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Effect of perforated aluminum on *Calotropis gigantea* fiber material's ability to absorption sound

Suhaeri[1,2], Husaini[2*], Muhammad Dirhamsyah[2], Iskandar Hasanuddin[2]

[1]Doctoral Program, School of Engineering, Post Graduate Program, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia

[2]Department of Mechanical Engineering, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia

*Corresponding author: husainiftm@unsyiah.ac.id

Abstract

Plants fibers such as *Calotropis gigantea* (CG) are very suitable as noise reduction material. Therefore, this research aims to determine the sound absorption coefficient of CG in the 20 mm test sample and the effect of the perforated aluminum layer on its ability. It was carried out using a test sample made with a thickness of 20 mm and 100 mm in diameter. The thickness of aluminum was 0.3 mm with hole diameters of 1 mm, 1.5 mm, and 2.5 mm. During the experiment, every sample was heated and pressed in a mold for 10 minutes at 200°C. The test equipment used is a Bruel & Kjaer Type 4206 impedance tube with 100 mm in diameter. The sample was tested using the transfer function method ISO 10534-2:1998 at a frequency of 1/1 octave. The results indicated that the uncoated sample absorbed noise α = 0.01-0.07 (1-7)% higher than the sample coated with perforated aluminum. This showed that the Noise Reduction Coefficient (NRC) without aluminum coating can reduce noise by 29%, and the measured sample is categorized in class D.

Keywords:

Calotropis gigantea fiber, perforated aluminum, sound absorption coefficient, impedance tube noise reduction coefficient.

1 Introduction

Noise has a bad impact on the surrounding environment and human health, which leads to temporary or permanent hearing loss, stress, mental illness, cardiovascular disease, sleep disorders, and others [1]. High noise levels are usually controlled using suitable sound control materials such as acoustic materials [2]. This can be achieved in three ways, namely changes to the source of noise and vibration. The secondary method includes modifications along the sound propagation path and the tertiary approach handles the sound receiver [1]. In industrial noise, acoustic materials absorb or muffle the sound to a safe limit [3]. To solve this serious problem, various sound-absorbing materials have been developed. Significant achievements have also been made in the development of porous materials and perforated plates. These porous materials are made of organic (plastics and rubber) and inorganic materials (metals and minerals) [4], which are used for high-frequency noise control. As an acoustic structure, perforated plates show excellent ability for low and medium frequency noise control [5].

A lot of fiber is obtained from various parts of the plant including leaves, stems (bark fiber), fruit, and seeds. Fruits and seeds fibers are only a few centimeters long, while those from stems and leaves are longer. The fibers produced in the seeds of various plants are called seed hairs or fibers, which include cotton fiber, threads from milkweed, dandelion, and thistle [6]. Several studies reported that *Calotropis gigantean* fiber, hereinafter abbreviated as CG, has been used as an alternative material for reinforcing composites due to its thermal properties [7][8][9] and low density (weight per unit volume). The hollow space along the fiber serves as a medium for trapping air or water vapor, therefore, it has potential as a thermal insulator and sound absorber [10][11]. Therefore, this research aims to determine the sound absorption value of the 20 mm thick test sample and the effect of perforated aluminum coating on the ability of CG fiber.

CG gummy plants are white resembling milk that comes out of the stems, leaves, and fruit. The sap is beneficial for health and used as herbal medicine for dizziness, asthma, bronchitis, dyspepsia, leprosy, tumors, and various digestive disorders [10]. Also, it was reported that the CG fiber has a diameter of the fiber was between 15 μm to 26 μm, its wall of thickness 0.8 μm to 2 μm, and hollow volume 92.3% to 94.7%, respectively. As seen in Fig. 2b, each seed has around 600 fiber strands.

Furthermore, for many years in India, Indonesia, and other ASEAN countries, it has been used as traditional medicine [11]. A previous report also stated that CG plant fiber is durable and can be used for ropes, carpets, fishing nets, and sewing thread.

2 Research Methods

2.1 Material

Sound-absorbing materials can absorb sound waves by reducing the energy of the waves that pass through them. These materials must be resistant to sound pressure and be fibrous or porous material. Due to their porous structure, they can absorb high-frequency sound waves.

The materials from CG seed fibers around Banda Aceh and Aceh Besar were used in this research. CG in the local language (Aceh) is called *rubek*, and generally, in Indonesia, it is known as the *widuri/biduri* plant. This fiber is almost like cotton and kapok fiber, which is usually obtained from fruit (Fig. 1).

