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Effect of Scirpus grossus fiber density on acoustic absorp-tion characteristics for insulation use

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Abstract

Noise control is essential for achieving comfortable living and working environments. Natural fibers such as Scirpus grossus offer a sustainable approach for sound absorption applications. This study investigates the effect of varying fiber densities of Scirpus grossus on sound absorption performance. Test specimens were fabricated at three density levels: 636.9 kg/³, 318.5 kg/m³, and 212.3 kg/m³. Each had a fixed mass of 50 grams, a diameter of 100 mm, and varying thicknesses of 10 mm, 20 mm, and 30 mm. The samples were hot-pressed at 200°C for 10 minutes. Sound absorption coefficients (SACs) were measured using a Brüel & Kjær Impedance Tube Type 4206, following the transfer function method (ISO 10534-2:1998) over third-octave bands. The results show that fiber density significantly affects the Sound Absorption Coefficient (SAC). A decrease in density to 212.3 kg/m³ led to a SAC increase of 0.12 points (approximately 20% relative to the initial SAC value of 0.5428 at 636.9 kg/m³), particularly at 4000 Hz. This indicates that lower-density samples exhibit better acoustic absorption behavior. The average Noise Reduction Coefficient (NRC) across all samples was around 45%, confirming their effectiveness in sound control. Based on SAC values, the samples are classified as Sound Absorption Class D. These findings suggest that Scirpus grossus fiber mats have strong potential for eco-friendly acoustic insulation materials, suitable for applications in building panels or vehicle interiors.

Keywords:
Scirpus grossus, fiber density, natural acoustic materials, sound absorption

1 Introduction

Indonesia, as a tropical agrarian country, possesses abundant potential for utilizing natural fibers sourced from wild plants commonly categorized as weeds. These fibers have been traditionally used in products such as yarn, ropes, and composite reinforcements. Recently, natural fibers have gained attention as environmentally friendly soundproofing materials [1].

Environmental noise has been increasingly linked to negative health effects. According to the World Health Organization (WHO), noise pollution contributes to annoyance, sleep disturbances, and cardiovascular disorders, including heart attacks [2][4][6]. Continuous noise exposure may also disrupt physiological and psychological well-being [7]. Common sources of noise include industrial machinery, power generators, and public environments, highlighting the need for effective sound-absorbing materials that perform across diverse frequency ranges.

To mitigate these negative effects, the use of sound absorbers, whether natural or synthetic, is critical. While synthetic materials are often efficient, they pose environmental risks when disposed of improperly. In contrast, natural fibers are biodegradable, non-toxic, renewable, and lightweight, offering a sustainable alternative for acoustic insulation [1][8].

Scirpus grossus (L.F.) (commonly known as giant bulrush or mensiang in Indonesia) is a fibrous wetland plant native to Southeast Asia, including Indonesia, Malaysia, Thailand, and India [9][10][11]. It features triangular, non-hollow stems, typically measuring 147–157 cm in length with diameters ranging from 0.8 to 1.2 cm [17]. Traditionally, local artisans have used their stems for weaving mats and bags. Several studies have investigated its mechanical properties in composites, especially its performance when mixed with polyester resin or combined with coconut fibers [12]-[16].

Despite these applications, the potential of Scirpus grossus as a sound-absorbing material remains largely unexplored. Previous studies have focused on its mechanical behavior but not on its acoustic performance. This research addresses that gap by evaluating how variations in the fiber's mass density influence its sound absorption characteristics. The novelty of this study lies in the application of Scirpus grossus in acoustic insulation, an area not yet studied in depth.

2 Research methods

2.1 Research material

The research focused on using the main raw material from the Scirpus grossus plant with a triangular cross-sectional stem profile, as shown in Fig. 1.

