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Physical Properties of Rice Husk-Pine Wood Particleboard

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Abstract: Rice husk is one types of sustainable and economical agricultural wastes that could produce particleboard as the substitute for solid wood. The problems that encourage this research are due to the increasing of deforestation and the increment demand for solid wood in various industries. Malaysia produces a significant amount of agricultural biomass waste every year. It is noteworthy to mention that agricultural wastes can be fully used in an environmentally friendly way. This study aims to evaluate the properties of particleboard made from rice husk at different fibre loading and mixture. Different formulated composition of rice husk and pine wood shaving was prepared for the production of particleboard by hot pressing at temperature 160 °C for 6 min using Urea-Formaldehyde (UF) resin with additional of ammonium chloride (NH_4Cl) as a hardener. The results showed the density values and moisture content of particleboards ranging from 0.547 to 0.660 g/cm^3 and 8.072 to 8.929 %, respectively. The thickness swelling and water absorption were increased as the increment of soaking time. Besides, the colour of the rice husk-pine particleboards has no significant difference and changes except for particleboard made from 100% rice husk. While the more proportion of pine wood shaving has the better compaction of particleboards, and the addition of grinded rice husk also make the particleboards have fewer voids. This study is expected to reduce deforestation activities and to maximize the usage of agricultural wastes.

Keywords: Particleboard, rich husk, deforestation, production

1. Introduction

Rice husk (or rice hull) is the outer covering on rice grain or seed and is a by-product of rice production during the milling process. It is including hard materials such as lignin and silica which can protect the seed during the growing season. According to Singh, current rice production in the world is estimated to be 700 million tons, in roughly 20 % of the paddy production is paddy residue such as rice husk and rice straw [1]. According to the statistic compiled by the Malaysian Ministry of Agricultural, through the milling and harvesting processes had produced approximately 0.48 million tons of rice husk in Malaysia [2].

Rice husk is a rich waste material in all rice-producing countries. It contains about 30 % to 50 % of organic carbon. Rice husk is considered to be a waste that usually throws or burned in open places, and it may cause environmental pollution and damage to the land [3]. Only a few amounts of rice husk have been used to produce brick, for generating heat for rice dryers, and for gasifiers and steam engines used to power rice mills. Many construction industries had used rice husk as raw material because of its low bulk density (90 – 150 kg/m^3), abrasive in nature, high availability, toughness, unique composition, and resistance to weathering [4].

As the demand to utilize wood-based products were increase because solid wood has the basic features which are more competitively than other materials [5]. In order to ensure the raw material can be supplied continuously, had led to

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extensive logging. Deforestation was caused an enormous impact on biodiversity and loss of habitats, emissions of greenhouse gases, ecological imbalance, flooding, migration of wildlife, and soil erosion [6]. Agricultural waste accounts for 61 % of total waste in Malaysia [7]. These agricultural wastes could produce various useful products such as particleboard that can be used for several applications which not only provides sustainable and cheap resource materials but also reduces environmental pollution [8]. Due to the low supply of high-quality wood, wood wastes and inferior wood had been widely used to produce particleboard as the substituted products [9]. Particleboard is usually used in furniture and floor or wall panels due to its denser, cheaper, and more uniform characteristics compared to solid wood and plywood. Rice husk is one of the agricultural wastes that can be promisingly used to manufacture particleboards. According to United States Department of Agriculture, the global production of milled rice was 488 million tons in 2017. Pinewood shaving has been chosen to add to the production of three-layer particleboards as the surface layers due to it has a higher aspect ratio and good durability compared to rice husk [10].

Particleboard is a wood composite panel made from lignocellulosic materials with a binder or resin under heat and pressure to improve the properties. Generally, particleboards can be classified into seven different classes based on their properties accordance with the British Standard EN 312. The manufacturing process of particleboard is simple and do not require additional process. To manufacture particleboard with equal swelling, smooth surfaces, and good strength, manufacturers preferably use a homogeneous raw material [11]. There are many factors affecting the characteristics of the particleboards and the most prominent such as compressibility, species of wood, hardness, fibre structure, density, type and size of particles, and technique of particle drying. Other factors include particle screening and separation, particle size distribution, type and number of binding agents, method of mat formation, moistening of particles prior to pressing, conditioning, curing conditions, thickness of board [12]. This research aims to evaluate the properties of rice husk-pine wood particleboard at different fibre loading and mixture according to Japanese Industrial Standard A 5908:2003.

