Gravitasi

Journal available at: https://bestjournal.untad.ac.id/index.php/GravitasiFisika

e-ISSN: 2654-4318 p-ISSN: 1412-2375

Measurement of the Sound Absorption Coefficient of Rice Straw (*Oryza Sativa*) Acoustic Material as Noise Dampener

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Information

Article history:

Received: 11 July 2024

Accepted: 29 December 2024

Published: 31 December 2024

Keywords:

Sound Absorption Coefficient

Acoustic Material

Rice Straw

Impedance Tube

Abstract

This study determines the sound absorption coefficient values of rice straw acoustic material as a noise reducer using the two-microphone impedance tube method based on ISO 10534-2:1998 standards. Two test variables were employed in this research. Composition variation consisting of three samples and thickness variation also comprising three samples. Composition variation was conducted to evaluate the ability of rice straw as a sound absorber, while thickness variation was used to determine the effect of thickness on the sound absorption coefficient of rice straw acoustic material. All test samples obtained the highest absorption coefficient values at a frequency of 1600 Hz. The acoustic material in the composition variation achieved the highest absorption coefficient values of 0.30, 0.34, and 0.37, respectively. The thickness variation obtained the highest absorption coefficient values of 0.73, 0.79, and 0.95, respectively. The obtained sound absorption coefficient values meet the standards established by the International Standardization Organization 11654.

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DOI: 10.22487/gravitasi.v23i2.17254

1. INTRODUCTION

Noise is a significant issue that needs attention in daily environments, especially in densely populated urban areas. Noise is unwanted sound from activities or processes at specific levels and times that can disturb human health and environmental comfort. Sources of noise can originate from both moving and stationary sources that disrupt hearing [1] [2]. Addressing noise issues can be achieved by dampening the noise source, using barriers, and absorbing sound with acoustic materials. Acoustic materials possess specific properties related to sound control and management, including absorption, reflection, diffusion, and isolation, thus enhancing acoustic quality in various environments such as rooms or buildings [3], [4]. The ability of acoustic materials to absorb sound is indicated by the sound absorption coefficient. The sound absorption coefficient describes the level of sound wave absorption by the material, influenced by fiber size, voids, porosity, and cavities [5].

Common acoustic materials used for noise insulation include glass wool and rock wool. Glass wool is made from fiberglass, while rock wool is derived from rock-based materials. Both of these sound insulators have drawbacks: they can pose health risks, often shedding fibers that adhere to the skin, causing itching or discomfort similar to being pricked by needles. Additionally, inhalation of glass wool particles can damage the lungs. Despite their wide availability in the market due to mass production, these composite materials are relatively expensive. These reasons underscore the need for new constituent materials [6], [7].

Currently, various studies in material technology have identified the potential use of natural materials as acoustic noise damping materials. Natural materials commonly used for acoustic noise damping include coconut husk fibers, betel nut fibers, rice straw, and banana stems [8], [9]. One abundant natural material that can be enhanced for its acoustic properties is rice straw. Rice straw consists of the stems and leaves left after harvesting rice grains. In tropical countries, particularly in Southeast Asia such as Indonesia, Thailand, and the Philippines, rice straw is abundantly available due to the intensive rice farming activities in these regions [10].

Rice straw contains the following organic materials: cellulose 32-47%; hemicellulose 19.27%; lignin, 5-24%; and ash 13-20%. Cellulose, hemicellulose, and lignin in rice straw provide a porous structure that aids in sound wave absorption. The fibers of rice straw have air spaces within them that help reduce sound intensity by absorbing acoustic energy. Additionally, its porosity and fiber structure play a role in sound damping. In the context of noise reduction, rice straw can be processed into products that exhibit good sound absorption properties [11], [12].

This research aims to create acoustic materials for noise reduction using rice straw as the base material. Rice straw will be composite with a binding matrix, specifically polyester resin. The study seeks to determine the sound absorption coefficient with different compositions and thickness variations. Composition variations aim to evaluate the effectiveness of rice straw as a sound absorber. Density testing will be conducted on the materials in the composition variations. Density affects the mechanical properties of acoustic materials, such as strength and durability for specific applications, ensuring the appropriate density for long-term durability. Thickness variations are used to assess the influence of material thickness on the sound absorption coefficient. The method employed is the two-microphone impedance tube method.

.2. RESEARCH METHOD

Time and Place

This research was conducted from September 2023 to January 2024. It took place at the Material and Energy Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, and the Building Technology Laboratory, Department of Architecture, Faculty of Engineering, Hasanuddin University.