Fig. 1. Scirpus grossus plant

The experiment was carried out by obtaining the stems of the Scirpus grossus plant from the rice field areas around the Lambaro district in Aceh Besar. These stems were flattened using a double plastic hammer to remove the skin and obtain the fibers, followed by a combination of a steel brush to separate the fibers from the remaining bark. Subsequently, the separated fibers were washed and completely dried indoors, as shown in Fig. 2.

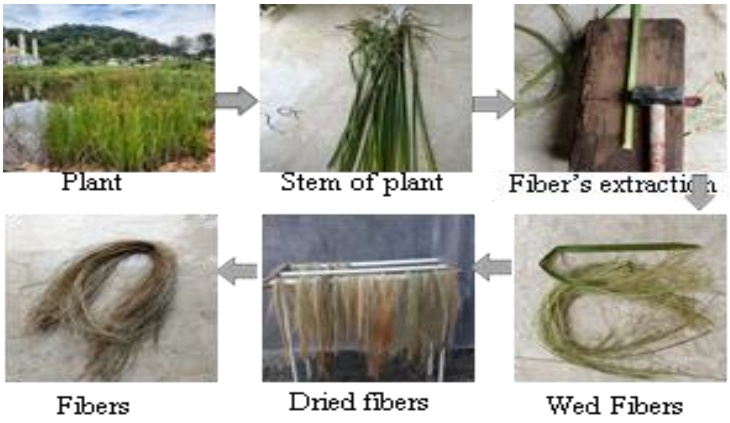

Fig. 2. Process of making Scirpus grossus fiber

After drying, the fibers were treated by soaking in a 5% NaOH chemical solution for 2 hours, followed by heating to a temperature of 70°C for 4 hours [12]. This chemical treatment was carried out to enhance the fibers' strength and ensure cleanliness.

2.2 Research parameter

The parameters employed in evaluating the sound-absorbing properties of the test specimens are summarized in Table 1. The density was determined using the equation $\rho = m/v$, where ρ represents density (kg/m³), m denotes the mass of the fiber (kg), and V indicates the volume of the specimen (m³), calculated as $0.25\pi D^2 t$. In this equation, D represents specimen diameter (m), and t denotes the thickness of the test specimens (m) [4][18]-[20].

Table 1. Parameters of the test specimens of Scirpus grossus fibers

Fibers	Thickness of Sample (mm)	Density, (ρ) kg/m^3
Scirpus grossus (SG)	10	636.9
	20	318.5
	30	212.3

2.3 Specimen formation

The dried Scirpus grossus fibers were sorted, cut into approximately 50 mm lengths, and weighed with a weight of 50 grams for each test specimen at thicknesses of 10 mm, 20 mm, and 30 mm, respectively. Specimen thickness and fiber weights were varied to achieve different densities, as shown in Table 1. Therefore, the samples can investigate the influence of density on sound absorption characteristics. Subsequently, the fibers were randomly placed into a metal mold with a diameter of 100 mm and pressed, as shown in Fig. 3. The pressing of the test specimens was carried out using the Stramit process through a Wabash G150H hot press machine at a temperature of 200°C [19][21] for 10 minutes. To ensure uniform adhesion on both sides, the samples were flipped and pressed until the desired thickness was achieved. The raw fiber material compressed between two hot plates was subjected to hydrothermal treatment, resulting in the release of lignin of 8-17%, hemicellulose of 28-33%, and cellulose of 33-42% [19]. Furthermore, stoppers were placed between the two surfaces of the hot plates to obtain the desired thickness according to the design, as shown in Fig. 3.