2. Methodology

2.1 Preparation of Materials

Three types of particles were prepared to produce the particleboard which were Rice Husk (RH), Grinded Rice Husk (GRH), and Pinewood Shaving (W). All the particles prior to the production of the boards were separately dried using a laboratory oven (Model Memmert UFE 600 Sterilizer) with temperature 80 °C for 4 hours to reach a moisture content of approximately 5 % and keep in the zipped plastic bag to avoid exposure to moisture in the air. The Urea-Formaldehyde (UF) resin was used as a binder. As a hardener, 1 – 2 % ammonium chloride (NH_4Cl) based on the UF resin solids content was added to the UF resin solution.

2.2 Mixing of Particles

A total of eight types of the particleboards were produced with different types and ratios of particles as shown in Table 1. The 12 % of UF resin was added ammonium chloride and sprayed on the particles separately to obtain a homogenized mixture according ratio as shown in Table 2.

Table 1 - Composition of particleboard

Type	Fibre loading	RH (g)	GRH (g)	W (g)
UG Mixture	100 RH : 0 W	755.1	0	0
	60 RH : 40 W	453.1	0	287.7
	40 RH : 60 W	302.1	0	431.5
	20 RH : 80 W	151.0	0	575.4
G Mixture	100 RH : 0 W	604.1	151.0	0
	60 RH : 40 W	362.5	90.6	287.7
	40 RH : 60 W	241.7	60.4	431.5
	20 RH : 80 W	120.8	30.2	575.4

Table 2 - Ratio of adhesive

Particles (%)	100 RH : 0 W	60 RH : 40 W	40 RH : 60 W	20 RH : 80 W
Adhesive (g)	144.3 : 0	86.5 : 57.7	57.7 : 86.5	28.9 : 115.4

** 12 UF resin: 142.6 g + 1 hardener: 1.66 g

2.3 Forming and Pressing

The wooden mould was placed on the steel plate, the particles were distributed manually into the mould by layers. The lid of the mould was then pushed into the mould and manually pre-pressed. After that, the mould and lid have been taken out and the mats were undergoing the hot-pressing process by using the hot press machine (Model Wabash G302H-15-ASTM). Another steel plate was placed on the mat and two stoppers were placed at both sides of the mat and then were pressed into 10 mm thick boards using pressure 15 tons force and press at temperature 160 °C for 6 min. To prevent the particles from contact directly with the steel plates during the hot press process, the release agent (WD-40) has been used.

2.4 Characterisation

(a) Density Test

The density was calculated using the weight of the specimen (m_1) divided by the volume of the specimen (V). All boards are targeted to produce with a density of 400 to 900 kg/m^3 were able to meet the minimum strength requirement of Japanese Industrial Standard (JIS) A 5908:2003. The higher density values, the higher property of the particleboards [13].

(b) Moisture Content (MC)

To determine the moisture content of particleboards, the specimens were weighed (m_1) after conditioning a few days in environmental temperature and also determined the oven-dried weight (m_0) after drying the specimens at temperature 105 °C for 4 hours using a laboratory oven. Moisture content was calculated as follows:

$$MC = \frac{m_1 - m_0}{m_0} \, x \, 100 \qquad (1)$$

(c) Dimensional Stability Test

The weight percentage gain and thickness changes of specimens were measured after immersion in water as stated in the previous study [14]. The specimens' thickness and weight were evaluated before (t_1) and after (t_2) the submersion into the water for 2 hours, 24 hours, 48 hours, 72 hours, and 96 hours at room temperature. The values of thickness swelling (TS) and water absorption (WA) were calculated as following:

$$TS = \frac{t_2 - t_1}{t_1} \, x \, 100 \qquad (2)$$

$$WA = \frac{w_2 - w_1}{w_1} \, x \, 100 \qquad (3)$$

(d) Colour Analysis

For the colour analysis, the relationship between the composition and colour changes of the panel board had been observed. The result of each board may no significant difference in terms of colour due to the surface layer were made by pine wood shavings, other than the single-layer particleboard with 100 % of rice husk.

(e) Void Content

In this study, the void content of particleboards has been observed. The result of each specimen may differ in terms of void content due to the different ratios of the fibre loading. A great number of voids per unit area are sufficient to cause failure under stress and eventually give low strength properties [15].

