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Physical Properties of Homogeneous Particleboard based on Acacia Tree and Polyurethane Adhesive as a Resins

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***Abstract:** The formaldehyde-based adhesives have always been chosen for manufacturer in the making of particleboard because of the cost. However, it has low moisture resistance and high water absorption. At the same time, formaldehyde-based adhesive also produced gaseous emission that can cause cancer and bronchial health. Meanwhile, the high water resistance, low moisture content and healthy to the human body nowadays becomes most important issues in the making of furniture for market. This research was discusses on the ability of Acacia tree as raw material and polyurethane (PU) as an adhesive for making the homogeneous particleboard. The aim of this research is to looking the impact of using different particle sizes from Acacia tree to the physical properties of the end product. This study also focuses on the potential of paraffin wax as a water repellent agent. The testing of physical properties was includes the thickness swelling (TS) testing, moisture content (MC), density and water absorption (WA testing). The size of Acacia particle was varied from x<2mm, 4mm>x>2mm and x>4mm. All particleboards produced was achieve the range of medium density according to the Japan Industry Standard (JIS). The results have shown that the value of the density and the particle size was influenced the result especially for the physical properties. From this research it is proved that the PU as a resin and sawdust of acacia tree with some specific size can be a good binder and material for the particle board industries in future. The paraffin wax also showed a great potential as a water repellent agent based on the reduction of water absorption of the particleboard. The particleboard with sizes between 2mm to 4mm proves better results compared to the smaller or bigger sizes of particle.*

***Index Terms:** Physical properties, polyurethane, paraffin wax, binder, acacia particleboards.*

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I. INTRODUCTION

The increasing of the furniture demand nowadays make more afford to searching new wood supply to replace depending on the wood from the forest as a main material in the making of particleboard [1]. At the same time, urea formaldehyde (UF) as a popular resin in the making process of the particle board production also has to be replaced with others new resin that is healthier and less hazards.

From the previous research, the formaldehyde-based binder group such as melamine formaldehyde (MF), phenol formaldehyde (PF) and urea formaldehyde (UF) known on the good performance and contribute to the low cost issues [2]. However, these formaldehyde-based binders possess lower water and moisture resistance [3]. This situation is significantly effected to the particleboard characteristics [4 - 7]. At the same time, the UF also produced same gases to the environment that can give a harmful effect to the consumer [8]. Consequently, the using of adhesives from natural based such as PU becomes more popular in order to replaces the using of chemical adhesives [8]. The choosing of resin becoming critical because it can influence the structure of molecule binder, level of water resistance, humidity and temperature, volume fraction and porosity [9 – 11].

In this research, the natural based polyurethane (PU) adhesive which from palm kernel oil will be used as a resin or binder in the making of particleboard. PU is a chemical reaction between polyol and isocyanate. This polymer is made up of urethane group. PU actually used in many types of purposes such as insulation for building, devices for medical, clothing for athletic, adhesives, solid plastics, foams, sealants and many others thing. Meanwhile, the selection of Acacia tree (abandon tree in Malaysia) as a raw material can increase the value of the acacia tree to be a useful marketable species. It will reduce the deforestation activities which caused the climate change, increased the greenhouse gases to the atmosphere, flooding and soil erosion. The aim of this research is to produce a medium density particle board based on Acacia sawdust by using the natural based (polyurethane) as the resin.

This research also focuses on the impact of using different particle sizes (Acacia sawdust) with palm kernel oil-based PU as an adhesive to the physical properties of the specimen or particle board. At the same time, the influence of PW as a water repelling agent was also be investigated.

II. MATERIALS AND METHODS

A. Materials

The selection of Acacia tree as a fiber material in this research is to reduce the forestation activities. For the time being, the acacia tree species is also known as an abandon tree and grow wildly in Peninsular Malaysia. By using the waste such as the branches of Acacia tree, it will increase the value of this species and avoid the air pollution because of open burning activities from the farmer.

All the components in the table 1 are the main factors in the making of particle board.

Table. 1 List of materials used

Component	Types
Fiber/Particle	Acacia tree
Resin	PU adhesive
Filler	Paraffin Wax

B. Preparation of Acacia Sawdust

The branches of Acacia tree were grinded using grinding ball machine type Pulverisette 7 from FRITSCH Model to get uniform size of particle as shown in fig.1. The sizes of particles were x <2mm, 4mm>x>2mm and x>4mm. After sieving process, all the particles were dried in an oven for 24 hours. The temperature was set at 80°C to obtain the moisture content or MC at between 2% to 6%. This process is very important before the fabrication process [1].