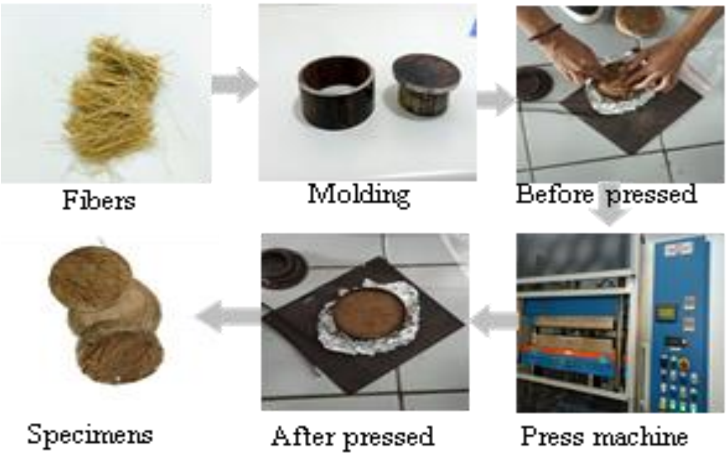

Fig. 3. Process of making test specimens from Scirpus grossus fibers

2.4 Research tools

A mold and a Wabash G150H hot press machine are used to form the test specimen, along with a Bruel & Kjaer Type 4206 impedance tube, a scale with 1-gram precision, and other supporting tools. The hot press machine, as shown in Fig. 4a, was used to compress the test specimens to the desired thickness limit in molds with a diameter of 100 mm, adjusted to match the diameter of the impedance tube [21].

(a) (b)

Fig. 4. (a) Wabash G150H hot press, and (b) Mold

2.5 Impendent tube

The impedance tube method is applied in this research to measure the Sound Absorption Coefficient (SAC) of materials. This equipment is located in the acoustic laboratory of the Faculty of Engineering, Universitas Syiah Kuala, as shown in Fig. 5.

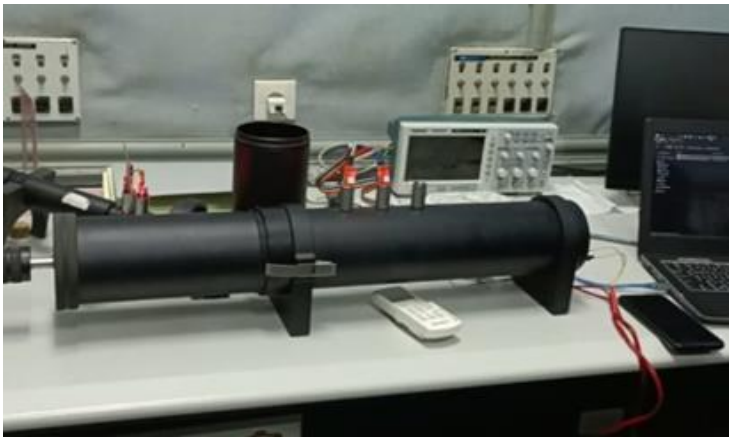

Fig. 5. Impedance tube Bruel & Kjaer type 4206

2.6 Experiment setup

The equipment settings for the impedance tube research are adjusted to conduct measurements and obtain data on the SAC of the test specimens, as depicted in Fig. 6. The testing was carried out across the frequency range of 125 Hz to 4000 Hz.