(f) Statistical Analysis

The data obtained were statistically analyzed using Statistical Analysis System (SAS) software. Analysis of variance (ANOVA) was used to determine whether there were differences in the particleboard with the various ratios on the properties was carried out [14]. Mean separation was carried out using the least significant difference (LSD) method.

(g) Particleboards Specification

The specification of particleboards was measured in compliance with the JIS A 5908:2003.

3. Results and Discussion

3.1 Density Test

The density of the particleboards was determined according to the requirement of JIS A 5908:2003, which was 400 to 900 kg/m^3. The density values were calculated by the average values of six specimens for each type of particleboard. All the particleboards had reached the minimum density requirement from approximately 0.547 to 0.660 g/cm^3 as tabulated in Table 3.

Table 3 - Density of particleboard

Ratio	Mixture	Density (g/cm^3)
100 RH : 0 W	G	**0.561**
	UG	0.556
60 RH : 40 W	G	**0.594**
	UG	0.547
40 RH : 60 W	G	0.595
	UG	**0.660**
20 RH : 80 W	G	**0.580**
	UG	0.566

For constant pressure and the same binder content, the density values were mainly affected by the mixture of grinded (G) rice husk. However, the different composition has no significant influence on the density values of particleboards. The highest density value was obtained from the boards with a ratio of 40 RH: 60 W, while the 60 RH: 40 W boards with ungrounded (UG) rice husk has obtained the lowest density value. Overall, the 100 RH: 0 W, 60 RH: 40 W, and 20 RH: 80 W boards with consist of grinded rice husk have better (higher) density values compared to the boards without the mixture of grinded rice husk, while the boards with ratio 40 RH: 60 W vice versa. The higher density values may improve properties and increases the bending strength of particleboards. Therefore, the 40 RH: 60 W particleboards had better dimensional stability properties (higher density values) in comparison to 60 RH: 40 W boards.

From observation, density of panel with a presence of pine is slightly higher compared to those made from 100% rice husk. This is due to higher density of pinewood compared to rice husk [16]. As compared to grinded (G) rice husk, panel with ungrinded rice husk apparently have course particle. According to previous study, the particleboard with course particles slightly has higher density [17]. Higher density normally will lead to high strength of board panel.

3.2 Moisture Content (MC)

The moisture content (MC) of particleboards was measured before and after oven-dried specimens using a laboratory oven with the temperature of 105 °C for 4 hours. The MC values of particleboards in this study were fulfilled JIS A 5908. This standard required an MC value between 5 and 13 %. As can be seen that the MC values presented in Table 4, the MC values of particleboards obtained in this study were in the range from 8.072 to 8.929 %, which has met the requirement of JIS A 5908.

Table 4 - Moisture content of particleboard

Ratio	Mixture	Moisture Content (%)
100 RH : 0 W	G	8.929
	UG	8.072
60 RH : 40 W	G	8.325
	UG	8.440
40 RH : 60 W	G	8.434
	UG	8.814
20 RH : 80 W	G	8.798
	UG	8.433

The highest MC value was obtained from a board prepared from 100 RH: 0 W with the mixture of grinded rice husk, whereas the minimum value was obtained from that prepared from 100 RH: 0 W without the mixture of grinded rice husk. Overall, there was insignificant influence of different fibre loading compositions. However, from the perspective of mixture, in 100 RH: 0 W, 60 RH: 40 W, and 20 RH: 80 W boards without consist of grinded rice husk have lower MC values compared to the boards with mixture of grinded rice husk, while the boards with ratio 40 RH: 60 W vice versa.

Lower moisture content will irregularly bend the board, while a higher moisture content will affect the strength of particleboards [18]. In all phases of the production process, particleboard's moisture levels are critical. The moisture content defines the board's durability and strength. Moreover, the board's surface appearance and performance are affected by the distribution of moisture.

Chalapud *et al.* [13] reported that the rice husk particleboards with no impregnated tung oil had obtained a higher moisture content of 7.65 ± 0.01 % compared to the impregnated with tung oil particleboards 5.59 ± 0.09 %. It is due to the tung oil filling ability and hydrophobic character caused the particleboards had lower moisture content. While Ciannamea *et al.* concluded that the boards with 11 % of binder content and press at pressure 0.83 MPa have the highest MC of 5.8 ± 0.3 % [19]. While the lowest MC was obtained from the boards with 0.28 MPa pressure and 8 % binder content. Hence, the moisture content of particleboards was affected by the content of the resin and the pressure of pressing.

