Study on the Effect of Different Adhesives on Properties of Hybrid Plywood from Coconut and Rubberwood

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Abstract

Shortage of wood as a raw material has forced wood-based industries to find alternative local raw materials. This study was undertaken to determine the properties of hybrid plywood from coconut and rubberwood veneer of different adhesives used and glue-spread rate. Experimental plywood panel from coconut veneers bonded with Polyvinyl acetate (PVAc) and Phenol formaldehyde (PF) were produced with adhesive spread levels; 180g/m^2 and for single glueline. The physical and mechanical properties were then accessed. The results show that hybridisation of coconut with rubberwood improves some properties of plywood, such as bending strength, tensile shear strength, water absorption and thickness swelling, and density. The tensile shear strength was higher in panel bonded with PF at 180g/m^2 compare with PVAc. The panels glued with PF using 180g/m^2 spread level showed better in MOR and MOE compare with plywood bonded using PVAc. Density of panel manufactured using PVAc using 180g/m^2 spread level was higher compare with panel bonded with PF. Water absorption and thickness swelling rate were slightly lower for plywood manufactured using PF at 180g/m^2.

Keywords: *plywood, coconut, rubberwood, veneer, PF, PVAc, spread level*

INTRODUCTION

Wood-based composite products are commonly substituted for solid wood in today's building structures. Structural and non-structural engineered wood composites based on oriented strand board (OSB), plywood, medium density fiberboard (MDF), laminated veneer lumber (LVL), thermoplastic wood fiber blends, etc. are now used in both interior and exterior applications (Laks, 2002). Their use, however, is often limited due to high sensitivity to moisture and decay (Baileys et al., 2003).

In wood-based industries, the shortage of wood as a raw material has recently become a great concern. Many plants that produce wood-based products, especially plywood and lumber, have already closed down. Wood-based industries are now facing a problem with the supply of raw materials, not only from natural forests, but also from rubber plantations. Annually, it is estimated that at least 20 million tonnes of solid wood is used in wood-based industries. Therefore, wood-based industries must find alternative sources of local raw materials. Some common species and lignocellulose plant like *Acacia*, rubber wood, coconut and oil palm currently appears to be most viable alternative.

The industry was established in the pre-war days, but it was only the late 60's that expansion of plywood industry really began (Ong, 1976). However, Lian, (1966) mentioned that the first mechanized plywood mill in Peninsular Malaysia was erected in 1956. Plywood was originally produced from tropical hardwood before shifted to rubber wood and *Acacia*. Plywood industry is the second most important wood industry after sawmilling, hut has been suffering from a structural recession since the first oil crisis. Indonesia, now the largest exporter of plywood in the world, has 40% of the ordinary plywood market of Japan. The demand for plywood in world market will be increase according to the sales and demand especially in Asia, Europe, and North America.

As the time erect, plywood had major problem in getting raw material at competitive price. Shortage of wood as a raw material has forced wood-based industries to find alternative local raw materials. Lignocellulosic materials like oil palm biomass, jute and kenaf were said could be useable wood aggregate in manufacturing wood based panel products.

The plywood manufacturing process is unique, because of a highly variable raw material is manufactured into a product that is stronger and certainly more versatile than original tree (Burble, 1972). Plywood has filled the demand for a construction material that is flight, flat, and strong. Its competitive advantages are manifold. The standard panel size, four feet by eight feet, speeds on-site and factory construction, resulting in lower construction, resulting in lower construction costs.

Coconut palm is a tropical crop and grows best when favoured with a hot moist climate. Grown in more than 80 countries of the tropics, it is the most important of all cultivated palms. Botanically, the coconut palm is Coros nufifera L. and belongs to the natural order Arecaceae (Palmae), an important member of Monocotyledons. The estimated total area under coconut in the world in 2001 was 11.8 million ha.

The coconut palm has a variety of uses. Every part of the palm is useful to mankind in one way or the other. It supplies food, drink and shelter and also raw materials for a number of industries. The coconut palm is one of the most important sources of vegetable oil in the world. Coconut palm also developed an industrial and commercial use in coir. In coconut leaves, there are used for making brooms in India. Coconut trunks are used for building small bridges. Besides, from the roots there are used as a dye, a mouthwash, and a medicine for dysentery.