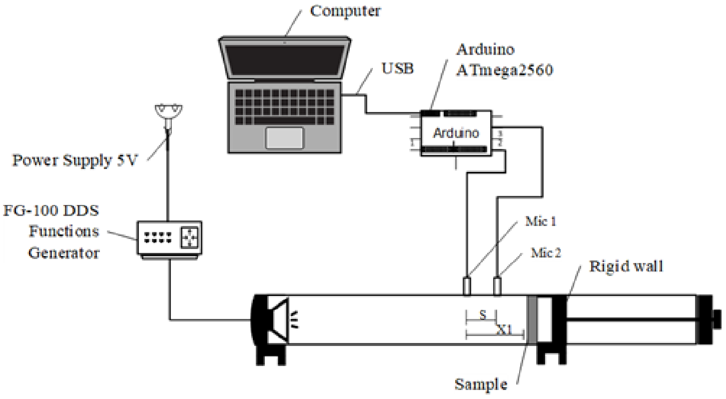

Fig. 6. Experimental set-up

2.7 Sample testing

The impedance tube method with the transfer function technique (ISO 10534-2) [22] was used to determine the absorption coefficient (α) capability of the test specimens. Specifically, this research used a Bruel & Kjaer Type 4206 impedance tube with a tube diameter of 100 mm. The testing was conducted across the frequency range of 1/1 octave (125, 250, 500, 1000, 2000, 4000) Hz. Initially, test specimens were inserted into the impedance tube without gaps in the inner walls. This was followed by the activation of the loudspeaker to generate white noise signals within the tube, which interacted with the test specimens, resulting in reflection, absorption, and transmission [23][24].

The amplitude values (in volts) were measured for the incoming waves generated by the loudspeaker at specific frequencies at microphone 1 (P1) to determine SAC. Subsequently, microphone 2 (P2) was used to record the reflected waves from the test specimens, and the recordings were captured by a computer at each frequency. Based on the equation, x1 denotes the distance between P1 and the test specimen, x2 represents the distance between P2 and the test specimen, and s is the distance between P1 and P2, or s = x1 - x2, as shown in Fig. 7. MATLAB® program was used to calculate the SAC value from the Scirpus grossus test specimen.

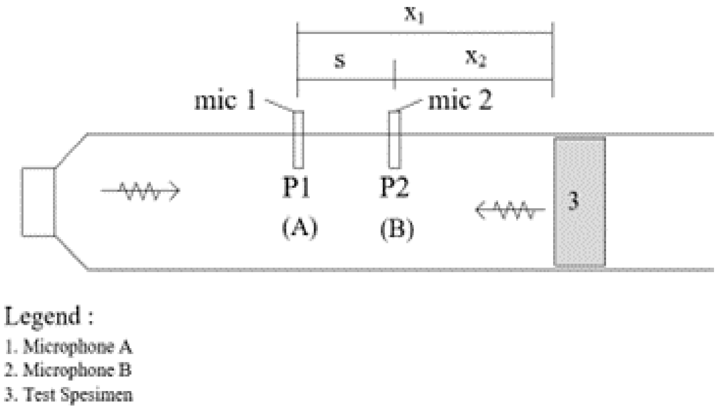

Fig. 7. Microphone positions and distances

The value of SAC was calculated using Eq. 1, where α is the sound absorption coefficient, and R is the sound reflection coefficient [25][26][27][28].

$$\alpha = 1 - |R|^2 \tag{1}$$

In this research, the Noise Reduction Coefficient (NRC) used was derived from the SAC using Eq. 2. Specifically, NRC refers to the surface's ability to reduce noise by absorbing sound or the percentage of sound energy that is not reflected by the test specimen, ranging from 0 to 1. This indicates that higher NRC correlates with improved ability of the product to absorb sound. Thickness and density of the test specimen are two factors in calculating NRC. An acoustic product with an NRC rating of 0.8 indicates that 80% of the sound is absorbed, while the remaining 20% is reflected and transmitted. Furthermore, NRC provides an easy visual comparison between different specimens, defined as the arithmetic average value of SAC at frequencies of 250, 500, 1000, and 2000 Hz [22][29]-[34].

$$NRC = \frac{(\alpha\ 250 + \alpha\ 500 + \alpha\ 1000 + \alpha\ 2000)}{4} \tag{2}$$

Based on the absorption coefficient values of the tested Scirpus grossus Fiber samples, several classifications were obtained, as shown in Table 2, [6][29][30][35]. The classification groups for sound absorption classes included A, B, C, D, E, or unclassified. To determine the Sound Absorption Classes, the procedure included calculating the Sound Average Absorption (SAA) from the SAC value [29][32] and referring to Table 2.