3.3 Dimensional Stability

The thickness swelling tested the particleboard's reaction to the frequent wetting or exposure to intense moist conditions for certain periods. Whereas the testing of water absorption is to evaluate the water affinity property of the particles. In this testing, six specimens from each type of particleboard were used to immerse in water for up to four days. The thickness and weight of all particleboards were measured before submersion in water and after 2 hours, 24 hours, 48 hours, 72 hours, and 96 hours of submersion in water. The calculations were carried out to obtain the percentages of Thickness Swelling (TS) and Water Absorption (WA) after the thickness and weight of the humidified specimens was measured.

The thickness swelling namely TS2, TS24, TS48, TS72, and TS96 were highly influenced by the interaction between ratio and mixture of particles as presented in Table 5. However, there is no interaction effect was observed for all water absorption properties. Among both parameters, the thickness swelling apparently more affected by the ratio than the mixture.

Table 5 - ANOVA analysis for thickness swelling and water absorption

Source	DF	p-value									
		TS2	TS24	TS48	TS72	TS96	WA2	WA24	WA48	WA72	WA96
Ratio	3	0.0017 ***	0.0001 ***	0.0001 ***	0.0001 ***	0.0001 ***	0.6171 ns	0.9196 ns	0.9813 ns	0.7869 ns	0.3589 ns
Mixture	1	0.6488 ns	0.1400 ns	0.0618 *	0.0438 **	0.0297 **	0.1402 ns	0.1480 ns	0.6484 ns	0.7069 ns	0.5411 ns
Ratio*Mixture	3	0.0065 ***	0.0012 ***	0.0009 ***	0.0010 ***	0.0009 ***	0.2379 ns	0.4718 ns	0.7392 ns	0.5248 ns	0.2901 ns

Note: Experimental coefficient of variation,
ns : Not significant
* : Significantly different at $p \leq 0.1$
** : Significantly different at $p \leq 0.05$
*** : Significantly different at $p \leq 0.01$

Fig.1 shows the thickness swelling (TS) values of particleboards in percentage after 2 hours, 24 hours, 48 hours, 72 hours, and 96 hours of submersion in water. The TS values were the average values of six specimens from the same ratio and mixture particleboards. Overall, the TS values of all types of particleboards with different ratio and mixture were increased as the increment of time. The specimens with the ratio of 20 RH: 80 W have the lowest TS values which indicated high dimensional stability of the board after up to 96 hours of submerged time. While the highest TS values were the boards with the ratio of 60 RH: 40 W. The RH particleboard without wood shaving has low dimensional stability, which indicates that the bonding strength between rice husk particleboard is weak, whereas a high amount of wood shaving gives better stability (low TS values). Besides, 100 % RH board with the mixture of grinded rice husk has comparable TS values with 20 RH:80 W. From the perspective of mixture, there are less significant effect of mixture in the same ratio except in 100 RH: 0 W board. In 100 RH: 0 W and 20 RH: 80 W, the board consists of grinded particles that have better (lower) TS values compared to those with ungrinded rice husk, while 60 RH: 40 W and 40 RH: 60 W boards, vice versa. In general, there are various chemical and anatomical properties in different lignocellulosic materials that may influence their water absorption and swelling. The level of stress and its potential impact on TS depend on the adhesive's ability to tolerate alternating swelling between adjacent particles [20].

Melo *et al.* [21] had evinced that particleboard produced with rice straw showed high water absorption and thickness swelling, which significantly reduced when the particleboards were mixed with wood in the same proportion. The percentage values were the average values of six specimens from the same ratio and mixture particleboards. Meanwhile,

Fig. 2 shows no significant effect on the water absorption (WA) properties of the particleboards with different ratio and mixture, where the WA taken at the same immersion time has a nearly identical quantity.

