The usage of natural materials for the green acoustic panels based on the coconut fibers and the citric acid solutions

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Abstract. Acoustic panels of sound absorbers are used to overcome noise in an environment. Expensive panels using fabricated materials, which contains a lot of chemicals are mostly used in practice for noise reduction. Natural fibers have been extensively used to produce environmentally friendly composite materials and therefore, known as green materials. Coconut fibers hold great potential for substituting the expensive synthetic fibers in manufacturing acoustic absorption boards. This study aims to determine the acoustical performance of a green particleboard made from coconut fiber and citric acid solution. The acoustical performance is represented by sound absorption coefficient. The sound absorption coefficient of these panels were tested based on ASTM E1050-98 standard using B&K impedance tube. The small test samples were tested in the frequency range of 50 Hz to 6,400 Hz. The results show that the tested panels are insufficient in absorbing sound of low frequencies. The panels absorption ability is improving in the range of 1,000 to 6,400 Hz. Furthermore, a morphological analysis has been done by using Phenom Pro X Scanning Electron Microscope to observe the effectiveness of citric acid solution in gluing the fiber. The variations of citric acid solution are 20%, 10% and 5%. It is shown that the lowest concentration has more pores distribution.

1. Introduction

Noise is an unwanted sound. It can be produced by many sources such as human’s voice, running engine, operating machine tool, etc. Noise has become one of the major pollution types in the world and continues to get worse due to the rapid developments of modern industries and transportation[1][2]. Constant exposure to noises can cause all kinds of health problems. According to the World Health Organization’s Guidelines for the community noise, the significant health-related effects of noise pollution are hearing impairment, interference with speech communication, degradation of speech performance, annoyance, and sleep disturbance[3][4].

Noise in a building can be eliminated by building materials with acoustical characteristic of a good sound energy absorption. Acoustic is one of the major parameters that determine a comfortable environment in the building. Acoustic comfort refers to the limits in decibels that must be respected in order to preserve the auditory health, making the environment acoustically appropriate and agreeable to the individual [4][5][6].

Currently, the acoustic panels (that are able to absorb the sound energy) available in market for acoustic treatment are made from synthetic materials such glass wool and foam glass. These synthetic materials are found to be not only harmful to human health, but may also cause pollutions and global warming[7].

These issues explore an opportunity to look for alternative materials from natural fibers to be developed as “green” acoustic panel as a new solution to the harmful materials. It is important to produce less-cost and green (eco-friendly) materials that can reduce noise in the buildings. Natural fibers are
extensively used to produce eco-friendly composite materials. Natural fibers, such as wood, hemp, and coconut fibers, possess great potential to replace the expensive synthetic fibers in manufacturing acoustic absorption boards. It is because natural fibers are easy to find (available in the nature) and do not require high cost to process. Natural fibers also have natural cellular structure that can effectively absorb acoustic energy [8][9].

Porous absorbers are the most commonly used sound absorbing materials. To be an excellent sound absorber, the sound waves must penetrate into the absorbing material where the sound is dissipated in the form of friction and heat. The amount of sound which enters the porous material depends on the wavelength of the sound and its angle of incidence on the absorbing material. The ability of a material to absorb sound of a particular frequency is often described by a sound-absorption coefficient (\(\alpha\)). [4][9].

In 2014 according to Badan Pusat Statistik (Indonesia’s National Statistics Institution), Indonesia produced 35,000 tons of coconut fiber per year. Unfortunately, its utilization is still insufficient. Therefore, the development of fiber-based sound absorber in Indonesia is really promising. This research aims to study eco-friendly and low cost acoustic panel (sound absorber) based on the coconut fiber and citric acid (natural materials) to reduce noise in the building. [10]

2. Materials and methods

This research aims to create/ or study the eco-friendly and low cost acoustic panel as sound absorber based on the coconut fiber and citric acid as the natural materials. The quality of the acoustic panel has been successfully analysed using impedance tube method and Scanning Electron Microscope (SEM).

2.1. Materials preparation

Coconut fibers as the main materials were collected from Gunung Kidul, Yogyakarta. The fibers were air-dried to reduce the moisture content and were cut into 2.5 cm ± 1 cm. Citric acid as the main material of the adhesive solutions was dissolved in water to a solution concentration of 59 – 60%. The solution was used as adhesive and distributed/mixed manually onto fibers at 5%, 10% and 20% based on the weight of the air-dried fibers.

2.2. Acoustic panel manufacturing process

The mixed fibers were then oven-dried over night at 80°C to reduce the moisture content. The fibers were hand formed into a mat using a forming box of 150 mm x 150 mm, followed by hot pressing into acoustic panel (board) with a distance bar of 10 mm to control the board thickness. The boards were pressed at 180°C for 10 minutes under a pressure of 2.5 MPa. The target densities of the board were 0.5 g/cm\(^3\), 0.25 g/cm\(^3\) and 0.125 g/cm\(^3\). Prior to the evaluation, all boards were conditioned at ambient conditions for approximately 7 days.
2.3. Laboratory testing
The quality of the acoustic panels is represented by sound absorption coefficient and morphological analysis of the board’s surface. In total, there are 7 samples that have been used in this research. The test was done by varying the density and citric acid concentration (Table 1).

| Sample | Density   | Concentration of adhesive solution |
|--------|-----------|-------------------------------------|
| 1      | 0.5 g/cm³ | 20%                                 |
| 2      | 0.5 g/cm³ | 10%                                 |
| 3      | 0.5 g/cm³ | 5%                                  |
| 4      | 0.25 g/cm³ | 10%                                |
| 5      | 0.25 g/cm³ | 5%                                 |
| 6      | 0.125 g/cm³ | 10%                               |
| 7      | 0.125 g/cm³ | 5%                                |

2.3.1. Sound absorption evaluation. The sound absorption coefficient was evaluated by using the impedance tube with two microphones. The diameter of the sample of this test was 3 cm with 1 cm of thickness.