Rubberwood as an important agriculture plantation in Malaysia early it was introduced until now. Today rubberwood is the most important material that used by furniture manufacture. Rubberwood is now advertised as an "environmentally friendly" wood, as it makes use of plantation trees that have already served a useful function. It is fairly easy to work, and glues well which it is mostly used in the form of engineered lumber (finger-jointed) which eliminates some of its disadvantages. Also, as it is a by-product and plentiful, it is cheap, which makes it a very popular material in the countries with plantations (Anon, 2010).

MATERIALS AND METHODS

Raw Material Preparation

Rubberwood and coconut veneer

Rubberwood veneer was obtained from Malaysian Timber Industry Board (MTIB), Kuantan Pahang. Coconut veneer was supplied by Forest Research Institute Malaysia (FRIM). Moisture content and thickness of the veneer will be measure before go to the next process. Also, the veneer randomly pick without crack to ensure that getting the high quality of board.

Adhesives

Phenol formaldehyde (PF) and Polyvinyl Acetate (PVAc) were supplied by the Malaysian Adhesive Company (MAC). Adhesives spesification likes moisture content, viscosity, and solid content have been provided by AkzoNobel.

Preparation of hybrid plywood

The coconut veneers were cut with dimensions of 400mm × 400mm × 3.0mm. While for rubberwood veneers were cut to the dimensions of 400mm × 400mm × 2.0mm (width x length x thickness). Veneer was oven dried for 24 hours at 90°C until 10–12% moisture content. The determination of moisture content was carried out in accordance with BS EN 322:1993. The moisture content of the samples was measured by placing the samples in a drying oven at a temperature of 105 ± 2°C for 24 hours.

The samples were then arranged into 3-ply hybrid plywood alternately consisting of rubberwood and coconut where the arrangement is parallel to the grain, as shown in Fig. 1. The veneer was glued using PF and PVAc with 180g/m^2 spread level using single glueline respectively. They were then hot pressed for 3 minutes at 140°C for PF, using 14 bars (203 psi) pressure. While, 9 min at a temperature of 70°C for PVAc, at approximately 10 bars (145 psi) pressure. Which are replicate 3 board for PF and 2 board for PVAc at each adhesives.

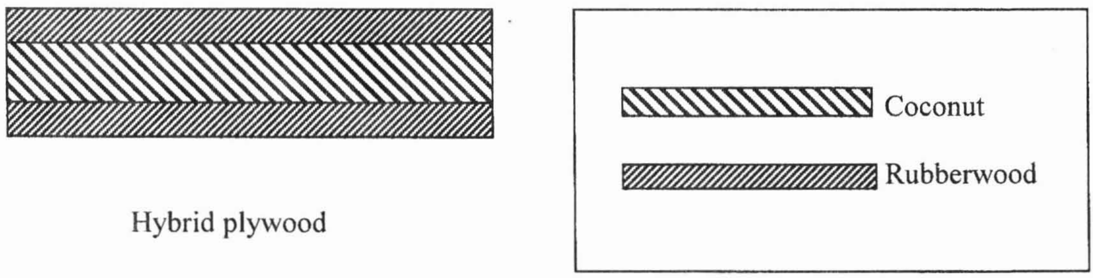

Figure 1: Arrangement of coconut and rubberwood veneer

Moisture content and density determination

The sample of moisture content was cut into the size (25mm x 25mm) and then place in the oven not exceeding 120°C for one day. Where, replicate 8 sample for PF and 3 sample for PVAc at each adhesives. The density of plywood was determined by measuring the mass and volume of each sample. Each sample was weighed to an accuracy of 0.01 g by using an analytical balance. The mass of each board was obtained by calculating the arithmetic mean of the mass of all test samples taken from the same board. The dimensions of each test sample were measured using a sliding calliper, in accordance with BS EN 325:1993. The volume of the samples was obtained by multiplying the length, width and thickness of the samples. The determination of moisture content was calculated using the following equation:

$$MC\ (\%) = \frac{W_{AD} - W_{OD}}{W_{OD}} \times 100$$

Where W_{AD} is the weight air dry and W_{OD} is the weight oven dry.

