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Potential of Soundproof Wallpaper Based on Indigenous Materials

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Abstract

Noise exposure can occur at any time and interfere with a person's psychological and biological condition. Alternative materials from banana midrib and soybean dregs can be used as sound absorbers based on their characteristics and abundance. This research aims to analyze the optimal composition for sound-absorbing composite materials from banana midrib and soybean dregs and the effect of adding a layer of varnish to its absorption capacity. The method includes the manufacture of the sample, the impedance tube, the box acoustic approach, and the CCD test. The drying process of banana midrib is divided into two types, namely those that are dried in the sun and oven with the banana midrib having gone through a 5% NaOH immersion process before drying. The application of varnish on the sample used the cold spray technique so the layer is not thick and provides durability and resistance to the sample. The impedance tube was carried out to analyze the value of the sound absorption coefficient of the sample at several frequencies which were then averaged. After being tested with the box acoustic approach, the sample has the ability to reduce sound when applied to the walls of the room with an average percentage decrease of 10.84%. Through the CCD test, it is known that the size and number of pores distribution affects the sound absorption capacity. Banana midrib and soybean dregs can be used as an alternative to sound absorbers with the average value meeting the ISO 11654 standard, which is > 0.15.

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INTRODUCTION

According to World Health Organization (WHO) estimates, noise-related traffic noise exposure accounts for an annual loss of more than 1.5 million years of healthy living in Western Europe with 61,000 years for ischemic heart disease, 45,000 years for cognitive impairment in children, 903,000 years for sleep disorders, 22,000 years of hospitalization, and 18,000 cases of premature death due to ischemic heart disease and stroke (Hahad et al., 2019). The National Institute for Occupational Safety and Health (NIOSH) recommends that the recommended exposure limit for occupational noise exposure is 85 dB(A), as a time-weighted average of 8 hours (8 hours TWA). Exposures at and above these levels are considered hazardous noise levels (Zaw et al., 2020). A recent meta-analysis conducted on behalf of WHO suggested the relative risk (RR) for ischemic heart disease incidence of 1.08 (95% Confidence Interval (CI): 1.01–1.15) per 10 dB increase in the past cross-road noise exposure above 50 dB based on a high-quality longitudinal study (Hahad et al., 2019).

One method to reduce noise in a room is to install acoustic panels or sound-absorbing material on the partition wall and ceiling (Thamrin et al., 2013). Materials that are often used today are those derived from synthetic materials such as glass wool. This material has a fairly expensive price with the price of one roll with a thickness of 7 mm and a width of 2 m at one shopping site reaching Rp. 1,250,000. Therefore, research is conducted on natural fibers that can provide alternative options for the use of synthetic fibers that have environmental issues.

Natural fiber-reinforced composite materials have many advantages compared to synthetic fibers such as their abundant availability, low density, moderate mechanical strength, better acoustical performance, bio composability or degradability, and a more affordable price (Lotfi and Li, 2019). Research on natural fibers that have been carried out includes those from sugarcane bagasse (Puspitarini et al., 2015), tofu waste (Rizal et al., 2015), tempeh pulp (Wijaya and Elvaswer 2015), areca fiber (Pratiwi et al., 2017), and also banana fronds (Astuti et al., 2019).

As a sound-absorbing material, banana midrib has a cellular network with interconnected pores, and when it is dried, it becomes solid and makes it a material that has good absorption capacity (Khotimah et al., 2014). In the research conducted by Gupta et al. (2020) stated that banana midrib fiber has a composition of 60-65% cellulose, 6-19% hemicellulose, 5-10% lignin, 3-5% pectin, 1-3% ash, and 3-6% extractive. In addition, soybean pulp also has a fine powder structure and contains many pores so that it can absorb sound (Rizal et al., 2015). Both of these materials can be used as fillers or natural fiber-reinforced composite fillers with the adhesive used being polyvinyl acetate (PVAc) polymer. This PVAc polymer is often used as an adhesive between fibers, in addition to being a cheap material, this polymer is also very strong, odorless, non-flammable, and solid.