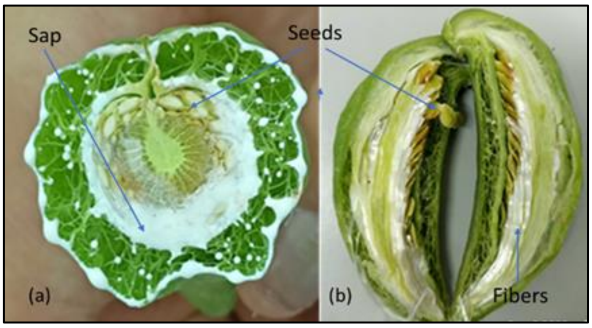


Fig. 1. CG fruit (a) cross-section (b) long section.

To get clean and dry fiber, freshly harvested CG fruit was dried in the sun until it was split, and the seed fiber was separated from the skin manually. CG fiber as shown in Fig. 2c was used as a sample to test the ability of the Sound Absorption Coefficient (SAC).

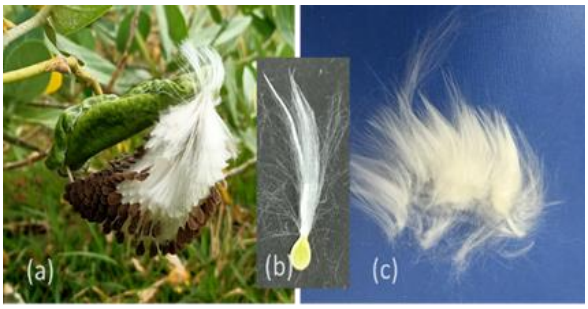


Fig. 2. (a) fiber in CG fruit, (b) CG seed fiber, (c) CG fiber.

2.2 Test Object

The preparation of the sample was carried out as shown in Table 1, namely the fiber weight of 50 grams, and the thickness of 20 mm, followed by the SAC test. This was conducted to determine the effect of holes on the surface of the sample in front of an aluminum sheet with a thickness of 0.3 mm, which is perforated with diameters of 1.0 mm, 1.5 mm, and 2.5 mm.

Table 1. Testing of the sound absorption capability of CG specimen

Weight (gr)	Thick (mm)	Perforated aluminum sheet (mm)
50	20	0
50	20	1.0
50	20	1.5
50	20	2.5

2.3 Research Tool

The weight of the sample is 50 grams, with a print diameter of 100 mm, according to the diameter of the impedance tube used. Next, 50 grams of CG fiber is put into the mold and hot pressed for 10 minutes, then the test sample is turned over and pressed again with a pressing temperature of 200ºC. To form the test specimens, a mold, and a Wabash G150H hot press machine were used as shown in Fig. 3.

a b

Fig. 3. (a) Hot press machine, (b) mold.

The sample to be tested for SAC is shown in Fig. 4.

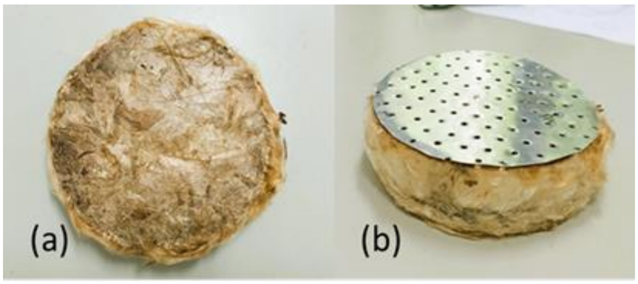


Fig. 4. (a) 20 mm test sample, (b) test sample with perforated aluminum.

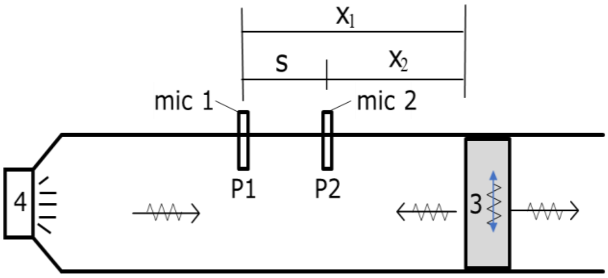
2.4 Sound Test Tool

SAC testing was carried out in the Anechoic chamber of the Acoustic Laboratory, Faculty of Engineering, Syiah Kuala University, Darussalam, Banda Aceh. The test equipment used was the Bruel & Kjaer type 4206 impendent tube with a diameter of 100 mm as shown in Fig. 5.

Fig. 5. Impendence tube B & K 4206.

The sample was inserted into the impedance tube and must not have an extremely small gap between the sample and the cell wall of the impedance tube. The loudspeaker as a white noise signal generator in a closed tube was mounted to the end of the impedance tube.

The loudspeaker generates broadband, stationary random sound waves that propagate through the tube as plane waves, hit the sample, and are reflected. The amount of sound pressure (amplitude) on microphone 1 and microphone 2 can be measured, see Fig. 6.



Legend :

Micrpphone 1, Microphone 2, 3.Test specimen, 4.Loudspeaker

Fig. 6. The distance of two microphones to the test CG specimen.

