The Performance of Corn Husk Particleboard as Insulation Material: The Effect of Varied Particleboard Densities

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ABSTRACT

Insulation materials are important in the construction field. They are produced from organic and inorganic sources, while they are non-renewable and not very friendly towards the environment. Given the environmental pollution concerns related to the construction sector, researchers are trying to use alternative materials for insulation purposes to save energy and reduce the environmental pollution. The present research investigates the performance of particleboard made of corn husk bonded with Water-Soluble Chitosan (WSC) as an insulation material. The most important insulation characteristics of the corn husk particleboard were examined for 3 different densities (0.6, 0.8 and 1.0 g/cm^3). The results showed that WSC is a suitable natural adhesive for particleboards, which are meant to be used as insulation materials, while their performance is determined by the targeted density.

Keywords-corn husk; insulation materials; particleboard; performance; target density

I. INTRODUCTION

Technologically advanced insulation materials are widely utilized in commercial, industrial, and residential buildings to reduce the Thermal Conductivity (TC) between the inner and outer part of such a building or a room. Therefore, a stable indoor temperature can be maintained while reducing the energy needed for cooling or heating the environment inside of a building. The application of insulation materials in building constructions has become an important issue due to the growing emphasis on energy efficiency and sustainable development. Insulation panels offer an effective solution for reducing the heat transfer and creating a comfortable environment inside a building. The global demand for insulation panels has risen significantly, representing approximately 57% of the total wood-based panel consumption, while it continues to rise at an annual rate of 2-5% [1, 2].

Traditional insulating materials, such as fiberglass, glass wool, and rock wool, have a negative impact on the environment. These materials are associated with high energy consumption during manufacturing and they are also non-biodegradable [3]. The demand for environmentally friendly building materials is increasing [4], with the utilization of natural fibers as alternative insulation materials offering a sustainable solution. Several tests have been conducted on particleboards using various natural fibers based on agricultural by-products, including rice stalks [5], coconut fibers [6], bamboo [7], jute [8], oil palm [9], hemp [10], and sisal [11]. Natural fibers are also suitable as an additive in construction materials, like foam concrete [12], gypsum plaster [13], and lime [14]. Authors in [12] discussed about the several advantages in using low-density construction materials, such as Light-Weight Concrete (LWC), the densities of which range from 300 to 1850 kg/m^3. LWC utilization accelerates the construction progress, decreasing the transportation and handling costs. That is, if the floors and walls of a building are made of LWC, the overall cost will decrease considerably. Another essential characteristic of LWC is its relatively low TC, which increases as the density of a material decreases. Furthermore, insulation materials, such as the Expanded Polystyrene (EPS) aggregate concrete, are highly beneficial. They can have low dry densities that range between 500 kg/m^3 and 1800 kg/m^3 depending on the amount of EPS particles used. They can also provide sound and thermal insulation, fire resistance, and low water absorption. The usage of such concrete in construction projects can significantly reduce the load on building foundations and contribute to substantial energy savings. Finally, the production of such a material is much friendlier in terms of environmental pollution [15].

Numerous agricultural by-products are related with insulation solutions. Corn husk stands out as an interesting alternative to wood due to its beneficial properties. It is a widely available agricultural by-product, with its biomass showing a great potential as a raw material when it comes to fabricating particleboard for insulating purposes. Authors in [16] stated that corn husk comprises cellulose (45.7%), hemicellulose (35.8%), lignin (4.03%) and ash (0.38%). Additionally, it was shown that corn husk has the highest amount of cellulose compared to other natural fibers, such as wheat straw, wheat bran, and rice straw [17 - 20]. Adhesives based on formaldehyde, including Urea-Formaldehyde (UF) and Phenol Formaldehyde (PF), were used as the primary adhesive in particleboards manufactured for the use of insulation materials. However, these adhesives are not so environmentally friendly, thus raising health issues among the consumers [21]. Therefore, an alternative to a suitable and non-toxic adhesive is required.