Acoustic materials derived from natural fibers will be susceptible to insect attack. Therefore, the acoustic material is given an additional layer in the form of varnish. The addition of this layer is used to increase the resistance and durability of the soundproofing of banana midrib and soybean dregs (Putri et al., 2017). The addition of a layer of varnish is done by using a spray gun so that the applied layer is not thick and does not reduce the ability to muffle the sound too much.

METHODS

Banana midrib is taken from the middle of the tree trunk. The banana midrib is then cleaned and cut. The process of decomposition of banana midrib fiber with 5% NaOH solution for 14 hours. NaOH treatment was carried out to minimize the levels of hemicellulose, lignin, or pectin. After the NaOH treatment, the fibers were cleaned with plain water so that the remaining NaOH was removed. Then the banana midrib goes through the stages of the drying process. This drying process is distinguished by two events, namely, drying in the sun for 4 days and in an oven at 80°C for 2 hours. The dried banana stems are then crushed with a blender. Then the drying process on soybean dregs is carried out by drying in the sun for 4 hours and in the oven for 30 minutes at a temperature of 70°C.

In the manufacture of acoustic composites of banana midrib and soybean pulp, the composition between fiber and PVAc is 60%:40%. Table 1 shows the fiber composition between banana midrib and soybean pulp used.

Table 1. Composition between Banana Midrib Fiber and Soybean Dregs

Banana Midrib (%)	Soybean Dregs (%)
30	70
40	60
60	40
70	30
100	0
0	100

Each mixture of PVAc polymer, banana midrib fiber, and soybean dregs was molded and pressed to form a composite. The mass used for the sample is 12 grams. The composite was made by means of a hydraulic press with a pressure of 150 kg/cm^2. The sample was then placed in an oven at 100°C for 1 hour 30 minutes. This is done so that the remaining water content in it evaporates. Samples that have been finished in the oven are then measured for thickness. The composition and mass of the sample will affect the thickness of the final sample made. Therefore, to identify the effect of thickness, samples with the same composition were made with mass variations of 7 grams, 12 grams, and 17 grams.

The sound absorption coefficient test was carried out using the impedance tube method. The frequency play scale on the signal generator (AFG) is varied on a scale of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz as for the amplitude of 10 V. This test is carried out using an impedance tube to determine the ability of the material to absorb sound. The impedance tube used is made of 1¼ inch PVC which is assembled together with a speaker that is connected to the AFG and also the Sound Level Meter (SLM). The sample is placed in a tube 50 cm from the sound source,wWhile the SLM is placed near the sample as far as 2 cm.

In addition, a test was conducted to determine and analyze the effectiveness of the composite of banana midrib and soybean pulp when applied to the walls of the room using a box acoustic approach. The composite panels were printed with a size of 20 cm×20 cm, then given a layer of varnish using a spray gun with a 0.05 mm nozzle. The sample uses one of the compositions from a predetermined ratio. This test uses acrylic panels as a substitute for room walls. This acoustic box is considered a room. Two SLM tools are placed in each room. The sound source is varied with the frequency scale as in the impedance tube. Composite panels are placed in the middle of the room as a divider. The panel is used as a sound absorber and is assumed to be a wall covering material. Not only that, the composite sample will go through a CCD test with a magnification of 75× to determine its morphological characteristics as a sound absorber.

The collection of data taken is quantitative and qualitative data. Quantitative data includes test results from the impedance tube and box of acoustic methods. Qualitative data in the form of sample CCD test results by looking at the characteristics of the resulting pores. Meanwhile, the calculation of the sound absorption coefficient (α) is carried out using:

$$\alpha = \frac{\ln I_0 - \ln I}{x} \quad (1)$$

where α is the sound absorption coefficient, I_0 the sound intensity before passing through the absorbing medium (dB), I the sound intensity after passing through the absorbing medium (dB), and x is the thickness of the absorbing medium (cm) (Said et al., 2020).