The test method uses ISO 105432-2 transfer function method [1][3][13]. The method transfer function between the two microphones x^1 and x^2 can be obtained by using Eq. 1 [13].

$$H_{12} = \frac{P_2}{P_1} = \frac{e^{jkx_2} + Re^{-jkx_2}}{e^{jkx_1} + e^{-jkx_1}} \quad (1)$$

The sound reflection factor R can be determined by using Eq. 1 and Eq. 2.

$$R = \frac{H_{12} - H_1}{H_R - H_{12}} e^{2jkx_1} \quad (2)$$

$$R = \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} e^{2jkx_1} \quad (3)$$

Therefore, the absorption coefficient can be determined by using Eq. 4 [14][15][16][17].

$$\alpha = 1 - |R|^2 \quad (4)$$

H_{12} = transfer function between two microphones
H_R = e^{jks}
H_1 = e^{-jks}
R = reflection coefficient
α = absorption coefficient
P_1 = P_2 is amplitude (sound pressures) of incident and reflected wave (volt).

The impedance tube research equipment setting is carried out as shown in Fig. 7 to perform SAC data retrieval on the test sample. The test was conducted at frequencies 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 7000 Hz, and 8000 Hz, and the SAC value was tested to get the Noise Reduction Coefficient (NRC) and sound absorption classes [13].

To calculate SAC, it is necessary to measure the amplitude value of the incoming wave generated by the loudspeaker at a certain frequency on microphone 1 (P1). Furthermore, microphone 2 records the reflected wave from the test sample, and the values obtained were used by the Matlab program to calculate the SAC value of the CG sample [18][19][20].

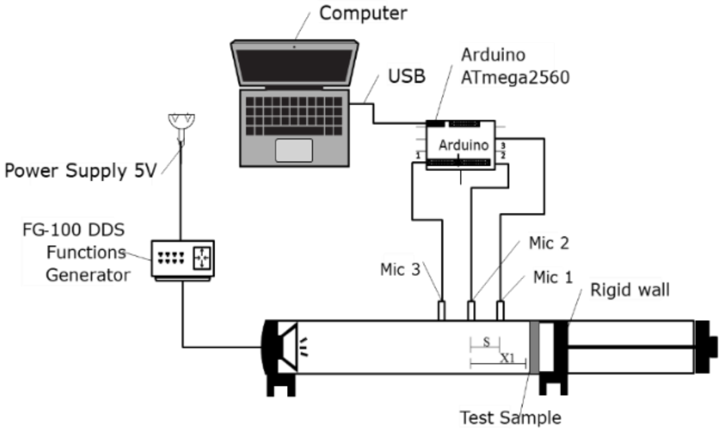


Fig. 7. The configuration of experiment for testing sound absorption capacity of G specimen.

The Noise Reduction Coefficient (NRC) is defined as the arithmetic mean of the sound absorption coefficients at 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz was used to make easy visual comparisons between different samples [13][17]. Subsequently, NRC was calculated by using Eq. 5 [21].

$$NRC = (\alpha\ 250 + \alpha\ 500 + \alpha\ 1000 + \alpha\ 2000)/4 \quad (5)$$

Based on the absorption coefficient value of the tested CG material, the sample is classified into several classes as stated in Table 2, which include A, B, C, D, and E until not classified [22][23][24]. The determination of the sound absorption classes is carried out by calculating the average Sound Coefficient Values (SAC) according to Tables 3 and Table 2 to determine the sound absorption class.

Table 2. Sound absorption classes (ISO 11654, 1997) [23][20]

Sound absorption class	Absorption coefficient (α)
A	0.90; 0.95; 1.00
B	0.80; 0.85
C	0.60; 0.65; 0.70; 0.75
D	0.30; 0.35; 0.40; 0.45; 0.50; 0.55
E	0.25; 0.20; 0.15; 0.10, 0.05
Not classified	

3 Results and Discussion

3.1 Sound Absorption Coefficient (SAC)

The results of the sound pressure amplitude data at P1 and P2 are calculated using the Matlab program and the Sound Absorption Coefficient (SAC) is shown in Table 3.

Table 3. SAC of CG fibers for difference frequency

Frequency (Hz)	Perforated aluminium plate			
	Without aluminum plate	1 mm	1.5 mm	2.5 mm
125	0.48	0.40	0.42	0.35
250	0.22	0.30	0.15	0.08
500	0.26	0.19	0.19	0.19
1000	0.30	0.24	0.22	0.19
2000	0.38	0.31	0.30	0.28
4000	0.47	0.45	0.42	0.34
7000	0.77	0.76	0.72	0.70
8000	0.48	0.41	0.40	0.36

The Fig. 8, the graph showed that at a low frequency of 125 Hz for all test samples, the average value of α = 0.4125 is achieved. The SAC value decreased at a frequency of 250 Hz, and the sound absorption ability increased by an average of α = 0.7375 at a frequency of 7000 Hz but decreased at 8000 Hz.