An effective alternative material, showing great potential is WSC [22]. The latter has a variety of ranges regarding molecular weights and a high degree of Deacetylation (DD) compared to Acid-Soluble Chitosan (ASC). On the other hand, WSC's usage as a single particleboard adhesive to substitute formaldehyde-based adhesives has not been investigated yet. Insulation materials have a porous surface or a hollow structure that affects their properties. The objective of this study is to analyze the suitability of corn husk bonded with WSC for manufacturing particleboard as an insulating material. This study also evaluates the properties of such a particleboard at different densities.

II. MATERIALS AND METHODS

A. *Materials*

The materials used in this study were corn husks supplied by a local agricultural industry in Cibinong West Java Indonesia. The corn husks were chopped into particles using a Pallmann ring-knife flaker machine. The resulting particles were then classified by size using a vibrating sieve. Afterwards, the particles were dried in a technical oven at 100 °C for 12 h to achieve a moisture content of less than 5%. WSC was purchased from CV. ChiMultiguna in Cirebon, West Java, Indonesia with the following specifications: industrial grade, particle size < 150 mesh, moisture regaint < 9.75%, average molecular weight of 153 kDa, degree of deacetylation > 95.22%, and viscosity of 52.88 mPa·s.

B. *Methods*

1) *Particleboard Fabrication*

The targeted density of particleboard was 0.6, 0.8 and 1.0 g/cm^3. The WSC adhesive used was 8% wt. (based on the weight of the particles). It was prepared by being dissolved in distilled water with a ratio of 1:10 (w/v). The corn husk particles were mixed with the WSC by using a drum mixer machine until they became homogeneous. The outcome was then dried in a technical oven at 80°C for 12 h to reduce the moisture content to less than 5% in order to prevent blister emergence during the pressing process. The mold plate utilized to manufacture the particleboard, measured 35 (length) x 35 (width) x 0.9 (thickness) cm. The particleboard was fabricated using a hot-pressing machine (SHINTO®) at a temperature of 180 °C for 15 min and a press pressure of 2.5 MPa.

2) *Assessment of Particleboard Properties*

The microstructure of the particleboard was observed by using the Dino-Lite Digital Microscope, the 3D Digital Microscope of Keyence (VHX 6000), and the Thermo Scientific Quattro ESEM. The particleboard's thermal insulating properties were measured with the QTM-500 KEM TC Meter that utilizes the PD-11 probe, at a room temperature of 22-24 °C and a relative humidity (rH) between 60 and 70%.

The sound insulating properties of the particleboard were also studied. The Sound Absorption Coefficient (SAC) of such materials varies with frequency. The Noise Reduction Coefficient (NRC) was defined by taking the average of 4 measurements at 5 different frequencies (250, 500, 1000, 2000, and 4000 Hz) [23]. The Transmission Loss (TL) value was measured in a normal frequency range of the human voice (125-4000 Hz) according to the "Coupled Mini Reverberation Chamber" method at a temperature of 25 °C and a humidity of 65%. The final test sample consists of 4 particleboards glued together using seals, to form one unit with a size of 70 (length) x 70 (width) x 0.9 (thickness) cm. The Sound Transmission Class (STC) value was determined according to the ASTM-E 413:2004 standard [24].

III. RESULTS AND DISCUSSION

A. *Microstructure Properties*

The corn husk particles that were used to produce the particleboard varied in size, morphology, geometry, and Slenderness Ratio (SR). They were generally thin and measured approximately 2-3 cm in length. Each particle's shape and size influenced the bonding quality between the particles, affecting the overall properties of the particleboard. The characteristics of the corn husk particles used in this study are presented in Table I. The value of SR is calculated as the ratio of the particle's length to thickness. The particles with a higher SR are thinner, more flexible, and have a better bonding capability because they have a larger surface area to interact with the adhesive.