Fig. 1 Grinding Balls Machine

C. Production of Particleboards

In the manufacturing of particleboard, polyurethane (PU) adhesive was used as a main resin. There are three different sizes (material) from Acacia tree were used such as x <2mm, 4mm>x>2mm and x>4mm. The research density was set at medium density range between 400 kg/m^3 to 950 kg/m^3 according to the Japanese Industry Standard (JIS) [12]. However, the target density for the research was set at 750 kg/m$^{3.}$ The percentage of filler was fixed to 5% for all particleboard formulations. From the table 2, it was shown the processing parameter used during the hot press machine process (HPM). The pressure of process was set at 160 (bar) and the temperature was set at 120^{0}C [5].

Table. 2 Parameters for particleboard production

Parameter	Details
Target density (kg/m^3)	750
Pressure Time (min)	5
Pressure (bar)	160
Temperature (^{0}C)	120

Meanwhile, the table 3 was shows the mold dimensions for making the specimen. It was mention the types of testing and the specific of dimension for each mold. From that, it shown the size of mold for moisture content (MC) was 100mm x 100mm x 10 mm. Meanwhile, for the Water Absorption and Thickness Swelling (TS) was set at 50mm x 50mm x 10mm [12 – 13]. Actually, all the size of mold in this research was follow the Japanese Industry Standard (JIS).

Table. 3 Dimension of Mold

Types of Testing	Dimension
Moisture Content	100 x 100 x 10 mm
Water Absorption and Thickness Swelling	50 x 50 x 10 mm

The formulations of particleboard are indicated in the table 4. The PU adhesive actually is creating by reacting between the isocyanides and polyol (palm kernel oil) with a ratio of 1:1 [5]. Meanwhile, the weight of dust wood of Acacia was calculated using the Equation 1 below:

$$\rho = m/\nu \qquad (1)$$

The Acacia particles were blended together with PU adhesive and filler (PW) and the mixture was stirred until it well blended. Then the mixture was fit into the mold and pressed by using a hot press machine (HPM) for 5 minutes [1] in 120°C. The table 2 was shown the pressure, temperature and time settings during the process.

Table. 4 Formulations of particleboard

Sample	Particle Size (mm)	Acacia Particles (%)	Resin, PU (%)	Filler, PW (%)
A70PW	<2			
B70PW	2 - 4	*70*	25	5
C70PW	>4			
A65PW	<2			
B65PW	2 - 4	65	30	5
C65PW	>4			

The picture of specimens after hot press machine process is shown in Fig.2.

Fig. 2 Particleboard specimens

D. Physical Testing Particleboard Panels

The determination of TS and WA were performed according to the Japanese Industry Standard (JIS A 5908) with size of 50mm x 50mm x 10mm. In this research, the specimens were immersed in clean water for 24 hours at 20^{0}C of temperature [3].

The specimens were weighed before soaking it into the water. Then, the specimens were removed from water after the first 2 hours. It will be cleaned and dried by using a clean dry cloth. After that it was be re-weighed and the reading will be recorded.

The same process went to the specimens within 24 hours [11 – 12] until finish. The data were recorded for each sample during the process and the percentage of WA percentage is calculated based on the reading13 – 14].

Table. 5 Physical properties of Acacia based particleboard

Sample	TS (%)	WA (%)		MC (%)	Density (kg/m^3)
	2h	2h	24h		
A70PW	5.10 ±1.49	17.65 ±7.90	29.92 ±7.54	5.19 ±0.25	709.82±5.73
A65PW	6.47 ±0.59	14.39 ±6.62	24.75 ±6.09	5.63 ±0.25	710.88±11.3
B70PW	6.45 ±1.63	22.09 ±7.74	34.24 ±7.04	6.02 ±0.32	692.67±9.87
B65PW	5.43 ±1.44	8.46 ±2.42	15.63 ±1.77	5.86 ±0.31	702.83±9.35
C70PW	9.69 ±3.64	20.2 ±8.03	29.02 ±2.51	5.83 ±0.28	686.67±6.73
C65PW	6.62 ±2.55	14.62 ±1.83	26.08 ±7.32	5.48 ±1.05	679.67±11.39
JIS and MS (Standard)	12 (max)			5 –13	400 – 950