The sample was tested is in the frequency range of 50 Hz – 6,400 Hz. The sound absorption coefficient is derived by measuring the incident and reflected components of noise, which are generated inside the impedance tube by the sound source. The reflected component is affected by the acoustic properties of the tested sample (sample placed in a holder at one end of a tube).

2.3.2. Morphological evaluation. The surface morphology of the boards was observed using SEM. An accelerating voltage of 10 – 15 kV was used to collect the micrographs on the surface of the samples. The size of the samples was 5 mm x 5mm. The morphology of the boards was observed at the room temperature. Before testing, the samples were sliced and mounted onto SEM stubs using double sided adhesive tape.
3. Results and discussions

3.1. Morphological Evaluation

The analysis was performed with two samples which had 20% and 10% of citric acid solution. Unfortunately, during the analysis, sample 3 which has 5% of citric acid solution was unable to meet the standard of the sample to be analyzed in the SEM. This analysis aimed to see the effectiveness of citric acid in creating the pores.

It is observed that both of the samples had irregular porous shape. The porous distribution represented by the red line in the figures. The captured micrographs of the porous of samples show that the porous distribution is decreased when the concentration of citric acid solution is increased from 10% to 20%.

![Figure 8. Porous distribution of 10% citric acid solution sample](image1)
![Figure 9. Porous distribution of 20% citric acid solution sample](image2)

These porous distributions will be affecting the sound absorbing quality. In Figure 8 the network of interlocking porous are clearly described. In a real field this network of interlocking porous plays an important part, because such a structure decreases air-flow resistivity and thus creates dissipates the sound energy in the pores.

3.2. Sound absorption evaluation

The sound absorption coefficients are graphically illustrated in Figure 10. The zero value in the y-axis indicates perfect sound reflection and the value of one implies a perfect sound absorption. The results showed that tested boards are insufficient in absorbing sound energy of low frequencies.

![Figure 10. Sound absorption coefficient for all samples](image3)
The value varies between 0 – 0.13 in the range of 125 Hz – 500 Hz. It occurred because the boards do not have a sufficient thickness. It claims the theory that in order for the sound absorber to have at least sound absorption of 80%, the thickness must be larger than 1/10 of the desired wavelength. Various studies that deals with sound absorption in porous materials have concluded that sound absorption at low frequencies has direct relationship with thickness.

The panel’s absorption ability is improving in the range of 1000 Hz to 4000 Hz. The values vary between 0.09 – 0.96. Sample 2, which contains of 10% of citric acid solution and has 0.5 gr/cm³ of density, indicates the best performance in the frequency of 1000 Hz and 2000 Hz, while the best performance in the frequency of 4000 Hz is Sample 3, which contains 5% of citric acid solution and has 0.5 gr/cm³ of density. The increased absorption coefficient value in the range of 1000 Hz – 4000 Hz occurred because the locked thickness of the boards (0.01 m) nearly met the minimum thickness required as shown in Table 2.

| Sound velocity (m/s) | Desired frequency | Wave length (m) | Thickness (m) |
|----------------------|-------------------|----------------|--------------|
| 125 Hz               | 2.750             | 0.275          |
| 250 Hz               | 1.370             | 0.137          |
| 500 Hz               | 0.690             | 0.069          |
| 1,000 Hz             | 0.340             | 0.034          |
| 2,000 Hz             | 0.170             | 0.017          |
| 4,000 Hz             | 0.080             | 0.008          |
| 6,400 Hz             | 0.050             | 0.005          |

At the frequencies above 4,000 Hz the absorption capability of Sample 1 – Sample 3 are decreasing. But Sample 1 – 5 still have a great ability in absorbing the sound. In the highest frequency, the best absorption capability is Sample 4 which has 0.25 gr/cm³ of density and contents 10% of citric acid solution. This indicates that at higher frequencies, thickness has insignificant effect on sound absorption.

Moreover, all the panels experienced increasing sound absorption coefficient because of the structure of the coconut fiber, which results in high absorption coefficient.

Figure 11. Micrographs of cavity on the coconut fiber

Figure 12. Micrograph of lumen inside the fiber

The white dots in Figure 5.9 are indicated as the cavity of the coconut fiber. The cavity on the surface of fiber is a great feature to improve the sound absorbing quality because additional thermal energy was dissipated more rapidly due to the increased frictional surface area. The sound absorption coefficient was therefore correspondingly increasing. The cavity inside the fiber (lumen) had been captured during the morphological analysis test. The sound waves propagated vibration energy through the air spaces in the fiber. Part of this sound energy was converted into heat.
4. Conclusions

Coconut fibers and citric acid solutions are found to be suitable materials to create acoustic panels. It has been proofed by micrographs on the surface of the samples. It is observed that coconut fiber has natural cellular structure (cavity and lumen) structure, which can effectively absorb the sound energy. Citric acid plays an important role in the bonding process and it is also observed that porous distribution is decreased when the concentration of citric acid is increased. Moreover, The acoustic panels are insufficient in absorbing sound in the low frequencies. The acoustic panel’s ability is improving in the frequency 1,000 Hz – 4,000 Hz. The best panel in those frequencies is sample 3, which can absorb more than 90% of sound energy in frequency of 4,000 Hz.

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