TABLE I. DIMENSIONS OF CORN HUSK PARTICLE

Parameter	Mean	Minimum	Maximum
Length (mm)	9.58±15.35	1.30	58.21
Thickness (mm)	0.14±0.05	0.07	0.28
SR	74.63±119.39	5.18	440.98

The SR value is an indication of the properties of the particleboard. Authors in [25] stated that an ideal SR value is 150, while in [26], it was shown that particles with a high SR value lead to the production of a stronger board. Figure 1 displays the microscope images of the particleboard that was made from corn husk particles and WSC. The observation of the samples through the microscope revealed that the corn husk particles were coated with WSC, which resulted in their glossy brown appearance. In order to have a particleboard with the best possible thermal and mechanical properties, it is important for all its inner components to be evenly distributed. The microscope images demonstrate this uniform distribution, suggesting a strong bond between the corn husk particles and the WSC within the board. According to [27], this bonding is crucial for the enhancement of the durability and structural integrity of the outcome. The results from the Scanning Electron Microscope (SEM) were also used to assess the bonding between the WSC, corn husk particles, and other components, as shown in Figure 2.

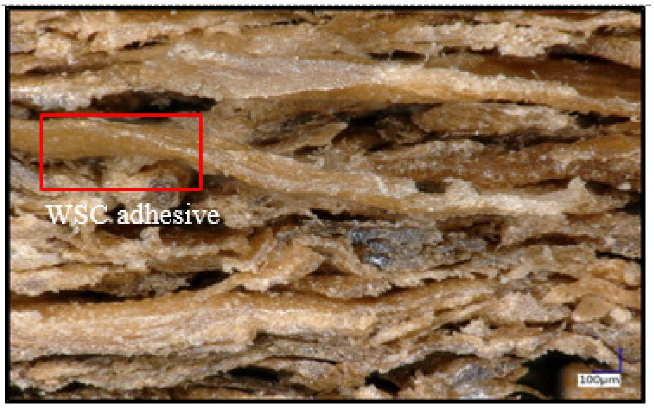

Fig. 1. The cross-section of particleboard (with magnification 150x).

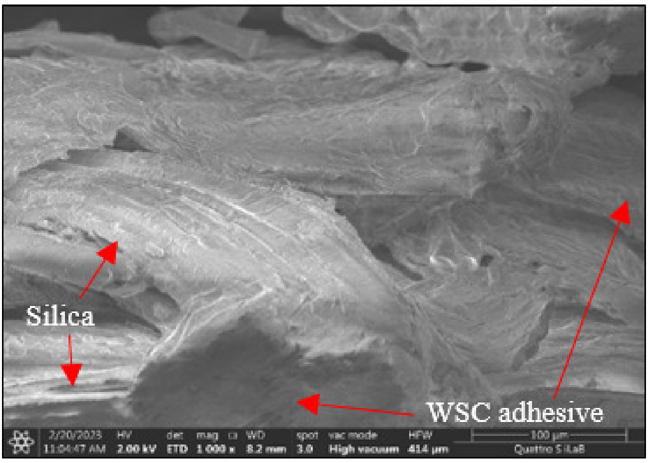

Fig. 2. SEM images of the surface morphological features of a randomly selected particleboard.

The SEM's micrographs also confirmed the homogeneous dispersion of the WSC in the particleboard. This spreading enhanced the gluing between WSC, corn husk particles, and other components from the original source (e.g. silica). This study's findings are in line with those of previous research, where studied particleboards made from coconut fibers and other natural fibers were studied [28-30].

B. *Thermal Properties*

The experimental particleboards had a range of TC from 0.1675 to 0.1962 W/m·K and a range of Thermal Resistance (TR) from 0.0478 to 0.0408 m^2K/W. For example, a particleboard with targeted density 0.6 g/cm^3 results in a TC of 0.1675 W/m·K. By increasing the particleboard density to 1.0 g/cm^3, a 17.13% rise in TC to 0.1962 W/m·K was observed. The relationship between the TC, TR, and target density of a particleboard can be seen in Table II. TC describes how efficiently a material transmits heat. On the other hand, TR refers to the material's capacity to resist the transfer of heat. This indicates that these quantities are inversely related, meaning that a material with higher TC will have lower TR, and vice versa. Table II displays that as the particleboard's density increases, TC also increases. This is because a board with higher density has a reduced level of porosity. The board's internal pores are usually filled with trapped air, which has a low degree of insulation, thus increasing the conductivity value. In general, a material can be used as an insulating thermal material when the conductivity value is less than 0.25 W/m·K. This was the present study's goal, which has been achieved.