RESULTS AND DISCUSSION

Potential Utilization of Banana Midrib Fiber and Soybean Dregs as Sound Damping Materials

Sounds that can be reached or heard by humans have a frequency range between 20 to 20,000 Hz (Ozdil et al., 2020). Excessive interior noise has significantly affected human comfort and can cause serious health problems (Jichun et al., 2018). The research was conducted using banana midrib and soybean dregs. The use of banana midrib and soybean pulp as soundproof materials is based on the abundance of raw materials available in Indonesia and the potential for sound absorption as soundproof materials. Banana plants in Indonesia can reach 50 million tons (Zulfikar et al., 2019). As for the potential yield of soybeans, according to BPS data in 2018, the production can reach 982,598 tons (Aisyah and Siti, 2021).

Banana midrib has cellular tissue and interconnected pores and makes it a material that has good absorption (Dewi and Elvaswer, 2015). Kepok banana midrib is a type of banana plant whose fiber has the best mechanical properties. Decomposition of banana midrib fiber was carried out by treatment with 5% NaOH solution. It also aims to make the fiber have good tensile strength, modulus of elasticity, and flexural strength (Wijianto et al., 2019). The longer the immersion of NaOH on banana midrib fibers, the higher the elongation value and able to improve its mechanical properties (Pramono and Widodo, 2012). Soaking the banana midrib in the solution was carried out for 14 hours to get good fiber conditions (Irmadona et al., 2018). The banana stem drying process is carried out in two different ways, namely in the sun and in the oven. This is to show whether or not there is a difference between the drying process through the sun and the oven to the final sample results.

The soybean dregs taken are the final product of tofu making at the tofu factory. Soybean pulp has a fine powder structure and contains many pores so that it can absorb sound (Rizal et al., 2015). Soy dregs from the tofu factory still have a high level of water content, even the humidity level can reach 95%. Due to the high-water content, a drying process is needed so that the soybean dregs do not rot and can last longer. This fine powder structure after drying contains a lot of material pores, so that it can absorb sound. Judging from its potential, raw materials for banana midrib and soybean pulp can be optimally utilized as sound-dampening materials for the benefit of the community.

Sound Absorption Coefficient of Banana Midrib and Soybean Pulp Composite

The samples were divided into two types, namely samples with banana midrib fibers which were dried in the sun and banana stems which were dried in an oven. Samples were made using a hydraulic press which was pressurized at 150 kg/cm^2 and had a diameter of 4 cm.

The sound absorption coefficient expresses the sound-absorbing efficiency of a material at a certain frequency. The average sound absorption coefficient value that meets the ISO 11654 standard is with a value of > 0.15 (Akbar, 2017). If the sound absorption coefficient is 0, it means that it does not absorb at all. Meanwhile, if the sound absorption coefficient is 1, it means that the material absorbs sound perfectly. Table 2 shows sound absorption coefficient values in samples of dried banana midrib against the frequency of sound sources and Table 3 sound absorption coefficient values in oven-dried banana stem samples.

Table 2. Coefficient of Sound Absorption (α) against Frequency (Hz) in Samples with Sun-dried Bananas

No.	Sample description		Mass (g)	thick-ness (cm)	Sound Absorption Coefficient				
	Banana Midrib (%)	Soybean Dregs (%)			250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
1	100	0	12	0.67	0.24	0.11	0.07	0.35	0.49
2	70	30	12	1.13	0.06	0.00	0.02	0.19	0.22
3	60	40	12	0.79	0.08	0.11	0.09	0.17	0.28
4	50	50	12	0.66	0.05	0.12	0.06	0.17	0.45
5	50	50	7	0.44	0.06	0.13	0.07	0.23	0.58
6	50	50	17	1.07	0.03	0.08	0.04	0.13	0.23
7	40	60	12	0.96	0.09	0.09	0.05	0.07	0.21
8	30	70	12	0.64	0.06	0.16	0.06	0.16	0.44

Table 3. Coefficient of Sound Absorption (α) against Frequency (Hz) in Samples with Oven Banana Midrib