Table 2. Sound absorption classes[29][30][35]

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; 0.40; 0.45; 0.50; 0.55
E	0.25; 0.20; 0.15
Not classified	0.10; 0.05; 0.00

3 Results and discussion

The measurement results using the independent tube from the test specimens showed the amplitude data (in volts) of the sound pressure at P1 and P2, recorded by the computer and calculated using the MATLAB® program [4][6][20][27]. Therefore, the SAC values of the test specimens obtained densities (ρ) of 636.9 kg/m^3, 318.5 kg/m^3, and 212.3 kg/m^3 as seen in Table 3.

Table 3. SAC of different densities

Frequency (Hz)	Density, ρ (kg/m^3)		
	636.9	318.5	212.3
125	0.2049	0.2049	0.2267
250	0.3267	0.3727	0.4267
500	0.3249	0.4115	0.4215
1000	0.4067	0.4328	0.4628
2000	0.5428	0.6228	0.6567
4000	0.4067	0.5267	0.567

Fig. 8 shows that in the low frequency range from 125 Hz to 250 Hz, the sound absorption capability increases, reaching α 0.3267, α 0.3727, and α 0.4267 for densities (ρ) of 636.9 kg/m^3, 318.5 kg/m^3, and 212.3 kg/m^3, respectively. At the medium frequency of 2000 Hz, the SAC value increases to α 0.5428, α 0.6228, and α 0.6567, while the absorption capability decreases at the beginning of 4000 Hz.

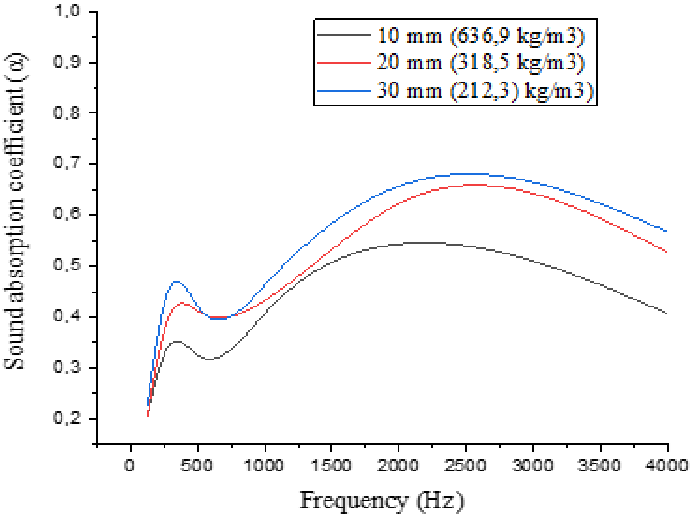

Fig. 8. SAC value of Scirpus grossus fibers

The increase in sound absorption across various frequency ranges shows that more sound energy with longer wavelengths can be absorbed by the material. Therefore, the greater dissipation (friction) of sound passing through the sample due to thermal-viscous interactions contributes to the SAC. The increase in density also enhances the resistivity of flow and tortuosity. Greater flow resistivity in sound absorbers increases the difficulty for sound waves to propagate through the fibers, leading to more energy loss due to friction. Regarding tortuosity, the complexity of paths within the Scirpus grossus fiber sample allows for the trapping and absorption of more sound waves [36].

Furthermore, as the density level decreases, the SAC increases, with α values of 0.5428, 0.6228, and 0.6567, respectively. The comparison of sound absorption capabilities for each specimen density is approximately 1.0:1.1:1.2. This indicates that for each decrease in density level, there is an increase in the α value by approximately 0.1.

NRC is the average value of the material's SAC at different frequencies, namely 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz. As shown in Fig. 9, the NRC for the test specimens shows that a thickness of 10 mm or a density of 636.9 kg/m^3 is capable of absorbing sound at α 0.4003. This shows that the SAC of 40.03% and 59.97% of the sound is reflected and transmitted. Meanwhile, the test specimen with a thickness of 20 mm or a density of 318.5 kg/m^3 absorbs sound at α 0.4599 (45.99%), with 54.11% of the sound being reflected and transmitted.