Tools and Materials

The equipment used in this research includes a two-microphone impedance tube based on ISO 10534-2:1998, a digital balance, a 100 ml measuring glass, containers, stirrers, 10 cm diameter round molds, aluminum foil, a ruler, a blender, and an oven. The materials used are rice straw, polyester resin, catalyst, and distilled water (aquades).

Research Method

Preparation of Rice Straw

Preparing the rice straw by separating it from dirt and dust. The rice straw is cut into small pieces to facilitate washing. The cut rice straw is washed using distilled water (aquades) until it is completely clean from dirt and other particles. Then, the washed rice straw is dried under sunlight. After drying, the rice straw is ground using a blender to achieve a consistent size.

Sample Preparation

Preparing rice straw that has been blended with a polyester resin matrix as adhesive. The type of polyester resin used is unsaturated polyester resin (UPR), and it is catalyzed to accelerate the hardening process [13]. The unsaturated polyester resin (UPR) matrix is poured into a measuring glass, then the catalyst is added and stirred until homogeneous. The composition used for the polyester resin (UPR) and catalyst is 100:1. Next, the prepared adhesive matrix in the measuring glass is mixed with rice straw in a container, then stirred until all materials are thoroughly blended. The rice straw and the evenly mixed adhesive matrix are then placed into a round mold with a diameter of 10 cm, which has been coated with Vaseline, and evenly pressed onto its surface. After that, the material in the mold is dried in an oven for 1 hour at a temperature of 70°C. Table 1 shows variation in composition and Table 2 shows variation in the thickness of acoustic rice straw materials.

Tabel 1. Research parameters for composition variations

Sample Code	Rice Straw (gr)	Polyester Resin (ml)
A	9	45
B	12	45
C	15	45

Tabel 2. Research parameters for thickness variations

Sample Code	Rice Straw (gr)	Polyester Resin (ml)	Thickness (cm)
D	20	60	2
E	25	75	2,5
F	30	90	3

The composition used in the thickness variations, namely samples D, E, and F, is derived from the composition of sample C. In sample C, the weight of rice straw is greater than the other components. By using a higher proportion of fibrous material in the acoustic composite material, the sample's ability to absorb sound is increased [14].

Measurement of Sound Absorption Coefficient on Samples

The sound absorption coefficient measurement is conducted in a closed room using an impedance tube. The measuring instrument follows the ISO 10534-2:1998 standard, employing an impedance tube with the transfer function method to obtain sound pressure values and calculate absorption coefficients. The tube comprises several components including microphones, amplifier, signal analyzer, removable cap, air gap plunger, loudspeaker, and computer. The sample under test is placed in a 10 cm diameter holder connected to an amplifier, pulse generator, and computer. The impedance tube used has a maximum frequency of 1600 Hz, while the sound source ranges from 125 Hz to 1600 Hz provided by the amplifier. Sound from the amplifier enters the impedance tube via a cable connected to the speaker within the tube. This sound then travels towards the sample in the holder, undergoes complex sound pressure transfer at two microphones, normal incidence complex reflection, and the absorption coefficient is determined [15], [16]. Impedance tube using the transfer function method is illustrated in the following Figure 1.

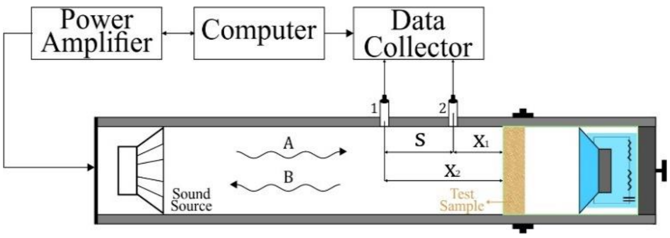

Figure 1. Scheme of impedance tube measurement

Where A and B are the amplitudes of incident and reflected acoustic waves, while X1 and X2 denote the distances from positions 1 and 2 of the microphones to the sample surface, and S is the distance between positions 1 and 2 of the microphones. The sound pressure at each microphone can be defined as follows:

$$P_1 = Ae^{-jkx_1} + Be^{jkx_1} \quad (1)$$

$$P_2 = Ae^{-jkx_2} + Be^{-jkx_2} \quad (2)$$

so the acoustic transfer function between these two microphones is:

$$H_{21} = \frac{p_1}{p_2} \quad (3)$$

snd its reflection factor:

$$r = \frac{H_{21} - H_1}{H_R - H_{21}} e^{2jkx_1} \tag{4}$$

where:

$H_1 = e^{-jks}$

$H_R = e^{jks}$

Thus, the sound absorption coefficient can be determined using the following equation [16]:

$$\alpha = 1 - |r|^2 \tag{5}$$

The sound reflections that are not absorbed by the material will be captured by the microphone inside the impedance tube. The data of the sound absorption coefficients will be directly processed by the computer via a pulse device, which can then be visualized in graph form using Excel application on the computer. The measurement results indicate the material's ability to absorb sound at various frequencies, with variations in the tested materials. A material can be categorized as a sound absorber if it has a minimum sound absorption coefficient value of 0.15 according to International Standardization Organization 11654 [17].

Density testing on the samples

The next test involves density analysis on each sample of composition variations. Density analysis in acoustic material manufacturing aims to determine how compact or dense the material is. The appropriate density can affect the material's ability to effectively absorb sound. According to JIS A 5908 Type 8 standards, a material is considered good as an acoustic material if its density ranges from 0.4 g/cm³ to 0.9 g/cm³ [8], [18]. The method of density analysis is conducted by weighing the sample to determine its mass and measuring its thickness to establish its volume. By obtaining the mass and volume of each sample, the density of the acoustic material can be calculated using the formula:

$$\rho = \frac{m}{v} \tag{6}$$

Where ρ is the density (g/cm³), m is the mass of the sample (g), and v is the volume of the sample (cm³) [19].

4. RESULTS AND DISCUSSION

Acoustic Material

This study successfully created acoustic materials based on rice straw with two test variables: composition variations and thickness variations. Composition variations aimed to evaluate the acoustic absorption capabilities of rice straw materials, while thickness variations were used to determine the effect of thickness on the sound absorption coefficient of rice straw acoustic materials. The composition variations consisted of 3 samples labeled as samples A, B, and C, and 3 samples with thickness variations labeled as samples D (2 cm), E (2.5 cm), and F (3 cm), with each sample having a constant diameter of 10 cm. Figure 2 and 3 shows image of the rice straw acoustic materials with composition and thickness variations.

In Figure 3, it can be observed that the acoustic material in sample F has a greater thickness compared to samples D and E. The thicker the acoustic material, the higher the sound absorption coefficient achieved. Thicker materials provide a greater volume for the sound waves to penetrate and dissipate their energy through mechanisms such as friction and vibration within the material's structure [14].

Sound Absorption Coefficient

Acoustic materials based on rice straw with composition and thickness variations were tested for their acoustic properties using the impedance tube method. Testing of the materials was conducted to determine the sound absorption coefficient values of the acoustic materials [16]. The relationship between the acoustic materials and the sound absorption coefficient values is shown in Figures 4 and 5.

(a) (b) (c)

Figure 2. Acoustic Material with Composition Variations: (a) Sample A; (b) Sample B; and (c) Sample C

(a) (b) (c)

Figure 3. Acoustic Material with Thickness Variations: (a) Sample D; (b) Sample E; and (c) Sample F