TABLE II. THERMAL PROPERTIES OF PARTICLEBOARD

Parameter	**Target density (g/cm^3)**		
	0.6	**0.8**	**1.0**
TC (W/m·K)	0.1675	0.1769	0.1962
TR (m^{2}K/W)	0.0478	0.0452	0.0408

Table II demonstrated that the TR value drops as the TC value rises. A higher TR value indicates that the material has a better capability to resist the heat flow. However, for insulation boards, a lower TR is desirable in order to allow the heat vanish more easily. This will keep the board's temperature low. As the density of the particleboard decreases, its porosity increases, which can slow down heat transfer. Nevertheless, the TC value obtained in this study remains below 0.25 W/m·K. This indicates that the material has still good potential and is safe for use as a thermal insulation panel [31]. Wood and non-wood particles or fibers inherently contain a significant volume of trapped air within their structures, which contributes to their insulation properties [32].

C. Acoustic Properties

A particleboard is in general a material with porosity. This means that it contains numerous interconnected pores that are open to the surface. Its structure consists of bigger internal channels that are interlaced with smaller ones. These channels are generally categorized into kinetic pores and dead-end pores. The acoustic performance of the particleboard was measured with the help of the NRC. The NRC was determined by using the average of SAC at frequencies of 250, 500, 1000, 2000 and 4000 Hz, as presented in Table III. The NRC describes the material's ability to absorb sound in the range that most humans can hear. A higher NRC indicates that the material has a better sound absorption. This research produces an NRC with values between 0.102 and 0.118, as presented in Table III. Authors in [33] also stated that when the density of the board increases, the NRC value is reduced. A board with higher density has less pores or pores with a smaller size. This means that in order to enter the board, more energy is needed. More frequencies (especially the lower ones) are, therefore, being reflected, which causes the reduction of the NRC value.

TABLE III. THE VALUE OF NRC FROM PARTICLEBOARD

Panel density (g/cm^3)	**SAC at Frequency (Hz)**					**NRC**
	250	**500**	**1000**	**2000**	**4000**	
A (0.6)	0.08	0.08	0.13	0.11	0.19	**0.118**
B (0.8)	0.06	0.02	0.21	0.11	0.15	**0.11**
C (1.0)	0.05	0.03	0.24	0.12	0.07	**0.102**

The TL values of a particleboard manufactured with different densities are shown in Figure 3. TL is a parameter that depends on frequency and is measured in decibels (dB). The TL value indicates the decrease in the sound intensity when passing through a material [3]. The TL value also exhibits how much sound energy is prevented from propagating through the acoustic material. Overall, the TL measures the effectiveness of an acoustic material.

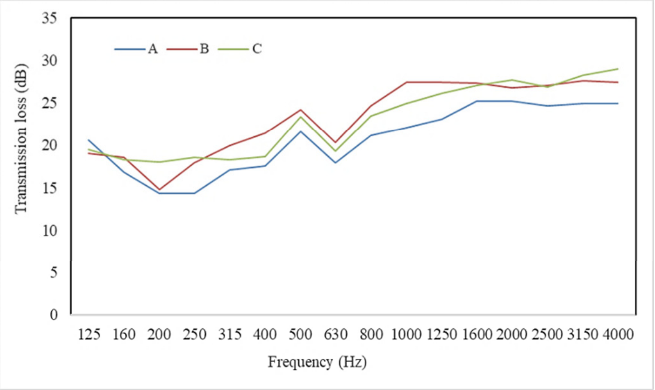

Fig. 3. TL results according to the density of the panels (A = 0.6 g/cm^3, B = 0.8 g/cm^3, and C = 1.0 g/cm^3).

The TL value of the Panel A (with density 0.6 g/cm^3) was between 14.3 and 25.2 dB. The Panel B (with density 0.8 g/cm^3) had a TL value between 14.8 and 27.6 dB, and Panel C (with density 1.0 g/cm^3) a TL value between 18.0 and 29.0 dB. All the TL results are shown in Table IV. It is obvious that as the density of a panel increases, the TL value also rises and this is applicable for the whole range of frequencies. A high TL value of a material indicates that it has better sound dampening capabilities [34]. Authors in [35] proved that the major factors that influence the TL value are the material's density, its porosity, its surface area, and stiffness.

