Sound absorption characteristics of the natural fibrous material from coconut coir, oil palm fruit bunches, and pineapple leaf

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Abstract. In this paper sound absorption characteristics of three kinds of natural fiber composite is evaluated. The fibers are made from coconut coir, oil palm fiber from empty fruit bunches, and pineapple leaf. The sound absorption coefficient is evaluated using a specimen thickness of 10 mm and 20 mm and two variants of fiber density. A simple impedance tube with two microphones is used in the measurement. The sound absorption coefficient is calculated by the transfer function of the two microphones within 200 Hz to 3000 Hz frequency range. It is revealed that three types of fibers can reduce reflected sound in relatively higher frequency. Denser and thicker of a fibrous material increases the sound absorption of the material and shifts the peak of the absorption coefficient into a lower frequency. Furthermore, pineapple leaf fiber has the highest sound absorption coefficient among others type of fibers. Smaller and uniform fiber diameter has a significant role to absorb sound energy in pineapple fiber. Whereas, coconut coir and palm empty fruit bunches fiber have larger, various and random fiber diameters, that could make the sound absorption coefficient become lower, especially within the frequency range of measurement.

1. Introduction
Material development in acoustic engineering has an important role in many applications like room acoustics control, industrial noise control, studio acoustics, and automotive noise control. Sound absorptive materials are commonly applied to reduce the unpleasant effects of noise reflection by hard and rigid interior surfaces and to help to decrease the reverberant noise levels. Some factors are influencing sound absorption ability of an acoustical material, i.e., fiber size, airflow resistance, porosity, tortuosity, thickness, density, compression, surface impedance and position of a fibrous material [1, 2].

Due to technology development and public awareness about noise in daily life, the use of a variety of sound-absorbing materials has increased significantly. Acoustical engineers and architect nowadays have wide alternatives of sound absorptive materials that not only related to the acoustical properties, but also offer a wider variety of colors, shapes, sizes, light reflectivity, and methods of attachment. A sound absorptive material absorbs most of the sound energy hitting them and reflects less part. It has been found to be very useful for controlling noise. A wide range of sound absorptive materials is available. The absorption properties depend on frequency, composition, surface, thickness, and mounting method. However, porous materials are generally found having a high sound absorption coefficient [2].
Porous absorbing materials can be classified into cellular, fibrous, or granular; that is based on their microscopic configurations. Fibrous porous materials like rock wool, glass wool, polyurethane and polyester are commonly found in practice. Moreover, mineral and polymer have been broadly applied for the reduction of noise. It has satisfied characteristics include its good viscoelasticity, simple processing, and commercial availability. However, because they are made from high-temperature extrusion and industrial processes based on synthetic chemicals, their carbon footprints are quite significant. The production process and application of some of these materials contribute to a negative impact on the environment and human health [3, 4].

Therefore, some researchers tried to develop alternative sound absorber from used materials, such as composite absorber by reused rubber particle [5], cellulose from recycled paper [6], granulates from tires [7], and the use of cigarette filter [8]. The recycled materials have good possibilities to be developed as sound absorber material.

Nowadays, the application of natural fibers as sound absorbing materials then has been attracted researcher attention. Natural fibers are completely biodegradable and modern technical developments can make its processing more economical and environmentally friendly. Some natural fibers that has good potency to be developed as sound absorbing material are kenaf, wood, hemp, cork, cane, cardboard, and sheep wool [9], extracted pineapple-leaf fibres [10], Arenga Pinata fiber [11], and combination of coconut coir fiber and rice husk grain [12]. These researches are conducted using its original natural fiber. Some researchers tried to develop fiber-reinforced composites to improve the mechanical properties and moisture disadvantages of the natural fibers [13-15].

Coconut coir fiber, oil palm fiber from empty fruit bunches, and pineapple leaf fiber are some of the natural fibers that abundantly available in Indonesia. Coconut coir fiber and pineapple leaf fiber are widely used for many applications traditionally made textile, rope and any home accessories, especially in Indonesia. Oil palm fiber also has a high opportunity to be developed commercially because it’s some advantages mechanical properties [16]. To increase the use and commercial value of these fibers, the research of it uses for interior sound absorber material is needed to be done.

In this paper, sound absorption characteristics of natural fiber that glued by paper glue to harden the fiber panel will be observed. The fiber is made from coconut coir fiber, oil palm fiber from empty fruit bunches, and pineapple leaf fiber. The sound absorption coefficient is evaluated in various thickness and fiber density. A simple impedance tube with two microphones is designed and used in the measurement. The sound absorption coefficient of the specimens is calculated from the transfer function of both microphones.

2. Measurement method
2.1. Material preparation
The natural fibrous materials that used in this study are coconut coir fiber, oil palm fiber from empty fruit bunches, and pineapple leaf fiber. The coconut coir fiber and oil palm fiber, firstly, are cleaned and spray with water, and let it dried in room temperature. On the other hand, the pineapple leaf fiber is bought from a commercial market. The samples are designed with variation in bulk density and thickness in cylindrical shape 54 mm diameter according to impedance tube size. A short PVC pipe is used as a die.