The value of the WA determined by using the formula as shown in the Equation 2:

$$WA(_t) = \frac{W(_t) - W_o}{W_o} \times 100\% \quad (2)$$

Where the WA($_t$) is mention as percentage of water absorption at time t. Meanwhile the W_o is mention as initial weight and the W($_t$) is mention as final weight at a given immersion of time t. The evaluation of TS was carried out by using the micrometer caliper. The value of specimen thickness during the testing was measured at the center of specimen before soaked into the water at 20°C [14]. After that, the specimen was soaked into the water for the first 2 hours [15 – 16]. After that, the specimens were removed from water and it will dried by placing it on a soft tissue for 30 seconds. Measurements will continue to be carried out there after according to Japan Industrial Standard (JIS). The values of the TS were determined by using the formula as shown in Equation 3:

$$TS_{24} = \frac{T_{24} - T_0}{T_0} \times 100 \quad (3)$$

Where the TS_{24} is percentage of thickness swelling of specimen. Meanwhile, the T_0 is mention as initial thickness and the value of T_{24} is mention as final thickness. The MC values were calculate by looking to the weight (specimens) before and after process. It was use the drying oven at 24 hours for 80°C [4] for the second time. The MC value was determined by using formula given in equation 4:

$$MC\ (\%) = \frac{W_a - W_0}{W_0} \times 100 \quad (4)$$

Where the MC is mention as a moisture content with W_a is mention as an air dried weight and the W_o is mention as an oven dried weight.

III. RESULTS AND DISCUSSION

The density, WA, TS and MC values of particleboard were recorded and analyzed as indicated in table 5. All values in the Table 5 were average of reading from three specimens of Acacia particle sample size.

A. Density of Particleboard

The A65PW sample shows the highest value (710.88 kg/m^3) of the specimen density while the C65PW sample was demonstrates the lowest value (679.67 kg/m^3) of the specimen density, respectively. Fig.3 it was shows that the density of particleboard is decreased when the particle size of Acacia increased. In other word, the value of the density profile for the particleboard is significantly dependent on the particle configuration.

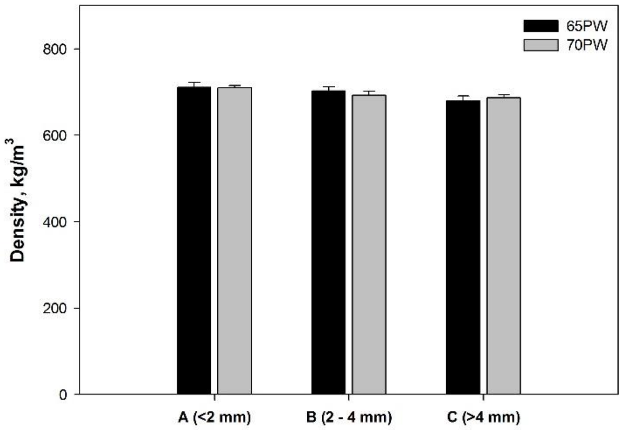

Fig. 3 Density of particleboards

In this research, the densities of all particleboards can be classified as medium density of particleboard according to Japanese Industry Standard (JIS). This is very important step to aware because it always give effected to the mechanical and physical properties of particleboard [1]. Besides that, the rise in the density value always led by the higher of the compaction ratio in the particleboard [2].

Meanwhile, Noorbaini et al. reported that the value of the density of the particle board will be increased when the properties of mechanical and physical ware also improved [8]. Lias et al. [1] in his research with title Investigation of influences for particleboard density and the particle sizes on Kelampayan based homogenous particleboard also stated that the percentages of water absorption (WA) value and the thickness swelling (TS) value also increased as the density of particleboard increased. This statement was agreed by Butylina et al. in his research [9].

B. The effect of different particle sizes on Moisture Content (MC) test for particle board.

The effect of particle size on moisture content (MC) is shown in Fig.4.

The average of MC value was in the range of 5.19 to 6.48%. From the figure, it is shown that the value of MC was increased with increasing size of particle.

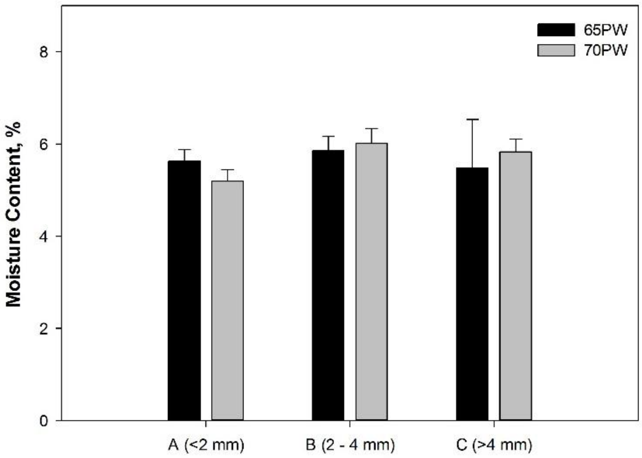

Fig. 4 Moisture content value of Acacia based particleboards

From the Fig.4, it is observed that the ratio of Acacia particles and PU adhesive (resin) affect the MC values of the particleboard. More resin in the particleboard resulted in higher MC. For instance, the A70PW has more particles compared to the A65PW but it has less resin compared to A65PW. It also has the same pattern of result goes the other particleboards. However, from this experiment, all of the MC results have met the JIS requirement which is between 5% – 13% [12]. The results showed that A65PW has the higher MC compared to the A70PW. The same pattern also to the B65PW and B70PWwhich the MC for B65PW was higher than B70PW. For the C65PW also shown the higher result of MC compared to the C70PW.