The material's density will be inversely proportional to the TL value. Moreover, the level of porosity will be directly proportional to the TL value. This is because a material with low porosity has more internal empty space which allows energy to pass through it more easily, thus resulting in a lower TL value. The stiffness and surface area of a material are inversely proportional to the TL value. Authors in [35] also stated that the insulation properties of a panel are also affected by the angle and the frequency of the sound waves trying to pass through them. STC can be determined from the TL test results. The STC is a value that expresses the ability of a panel to block the sound. The STC value is obtained by finding the average TL value of each panel in the frequency range from 125 to 4000 Hz based on the guidelines of the ASTM-E 413:2004 standard [36].

The STC measurement results for different panel densities, TL values, and frequencies can be seen in Table IV. The standard STC values range from 20 to 65, according to the ASTM E 413:2004 standard. An average STC value of 20 indicates a higher Noise Transmission (NT), while STC values near 65 result in lower NT values. In general, a higher STC rating is considered better. However, it is also important to note that many noise sources fall below the 125 Hz frequency threshold.

TABLE IV. THE LEVEL OF THE STC FROM PANELS

Panel	**TL at frequency (Hz)**						**STC**
	125	**250**	**500**	**1000**	**2000**	**4000**	
Panel A	20.6	14.3	21.6	22.1	25.2	24.9	**22**
Panel B	19.0	14.8	24.2	27.4	26.8	27.4	**25**
Panel C	19.5	18.0	23.4	24.9	27.7	29.0	**25**

Table IV shows that for frequencies from 125 to 1000 Hz, the amount of sound that panels can block is still below the STC value of 25, which is a reference value. However, at high frequencies (1000-4000 Hz) the performance of panels B and C in reducing sound becomes better, reaching the reference STC value of 25. These results indicate that particleboards as insulation materials with densities of 0.8 and 1.0 g/cm^3 are considered soundproof materials, since they reflect more sound than they absorb. The STC value is defined as a metric of the soundproofing quality produced by a panel. When a panel has an STC value of 22-25, this means practically that there is 22-25 dB of sound that can be reduced. The creation of a room with insulation panels cannot be seen though only from the STC point of view. The combination of the panels that will be used and the selected installation structure will also affect the ability of the room to block sound in order to become soundproof. The corn husk particleboard as an insulation material has been tested with success for all crucial parameters and is standardized as an insulation panel. The TL values at the same density of 0.8 g/cm^3 were better than the ones of the fast-growing wood-isocyanate wool board or the wool-cement board [37]. The corn husk particleboard as an insulation material is more rigid and has a lower level of porosity than other solutions on the market. It absorbs less sound, which means that the panel reflects more sound and is, therefore, more soundproof.

The STC level of the panel is still below the STC value of soundproof materials, such as glass, gypsum board, asbestos board, and calcium board. Their STC level is above 26. However, these materials have other advantages, namely they are not fragile, they have a strong bonding with other materials, and they are quite safe for health, easy to recycle, and sustainable.

IV. CONCLUSION

A corn husk particleboard bonded with WSC chitosan proved to be a feasible insulation material. The utilization of bio-based materials in insulation panels is an improvement for the thermal and acoustic properties of a panel, offering a promising alternative for the substitution of multiple synthetic materials.

It was shown that the different target densities have an impact on the values of the Thermal Conductivity (TC), Thermal Resistance (TR), Sound Absorption Coefficient (SAC), Noise Reduction Coefficient (NRC), Transmission Loss (TL), and Sound Transmission Class (STC).

All the experimental particleboards that were tested in this research, had better properties compared to the ones produced exclusively for acoustic and thermal insulation purposes. This study showed that such particleboards are sufficient as insulation materials when used for sound absorption and sound proofing. They may also be efficient for thermal purposes in comparison to other commercial particleboards made from lignocellulosic materials.

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