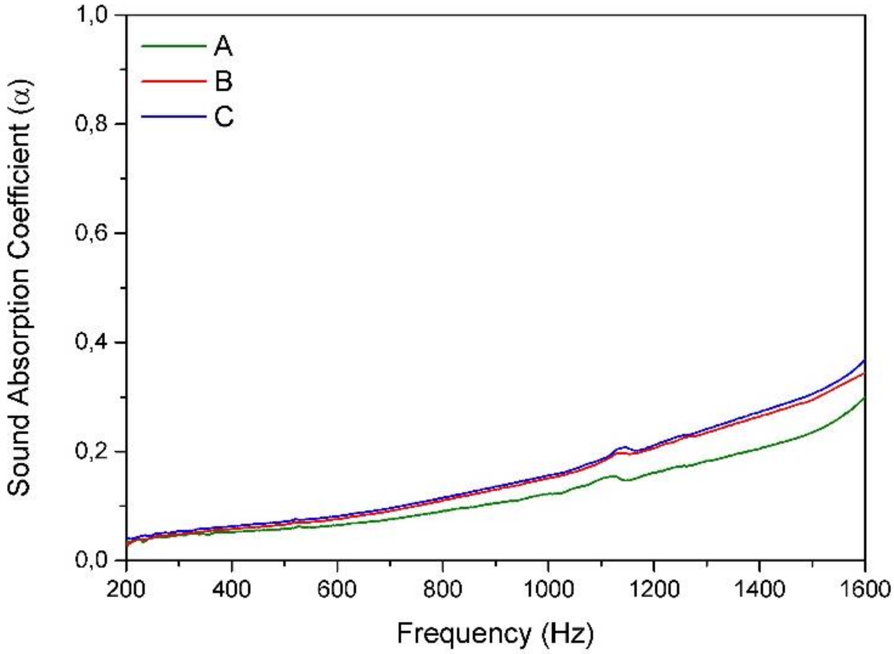

Figure 4. Graph of Sound Absorption Coefficient for Composition Variations

In Figure 4, the graph shows the results of the sound absorption coefficient of rice straw acoustic materials with composition variations. Sample A demonstrates good performance in the frequency range of 1200-1600 Hz, indicating that the composition of Sample A effectively absorbs sound within that range. On the other hand, Sample B shows good performance at frequencies ranging from 1050 to 1600 Hz, suggesting that the composition variation in Sample B also effectively absorbs sound within that frequency range. Sample C, meanwhile, shows improved performance in the frequency range of 1000-1600 Hz, indicating that the composition of Sample C is effective in sound absorption within that frequency range. The sound absorption coefficient values show the highest value at a frequency of 1600 Hz for all composition variation samples. Sample A has the highest sound absorption coefficient value of 0.30, Sample B has a value of 0.34, and Sample C has the highest value of 0.37. The changes in the sound absorption coefficient values among these three materials are influenced by the addition of rice straw composition to the materials. The higher the proportion of rice straw added, the higher the sound absorption coefficient value. This indicates that the composition of rice straw has an impact on the material's ability to absorb sound.

In Figure 5, the graph shows the results of the sound absorption coefficient of rice straw acoustic materials with thickness variations. It is evident that variations in thickness among the acoustic materials, samples D (2 cm thickness), E (2.5 cm thickness), and F (3 cm thickness), demonstrate in-

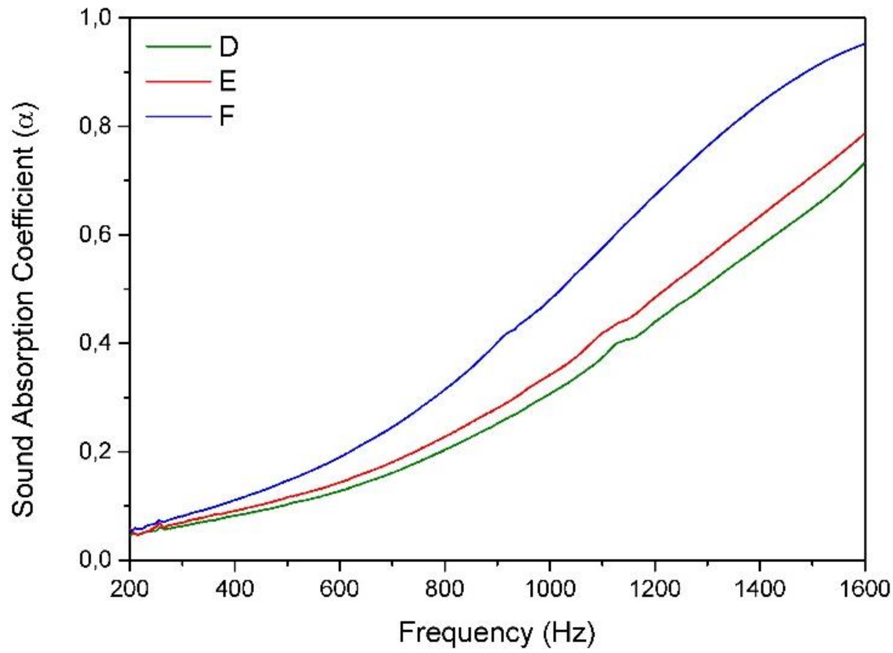

Figure 5. Graph of sound absorption coefficient for thickness variations

creasing sound absorption coefficient values with increasing frequency. The sound absorption coefficient values for the 2 cm thickness sample are effective in the frequency range of 700-1600 Hz, for the 2.5 cm thickness sample in the range of 650-1600 Hz, and for the 3 cm thickness sample in the range of 550-1600 Hz. This indicates that increasing the thickness of the material enhances its ability to absorb sound over a broader frequency range.