No.	Sample description		Mass (g)	thick- ness (cm)	Sound Absorption Coefficient					Average
	Banana Midrib(%)	Soybean Dregs (%)			250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	
1	100	0	12	0.63	0.21	0.12	0.11	0.34	0.49	0,25
2	70	30	12	0.99	0.18	0.05	0.03	0.15	0.31	0,14
3	60	40	12	1.50	0.23	0.08	0.07	0.17	0.17	0,14
4	50	50	12	1.07	0.14	0.10	0.06	0.08	0.17	0,11
5	40	60	12	0.96	0.12	0.05	0.04	0.09	0.17	0,09
6	30	70	12	0.74	0.28	0.11	0.08	0.31	0.53	0,26

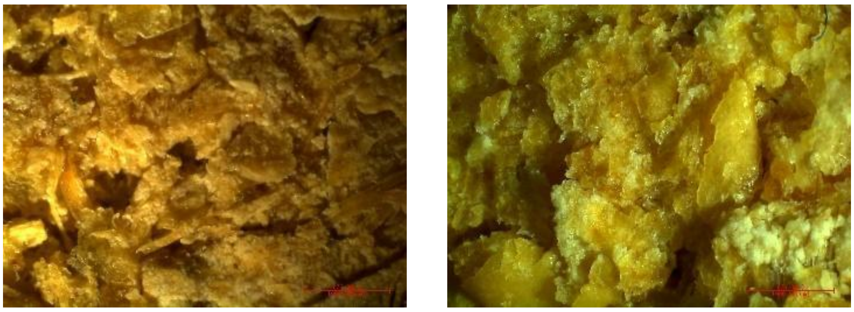
The different drying methods on the banana midrib showed that there was an effect on the dryness level of the fiber on the absorbency of the absorbent. It can be said that with the oven method, the banana midrib drying is more even, more efficient, and the fibers can dry completely compared to those in the sun. A material is said to be a good absorber if the minimum value of the average sound absorption coefficient is 0.15 (Akbar, 2017). The optimum result obtained from the sample using the drying method of banana midrib which is dried in the sun is the composition of 100% banana midrib fiber with an average coefficient value of 0.25. Meanwhile, in the oven drying method, the optimum value was obtained, namely the sample with a composition of 30% banana midrib fiber and 70% soybean dregs with an average coefficient value of 0.26. Although the optimum value for dried banana midrib is obtained from the composition of 100% banana midrib, the silencer from the combination of banana midrib and soybean dregs has the advantage of providing high economic value for people who use this material as a sound absorber. Not only that because of its application on the walls of the room, the artistic aspect of a room is also considered (Thamrin et al., 2013). The presence of soybean pulp in this composite wallpaper gives a better appearance to the final product because it looks smoother or smoother than the composition of 100% banana midrib fiber. From this test, it can be seen that the thickness of the sample also affects the value of the sound absorption coefficient. The thicker the sample, the value of the sound absorption coefficient will decrease, or in other words, the value of the sound absorption coefficient is inversely proportional to the thickness of the sample (Puspitarini et al., 2014).

In addition, this research also analyzes the effect of an additional layer in the form of varnish on the sample on the sound absorption coefficient. Samples that were given a layer were carried out on samples with a composition of 30% banana midrib fiber. With the impedance tube method, it was found that the average sound absorption coefficient in the varnish-coated sample was smaller than that of the unvarnished sample, namely 0.16 with an average sound absorption coefficient of 0.02. This is because the varnish layer can cover the pores of the composite so that the ability to absorb sound is lower than samples without a varnish coating.

Charge Coupled Device (CCD) Test

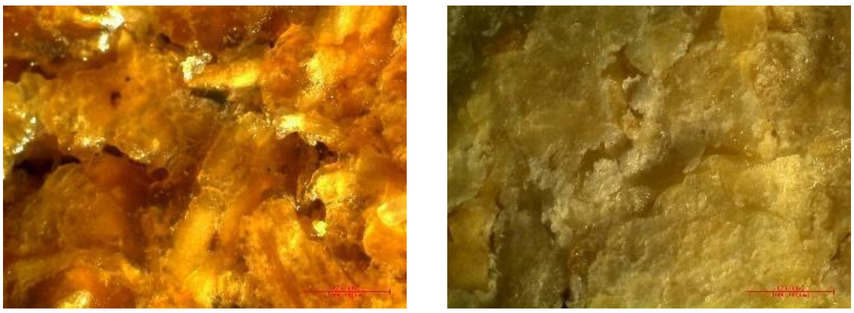
The CCD test was carried out to see the characteristics of the pores of the sample as a sound absorber. The sample used is a sample with dried banana midrib. The sample with the composition of 100% banana midrib fiber had a large number of pores and a large size with an average pore size of 119638.28 μm. This is also in accordance with the high sound absorption coefficient value with an average of 0.25. It is different for the sample with 40% banana frond composition, the sample has a large pore size, but the distribution of the pores is not much so that the sound absorption coefficient value is not high. As in the case of samples of banana midrib that are dried in the sun, the size and number of pores in the sample of banana stems that are baked in the oven also affect the value of the sound absorption coefficient. As for the sample with a composition of 100% soybean pulp, the distribution of pores is not as much as that of the sample with a banana midrib fiber composition, although the average pore size is quite large.

