The available retting processes to extract the fibres are mechanical retting or hammering, chemical retting, steam or vapour retting and water or microbial retting [21].

2. Preparation of the materials

2.1. Sample fabrication

We obtained the fibres from Malaysian Palm Oil Board where the fibres were extracted from the OPEFB through mechanical retting process. Under the steam sterilisation process to separate the fruits and the bunches using high pressure and high temperature, the fibres in the bunches become loose. After the bunches have been dried, extraction of the fibres can be conveniently made through the shredding process using a shredder machine. The fibres can be categorized as hard fibres with diameter ranging from around 70 to 500 μm as shown in Fig. 1.

Samples of sound absorbers from the fibres were prepared so that they can be fitted into an impedance tube for absorption coefficient measurement. The OPEFB fibres were weighted from 1 g to 7 g. The raw fibres were then fitted into an aluminium mould with diameter of 33 mm, the same as the diameter of the impedance tube in the experiment. By using hot compression moulding, the OPEFB fibres with different weight were compressed under temperature of 100 °C and 5 min of compression time into samples with thicknesses of 10 mm and 20 mm. Examples of the samples are shown in Fig. 2. In this paper, the measured sound absorption coefficient of the OPEFB fibre samples were defined through its bulk density and thickness. The bulk density of the sample is defined as the ratio of mass of the fibre m, over the total volume of the cylindrical shape of the sample V given by $\rho_{bulk} = m/V$. Table 1 lists the OPEFB fibre samples with the corresponding mass, thickness and the calculated bulk density.

2.2. Experimental setup

The measurement of sound absorption coefficient was conducted by using the impedance tube following the ISO 10534-2 [27]. The measurement setup is shown in Fig. 3. The sample was fitted into the tube (as shown in Fig. 4) and was located at one end of the tube. At the other end of the tube is a loudspeaker producing white noise signal fed into the tube. Two 1/2″ pre-polarised free field microphones (GRAS 40AE) with 1/2″ CCP pre-amplifier (GRAS 26CA) recorded the built-up sound pressure inside the tube. The sensitivity of microphones was calibrated by using Brüel & Kjær sound calibrator type 4231 at 114 dB level and 1 kHz. RT Pro Photon + analyser was used as the data acquisition system to process the recorded signals and to obtain the transfer function between the two microphones. MATLAB software was then used to calculate the absorption coefficient.

For the tube diameter of 33 mm, the results are valid between frequencies of 500 Hz to 4.5 kHz. In this paper, frequencies from 500 Hz to 2 kHz are denoted as mid frequency range, while frequencies from 2 to 4.5 kHz are denoted as high frequency region.

The experimental work was conducted to study the effect of fibre density or total mass of fibres, thickness of the sample and introduction of air gap behind the sample on the performance of sound absorption. Measurement was performed three times for each sample. For each test, the sample was taken out from the tube and then inserted back into the sample holder. This is to ensure that no errors due to installation of the sample in tube was presented, for example the sample might have small air gap between its side surface and the inner surface of the tube, the rigid plunger might not be attached properly to the back of the sample (rigid backing), or the air cavity distance behind the sample was not spaced accurately.