C. The effect of different particle sizes on Thickness Swelling (TS) test for particle board

The thickness swelling (TS) characteristic on the specimen always be describes the dimension and stability of the particleboard itself. It can be proven by running the Scanning Electron Microscopy or SEM testing. The lowest value of TS means the specimen has a good dimensional and stability. The good average of TS value were in the range of 5.1% to 9.69%. For the C70PW sample, it was shows the lowest value of TS was 5.1%. Meanwhile, for the A70PW sample was demonstrates the highest TS value is of 9.69%. From Table 5, it was shown the particleboard produced by using PW as a filler had the good result of TS. It was reach to 9.69% and the minimum value for TS was reach 5.1%.

This research shows the value of TS decreases with the increasing of the particle size. This result was supported by the research from Lias et al. [1], where the influence of particle size on WA and TS is significant. Niemz and Steinmetzler also stated that the increase of thickness swelling values reflects the higher density of particleboard [4] and it is crucial to its physical properties.

Meanwhile, Chiang et al. [11] in their research found that the value of swelling for the specimen was increased when the densification of the wood also increased. This statement also supported by Ghalehno et al. [17]. However, in this research, all the TS values did not show the same characteristic with others research. The result of TS shows when the density increased the value of TS was decreased. This might be happened because of the particle size [18]. However, all the TS result in this research still achieved the Japanese Industrial Standard (JIS) requirement which the result of experiment is do not beyond than 12% of swelling for 2 hours soak in the water.

D. The effect of different particle sizes on Water Absorption (WA) test for Particle board

The water absorption or WA values for particleboard specimen after soaking for 2 hours and for 24 hours are shown in Fig.5. PW as filler is added to study the ability of particle board to prevent water absorption. From Fig. 5, it is observed that the B65PW sample which from particle size of 2 – 4 mm has an excellent ability to repel water with WA of 8.46% (2h) and 15.63% (24h).

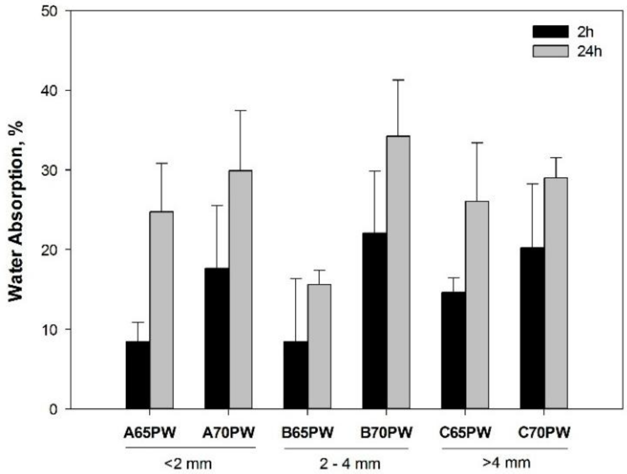

Fig. 5 Water Absorption

Nascimento et al. reported that the values of WA for medium density of the particle boards which employed from Eucalyptus and Pinus had an average value between 12% and 16% for water absorption in 2 hours [19]. Valarelli et al. [20] also reported the similar results for the particleboards from bamboo and castor oil based adhesive.The effect of particle size of material on the water absorption is not significant. However, from both results (WA and TS), it shows the ability of particleboards to produce the lower percentage of WA was increased as the ratio of resin was reduced. In the other words, the decreasing of the resin will increase the WA and TS result. This result was agreed by Aigbidion et al, in his research [21].

IV. CONCLUSIONS

From the research results, it shown that the acacia tree and palm kernel oil based polyurethane adhesive has a great potential as an alternative of wood and urea formaldehyde as a resins. The physical properties of the particleboard produced also have met the standard of Japanese Industry Standard (JIS).

It is proved that the smaller particle size produced the particleboard with higher density. At the same time, the higher result of density leads to lower result of moisture content (MC). However, the thickness swelling (TS) decreased. It might be happened because of particle size influent.

It is also showed that the particleboard with particle size between 2mm to 4mm has a better physical properties result. Therefore, it can be concluded that the particle size and paraffin wax as a water repelling agent were significantly affect the physical properties of the specimen. However, the further research need to be done especially on the mechanical properties such as modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB). This is very importance before the Acacia tree species can be commercialized as main raw material for particleboard industry.

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