The WA values were also kept increased with the growth of time. The board with a ratio of 60 RH: 40 W has the lowest WA values which indicated high dimensional stability of board after submerged in water after 2 and 24 hours, however after up to 96 hours submerged time, the 20 RH: 80 W boards have the lowest WA values. The highest WA values were observed from the boards with a ratio of 40 RH: 60 W after 2, 24, and 48 hours, while after 72 and 96 hours the highest WA values were obtained from 60 RH: 40 W board. The board with a higher amount of wood shaving having lower WA values whereby provided better stability of particleboards. Moreover, from the perspective of mixture, there was less significant effect of the mixture in the same ratio. In 60 RH: 40 W and 40 RH: 60 W, the board consists of grinded particles have better (lower) WA values compared to those with ungrinded rice husk. Whereas the board with ratio 100 RH: 0 W and 20 RH: 80 W, vice versa. WA was usually caused by the water spread through the amorphous region of cellulose in raw materials when water penetrates into the board. The result of higher WA values obtained from the board consists of a larger amount of rice husk because the chemical composition of rice husk had interfered in the physical properties and bond quality of the particleboards [20].

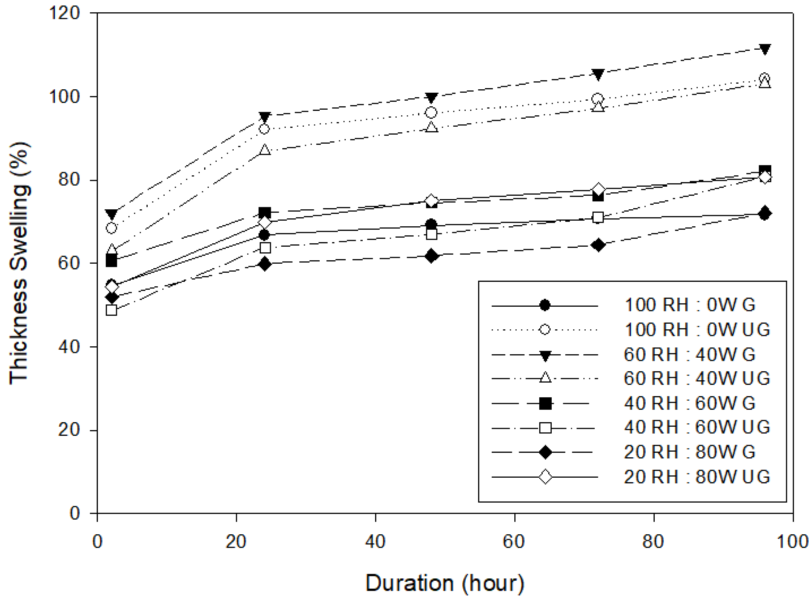


Fig. 1 - Thickness swelling of particleboard

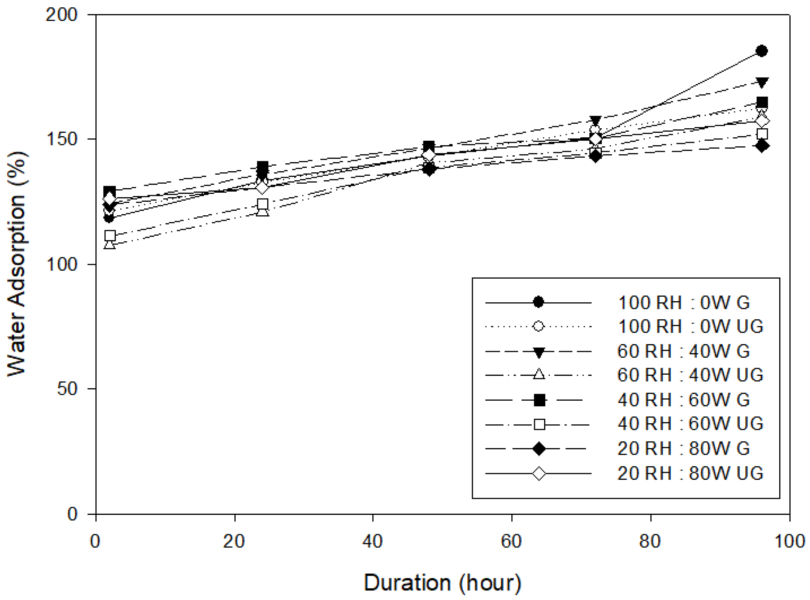
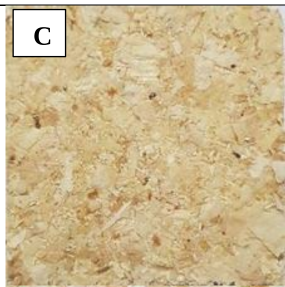