All samples with thickness variations achieve the highest sound absorption coefficient values at a frequency of 1600 Hz. The 2 cm thickness sample records the highest sound absorption coefficient value of 0.73. The 2.5 cm thickness sample shows improvement, reaching the highest sound absorption coefficient value of 0.79. Meanwhile, the 3 cm thickness sample, being the thickest material in this experiment, demonstrates the best performance with the highest sound absorption coefficient value of 0.95. Thickness directly influences the sound absorption capability, with thicker materials generally exhibiting more effective sound absorption performance.

From the measured values of the sound absorption coefficient for samples with composition and thickness variations, it can be concluded that all samples meet the standard set by the International Standardization Organization (ISO) 11654. This standard states that a sound-absorbing material is considered effective if the Noise Absorption Coefficient (NAC) exceeds 0.15 [17].

Density of Test Samples with Composition Variations

Density testing is a measurement of density, where density is a measure of the compactness of particles within a sheet, conducted under dry conditions and the volume of dry air. The test samples are weighed for their mass and then measured for their average thickness to determine their volume. The density of the test samples is calculated using equation (5), and the calculation results obtained are shown in Figure 6.

In the acoustic material composition variations, density analysis was conducted. The density results of the acoustic materials with composition variations for samples A, B, and C can be seen in Figure 6. Samples A, B, and C have densities of 0.477 g/cm³, 0.518 g/cm³, and 0.551 g/cm³, respectively. In this test, samples A, B, and C meet the density requirements for acoustic materials according to JIS A 5908 Type 8 standards, which range from 0.4 g/cm³ to 0.9 g/cm³.

Generally, increasing the proportion of rice straw in polyester resin can increase the density of the material. This is because more fibers mixed with the matrix fill the pores and increase the material density. However, this needs to be balanced with the mass of fibers and matrix; if there are too many fibers and too little matrix, the density of the acoustic material can decrease. The decrease in density when adding fibers and matrix can be caused by inadequate control during the transfer of the composite into the sample mold, which affects the volume and density of the sample.

The acoustic absorption coefficient (α) of Oryza Sativa L. straw (rice straw) at 1600 Hz, measured as 0.95, demonstrates a highly efficient sound-absorbing capacity compared to other natural materials investigated in similar studies. For instance, areca fruit fiber exhibits the highest absorption coefficient of 0.98 [6], slightly surpassing jerami padi, making both materials exceptional for soundproofing applications. In contrast, oil palm frond also shows high performance with α=0.90 [20], while sugarcane bagasse follows closely at α=0.92 [4]. These variations underscore the superior soundproofing capabilities of certain agricultural byproducts like rice straw, offering sustainable alternatives to synthetic materials.

4. CONCLUSION

Based on the research results, all samples achieved the highest sound absorption coefficient values at a frequency of 1600 Hz. The samples with composition variations obtained the highest absorption values of 0.30, 0.34, and 0.37, respectively. In contrast, the samples with thickness variations achieved the highest absorption values of 0.73, 0.79, and 0.95, respectively. The rice straw-based acoustic materials with polyester resin adhesive in composition variations showed that the addition of rice straw to the matrix enhances the sound absorption capability. Additionally, thickness variations also influenced the results, with increased material thickness yielding higher sound absorption values. Based on the obtained sound absorption coefficient values, all samples met the standards set by the International Standardization Organization (ISO) 11654. Therefore, rice straw acoustic materials with polyester resin adhesive can be used as noise-reducing materials.

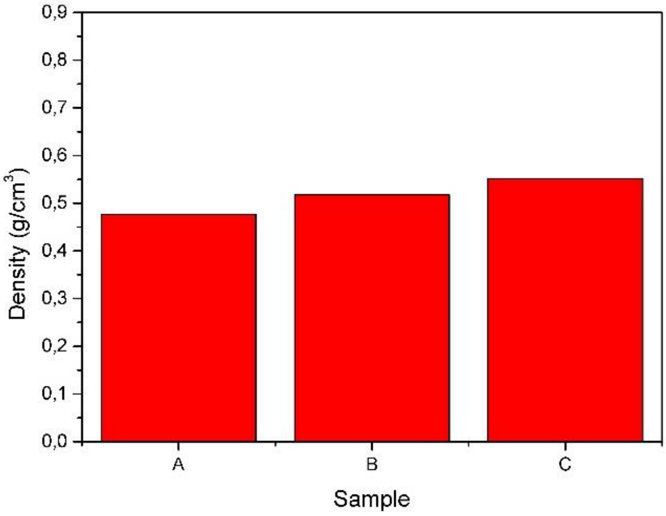

Figure 6. Density of rice straw acoustic materials with composition variations

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