Additionally, NRC with a thickness of 30 mm or a density of 212.3 kg/m^3 reduces sound at α 0.4919 (49.19%), with 50.91% of the sound being reflected and transmitted. This indicates that test specimens with lower density (212.3 kg/m^3) are more capable of reducing sound by almost 50% compared to higher densities. From the Scirpus grossus fibers with three different densities, the average sound reduction (NRC) is approximately 45%.

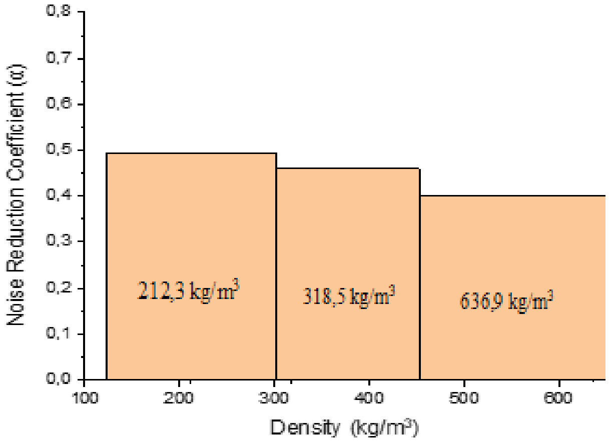

Fig. 9. NRC values

To determine SAA, the average value of SAC is calculated at each frequency in Table 3. The results showed SAA values of α 0.37, α 0.43, and α 0.46 for densities of 636.9 kg/m³, 318.5 kg/m³, and 212.3kg/m³, respectively, as presented in Table 2. Therefore, the SAA for all three density test specimens is categorized into class D.

As shown in Table 4, Scirpus grossus at 30 mm thickness achieved a peak SAC of 0.65 at 2000 Hz. While this value is slightly lower than the maximum SAC reported for banana stem (0.99 at 3000 Hz) and grass (0.92 at 3500 Hz) [29], it remains competitive considering the lower frequency range and moderate thickness used. Compared to coconut fiber (0.88 at 4000 Hz) [37], the SAC of SG is lower, but the absorption performance in the mid-frequency region (1000–2000 Hz) is more consistent.

Table 4. SAC of natural fibers by other researchers

Researchers	Material	Thickness (mm)	SAC (α)	Peak freq. (Hz)
[37]	Coconut	10	0.46	4000
	Corn		0.70	3000
	Grass		0.46	4000
	Sugarcane		0.88	4000
[38]	Coconut	10	0.39	5000
[29]	Banana stem	10	0.99	3000
	Grass		0.92	3500
[36]	Oil palm empty branch	20	0.9	2500
		40	0.9	1000
		50	0.9	1000
Now study	Scirpus gross (SC)	10	0.54	2000
		20	0.62	2000
		30	0.65	2000

Although Scirpus grossus may not surpass all other natural fibers in peak SAC value, its balanced performance at mid-frequency, lower thickness requirement, and lightweight nature makes it a competitive and eco-friendly candidate for acoustic applications.

4 Conclusion

This study confirms that the density and thickness of Scirpus grossus fiber specimens significantly influence their acoustic absorption properties. Lower-density specimens demonstrated better performance in mid-to-high frequency ranges, indicating their potential as sustainable sound-absorbing materials.

Despite promising results, the study has limitations, particularly in terms of limited replication and lack of long-term durability testing. Therefore, further research is recommended to explore large-scale panel applications, combinations with other natural or synthetic materials, and real-world performance under variable environmental conditions. These steps are essential to develop Scirpus grossus into a practical and cost-effective alternative to conventional acoustic materials.

With its lightweight nature, eco-friendly characteristics, and efficient sound absorption performance, Scirpus grossus has the potential to be used in building acoustic panels and automotive interior insulation. Its development at an industrial scale is also worth considering as a sustainable alternative to synthetic materials.

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