Fig. 2 - Water absorption of particleboard

3.4 Colour Analysis

Surface colour is one of the major criteria in product quality evaluation [22]. Less variation of colour is preferred to have more uniform board panel during application. There were eight types of specimens with different composition of fibre loading and mixture. The colour of particleboards was observed between the relationship of the compositions and colour changes of the panel board. There were two types of particleboards which were the single layer particleboard A and E with 100 % of rice husk and the three-layer particleboards B, C, D, F, G, and H with different ratios of rice husk and pinewood shaving. All three-layer particleboards have a bright brown colour as shown in Table 5, while the single-layer particleboards were brown (darker) in colour. The colour of particles were no changes before and after sprayed resin and undergo the hot-pressing process, only some darker colour stain was due to the uneven resin sprayed. As can be seen from Table 5, in the single-layer particleboards namely A and E, apparently has no difference in colour between added and not added grinded rice husk.

Table 5 - Top view of particleboards with different ratio

	100 RH : 0W	60 RH : 40W	40 RH : 60W	20 RH : 80W
UG Mixture				
G Mixture				

The particleboards in this experiment were only conducted until the hot pressing and trimming process. To commercialize the particleboards to market, the boards need to be complete by sanding and applying coatings or laminating [9]. The process of lamination or coating adds to the aesthetic value of the product and makes it look richer, elegant, and easily treated with fire retardants or with preservative chemicals. After all those processes, the particleboards can be used for various purposes by the end-users either interior or exterior.

3.5 Void Content

The void content of particleboards was observed from the edges part of the specimens. The four types of ratios in fibre loading were 100 RH: 0 W, 60 RH: 40 W, 40 RH: 60 W, and 20 RH: 80 W. While the ratio in mixture were added grinded rice husk into rice husk as shown in Table 6. Therefore, all specimens were look different from the edge view due to the different ratios. The single-layer particleboards were produced by 100 % of rice husk and grinded rice husk, whereas the three-layer particleboards were produced with pinewood shaving on both surface and rice husk in the middle layer.

After the hot-pressing process, the pinewood shaving (outer layer) had better compaction compared to the rice husk (inner layer). From observation, the voids in the rice husk were more obvious. However, the rice husk in specimens E, F, G, and H were seen more compact compared to the rice husk in specimens A, B, C, and D. It may be due to the rice husk in specimens E, F, G, and H had added the grinded rice husk. The convex shape of rice husks created voids or gaps between the particles. When the particles have high void content which means there is lack of inseparable connection. While the finely grinded rice husk particles can fulfil the thicker rice husk particles, thus provides better compression and adhesion between particles. According to Halip *et al.* [15], the great quantity of voids not only leads to lower bonding and strength properties in the particleboards, but also reduces the values of modulus of elasticity (MOE) and modulus of rupture (MOR).

Besides, it can be seen from the figure that specimens D and H which have a ratio of 20 RH: 80 W were more compact and fewer voids compared to specimens A and E with 100 % rice husk. The same goes for the specimens of B, C, F, and G which have 40 RH: 60 W and 60 RH: 40 W, the more proportion of pinewood shaving, the better compaction of particleboards. Hence, the large amount of pinewood shaving can cause the particleboards to have higher strength because pinewood shaving has fewer voids compared to rice husk after compression.

Ota and Okamoto [23] concluded that increasing the amount of rice husk particles in the particleboard was decreased the pore amounts concomitantly. Therefore, the study result indicated that the increment of pore amounts would lead to a decrease in mechanical properties due to it is more likely to fracture.

Table 6 - Side view of particleboards with different ratio

	Fibre Loading	Mixture
100 RH : 0W		
60 RH : 40W		
40 RH : 60W		
20 RH : 80W		

4. Conclusions

The particleboards made form rice husk and pine wood were successfully manufactured. According to the results, all of the particleboards have density values ranging from about 0.547 to 0.660 g/cm^3, and the moisture content of the particleboards manufactured ranged from about 8.072 to 8.929 %. Particleboards' density and moisture content both passed the standards of Japanese Industrial Standard A 5908:2003. Additionally, all three-layer particleboards have a uniform and bright colour surface compared to single-layer particleboards. In summary, the best sample for density and moisture content testing was the composition of 40 RH: 60 W boards compared to other particleboards. While in terms of thickness swelling, water absorption, and void content, the optimum particleboard composition was the 20 RH: 80 W, as it had lower TS and WA values and less voids.

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