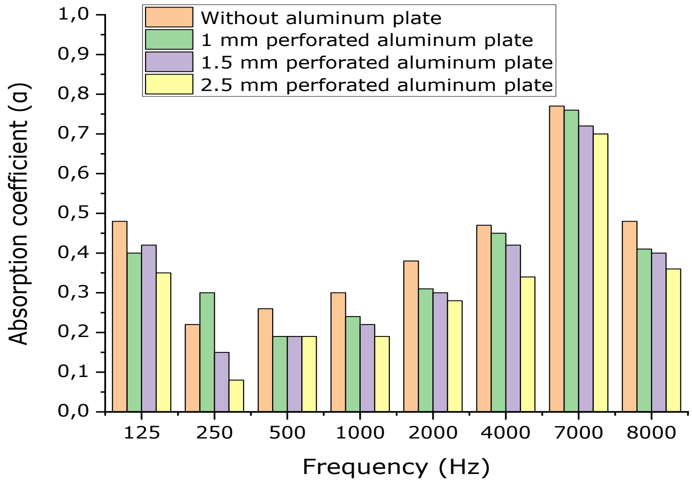


Fig. 8. SAC of different frequency.

The test sample without perforated aluminum layer obtained SAC that reached α = 0.77, followed by α = 0.76, α = 0.72, α = 0.7 for diameters 1 mm, 1.5 mm, and 2.5 mm, respectively. It was discovered that the diameter affects the value of SAC. Meanwhile, the sample coated with perforated aluminum reduces the ability of the sound absorption coefficient by an average of α = 0.01-0.07 (1-7) %. This is because the incoming sound is reflected more than absorbed by the test sample.

3.2 Noise Reduction Coefficient (NRC)

To determine the value of the Noise Reduction Coefficient (NRC), Eq. 5 was used with the SAC data in Table 3. This is the arithmetic mean of the SAC values at the frequencies 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz, as shown in Eq. 5. The calculation results are shown in Fig. 9.

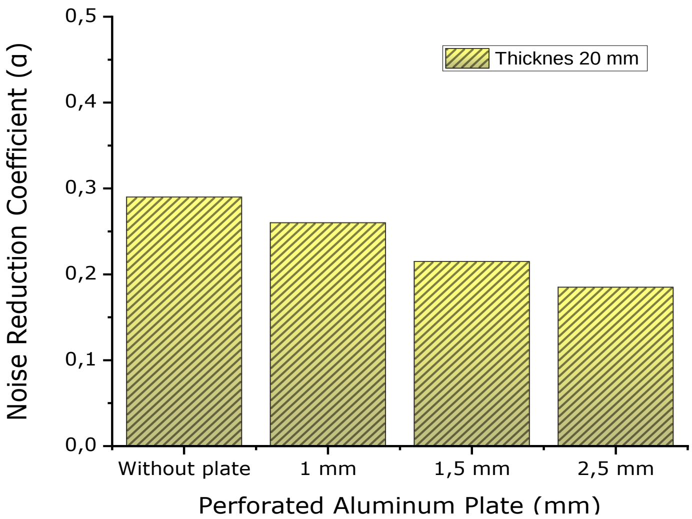


Fig. 9. NRC values for different hole diameters.

The result of the NRC calculation with a thickness of 20 mm is α = 0.29 for CG fiber without coating as shown in Fig. 9. This indicated that the material can reduce noise by 29%. Furthermore, the NRC of the sample coated with aluminum with hole diameters 1 mm, 1.5 mm, and 2.5 mm was α 0.26, 0.215, and 0.1875 or 26, 21.5, and 18.75%.

The determination of sound absorption classes is α = 0.42 for samples without coating, while for those treated with aluminum coating with hole diameters 1 mm, 1.5 mm, and 2.5 mm are α = 0.3825, 0.3525, and 0.3112, respectively. Based on Table 2, the material is included in class D, therefore, CG fiber can be used as a sound-dampening material.

4 Conclusion

The test sample without coating is more capable of absorbing sound than the sample coated with perforated aluminum about α = 0.01-0.07(1-7)%. This is because the incoming sound is more reflected than absorbed by the test sample.

CG fiber has been shown to have moderate sound absorption performance with SAC value α = 0.48 at 125 Hz and α = 0.77 at 7000 Hz. Furthermore, the Noise Reduction Coefficient (NRC) in *Calotropis gigantea* fiber reached α = 0.29 (29%) in its ability to reduce noise.

The test samples without coating and with perforated coating are included in the class D category, which showed that the CG fiber can be used as a sound-dampening material.

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