The results of this CCD test indicate that the distribution of pores and the size of the pores of each sample affect the value of the sound absorption coefficient of the sample (Eriningsih et al., 2014). The larger the size and the number of distributions of the sample pores, the higher the average sound absorption coefficient of the sample so that it is feasible to be used as a sound dampening material. Especially for samples with a layer of varnish, the pores of the sample are somewhat covered by varnish so that the results of the sound absorption coefficient are not as good as those without layers. The following is a picture of the CCD test results on several samples shown in Figure 1 and Figure 2.



(a) (b)

Figure 1. (a) CCD Test Results for Samples with 100% Drying Banana Midrib Fiber Composition; (b) Composition of 40% Dry Banana Midrib Fiber and 60% Soybean Dregs



(a) (b)

Figure 2. (a) CCD Test Results for Samples with Varnish Coating; (b) CCD Test Results for Samples with 100% Soybean Dregs Composition

The Effect of Adding a Layer of Varnish on a The Effect of Adding a Layer of Varnish on a Sample on its Ability to Dampen Sound Sample on its Ability to Dampen Sound

The sample for the acoustic box is in the form of tiles with an additional layer of varnish. The layer is given with a cold spray coating technique so that the given layer is not thick and the liquid droplets from the varnish can reach every part of the surface of the composite (Fotovvati et al., 2019). Coating is done twice to produce a good and even surface gloss. Coating done twice made the absorption coefficient value decreased by 0.02, so we can say that one coat of varnish can reduce the absorption coefficient value by 0.01. Thus, it is recommended not to exceed three coats of varnish because the coefficient value will be below 0.15.

Table 4. Test Results with the Box Acoustic Approach

Frequency (Hz)	Sound Intensity Captured Without Sample (dB)	Sound Intensity Captured After Sampled (dB)	Percentage of Voice Loss (%)
250	103.3	99.4	3.7
500	92.9	81.8	12.0
1000	97.1	88.7	8.6
2000	115.9	103.9	10.4
4000	120.7	97.2	19.5
Average	**529,9**	**471**	**54,2**

After approaching the acoustic box, there was a decrease in sound as expected with the average percentage of sound loss after passing through the separation wall from the acoustic box was 10.84%. Banana fronds and soybean dregs can be used as materials for the manufacture of soundproofing products with an additional layer of varnish that provides durability and product durability.

CONCLUSION

Banana midrib and soybean dreg can be used as sound dampening materials with an average sound absorption coefficient value that meets ISO 11654 standards. The optimum result obtained was from the sample with the composition of banana midrib fiber and soybean dreg 30%:70% through the drying method of banana midrib through the oven with an average absorption coefficient value of 0.26. The sound-dampening samples from banana midrib and soybean dreg were given an additional layer of liquid varnish with a coating technique using the cold spray technique twice without damaging the damping ability with an average sound reduction percentage of 10.84%. The application of this layer is intended so that insects, especially insects that like wood and similar materials, do not easily damage the dampening material which in the manufacture of this sample has the largest average pore size of 119638.28 μm. Although a layer of varnish covers the surface of the sample, the value of the sound absorption coefficient of the sample is quite good and is still feasible to be used as a sound absorber. The varnish coating provides resistance and durability to the product, so those insects and water do not damage it easily.

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