Thin layer by layer of fiber is added into the dies, and brush between the layers dab a thin paper glue. The specimen then is compressed by different force to obtain lower and higher density of specimens in 10 mm and 20 mm thickness. Then, let the glue dry in room temperature. Table 1 shows the average density of the specimens and Figure 1 shows the three specimens with 20 mm thickness. Pineapple leaf fiber specimen has a higher density compared to the other ones.
Table 1. The average density of specimens

| Fiber materials      | Lower density (gr/cm³) | Higher density (gr/cm³) |
|----------------------|------------------------|-------------------------|
| Coconut coir         | 0.1324                 | 0.1978                  |
| Palm empty fruit bunches | 0.1639               | 0.2328                  |
| Pineapple leaf       | 0.3279                 | 0.4983                  |

Figure 1. Fiber specimen 20 mm thickness; coconut coir fiber (left), palm empty fruit bunches fiber (middle), and pineapple leaf fiber (right)

2.2. Experimental setup

The impedance tube made of aluminum pipe with 54 mm inner diameter is used to cover measurements within the frequency range from 200 Hz to 3000 Hz. The impedance tube is design based on ASTM E 1050. Chirp sound with frequency range 100 Hz to 10 kHz generated from computers is used for a sound source in the experiment. Two microphones of BSWA MPA 215 with 51.2 Pa/mV and 43.7 Pa/mV of sensitivity factors are used to measure the sound pressure in two channels. Measured signals from microphones then are amplified by signal conditioner and then is connected to a multifunction National Instrument data acquisition card. The signal is collected and processed by Labview software.

Firstly, the impedance tube is calibrated using Rockwool 45 with a density of 45 kg/m³ and 40 mm thickness. The sound absorption coefficient is calculated using the transfer function generated from two microphones. The experimental set-up is illustrated in Figure 2.

Figure 2. Impedance tube set up
3. Result and discussion
The sound absorption coefficient of the coconut coir fiber in various densities and thickness is depicted in Figure 3. Generally, it is observed that sound absorption ability is not more than 0.5 up to 1500 Hz and rising gradually in higher frequency. Material density gives a more dominant effect to the absorption coefficient than the thickness of the specimen. Higher density and higher thickness increase the absorption coefficient. More fibers make more energy of acoustical pressure trapped within the material. Material with 20 mm thickness and 0.1978 gr/cm$^3$ density can absorb the sound, maximum 90% at frequency 3000 Hz, and possibly still increases at a higher frequency. Also, other specimens also have possibility higher sound absorption at a frequency more than 3000 Hz. It also shows that the compression of fibrous materials decreases the sound absorption properties. Under compression, the various fibers in the material are brought nearer to each other without any deformation or any change in fiber size [1].

Similar phenomena also can be observed in oil palm empty fruit bunches fiber as shown in Figure 4. The higher absorption coefficient belongs to the specimen with higher density 0.2328 gr/cm$^3$ and 20 mm thickness. Almost a perfect absorption occurs at a frequency about 2225 Hz and then decreases at a higher frequency. Other specimens still show a tendency to increase and have a peak characteristic at a higher frequency.

![Figure 3. Coconut coir fiber sound absorption coefficient.](image)

![Figure 4. Palm empty fruit bunches fiber sound absorption coefficient.](image)
Moreover, the sound absorption characteristic of pineapple leaf fiber is shown in Figure 5. It is seen that in general sound absorption ability of this fiber is better than others, especially at a lower frequency. Specimen with 20 mm thickness and 0.3279 gr/cm$^3$ density has maximum absorption almost 100% at frequency 2500 Hz. Other specimens still show a tendency to increase and have a peak characteristic in higher frequency. An anomaly occurred in 20 mm thickness and 0.4983 gr/cm$^3$ density, where the absorption coefficient higher at a lower frequency and tend to be flat at a higher frequency. This phenomenon is possibly caused by the high density of glue that used in the specimen.

Furthermore, comparison of absorption capacity between three types of fibrous material with 10 mm thickness and higher density is shown in Figure 6. It is shown that pineapple leaf has the highest capacity for sound absorption among other types of fiber. Also, oil palm fibers are better than coconut coir fiber at a higher frequency.

![Figure 5. Pineapple leaf fiber sound absorption coefficient.](image)

![Figure 6. The sound absorption coefficient of three type of fibers](image)

Then, the size of the fiber is depicted in Figure 7. It is shown that coconut coir fiber has various and random fiber diameters and tends to have an empty volume that makes its density lower than others.
The oil palm fiber has more uniform and bigger diameters and also has empty volume and low density too. On the other hand, pineapple leaf fiber has a a uniform and high density. This diameter and density of fiber will affect the ability of the fiber to absorb the acoustic wave that hit its surface. One of the important parameters influencing the sound absorbing characteristics of the fibrous material is the specific flow resistance per unit thickness of the material. The characteristic impedance and propagation constant, which describes the acoustical properties of porous materials, are governed to a great extent by the flow resistance of the material.

![Figure 7. Three natural fibers under the microscope; coconut coir (left), palm empty fruit bunches (middle), and pineapple leaf (right).](image)

It is also confirmed that the coefficient of sound absorption increases by reducing in fiber diameter, because fibers have a small diameter, it can move more easily than the big one on sound waves. Furthermore, the fine and dense fiber content will increase sound absorption coefficient values by increasing airflow resistance by the friction of viscosity through the vibration of the air [1].

4. Conclusion
Measurement and analysis of the sound absorption coefficient of coconut coir fiber, oil palm fiber from empty fruit bunches, and pineapple leaf fiber have been done. From the discussion, some conclusion can be made as below:
1. The pineapple leaf fiber has the highest sound absorption coefficient among the three types of fibers. Smaller and uniform fiber diameter has a significant role to absorb sound energy in this fibrous material. On the other hand, coconut coir and palm empty fruit bunches fiber have larger, various, and random fiber diameters, that could make the sound absorption coefficient become lower, especially within the frequency range of measurement.
2. Denser and thicker of a fibrous material increases the sound absorption of the material and shifts the frequency peaks into the lower frequency.

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