Determination of density was done in accordance with BS EN 323:1993, using the following formula:

$$D\ (Kg/m^3)\ \frac{m}{v}\left(\frac{Kg}{m^3}\right) =$$

where m is the mass and v is the volume of the plywood sample.

Bending Strength

The bending test was performed according to BS EN 310:1993 using an Instron Model 5569 testing machine. The bending test was carried out using rectangular strips with dimensions of 300mm x 50mm x 12mm. The lengths, widths and thicknesses of the samples were measured and recorded. Samples were tested at a crosshead speed of 10mm/min and span of 240mm. All the specimens were conditioned at an ambient temperature of 25 ± 3°C and at a relative humidity of 30% (±2%) before testing. Where it replicate 6 samples for each adhesives.

Tensile Shear Strength

The number of panels sampled shall be in accordance to BS 6566 using an Instron Model 5569 testing machine. The shear test was carried out using rectangular strips with dimensions of 135mm x 25mm x 12mm. The lengths, widths and thicknesses of the samples were measured and recorded. Samples were tested at a crosshead speed of 1.5mm/min. All the specimens were conditioned at an ambient temperature of 25 ± 3°C and at a relative humidity of 30% (±2%) before testing. In testing machines provided with a means of controlling the rate of increase of load, the rate of increase of load shall be between 1.3 kN/min and 2.7 kN/min. In testing machines where control is of the rate of separation of the straining heads, the rate of separation shall be between 6 mm/min and 12mm/min. The testing machines shall be such that at least one grip is free floating to allow alignment of the specimen. The distance between the clamps shall be 50mm to 60mm, with the specimen mounted centrally. Three test pieces shall be cut from each panel sampled. The test specimen shall be of rectangular form, 135 ± 0.2mm long (in the direction of the face grain) and 25 ± 0.1mm wide. It shall be free be of obvious strength reducing defects.

Water absorption and thickness swelling

The sample was cut into the size (25mm x 25mm). Then, the samples were soaked in water for 24 hour. The weight of sample will be recorded at every 2 hour until the value is constant at 24 hour. The rate of water absorption increased with immersion time of the samples, before stabilising. The absorbed water (A) and thickness swelling (G) of the samples were calculated as percentages, according to the procedure of BS EN 317:1993. The amount of absorbed water was calculated using the following equation:

$$A\ (\%) = \left(\frac{M1 - M2}{M2}\right) \times 100$$

where M2 is the weight before the test and M1 is the measured weight (g). The thickness swelling was calculated using the following equation:

$$G(\%) = \frac{A1 - A2}{A2} \times 100$$

where A2 is the thickness before the test and A1 is the thickness (mm) after the test.

RESULTS AND DISCUSSIONS

Moisture content and Density

Table 1 showed the moisture content (MC) of hybrid plywood with different adhesive with same spread levels. The results showed that plywood using PVAc exhibited higher MC as compared to plywood glued with PF. The extremely rises of MC can be seen obviously for hybrid plywood produced from PVAc for 24 hours period. Razali and Diong (1998) also reported that moisture content peaked at the end of the storage period. Biological activity was intense in the early stage of the storage period.

Table 1:Moisture content of hybrid plywood

Adhesives	MC (%) Plywood
PF	9.66 (0.41)[a]
PVAc	12.83 (0.49)

[a]Values in parenthesis are standard deviations.

Table 2 showed the density of hybrid plywood with glue spreads of 180 g/m^2 using PF and PVAc. During experiment, it observed that the glue spreads of resin and the compression of the veneer during hot pressing affect the density of the plywood. The plywood using PVAc showed higher densities than the plywood glued with PF as shown in table 2. In contrast to the PVAc glued samples, the PF glued samples showed lower densities. This effect can due to the raw materials density, which affects the plywood density. In addition to the raw materials density, the adhesive properties of the resin also contribute to the density of the plywood as mentioned by (Sulaiman et al.,2009).

Table 2:Density of hybrid plywoods

Adhesives	Sample	Density (kg/m^3)
PF	Coconut + Rubberwood	644.8 (34.31)[a]
PVAc	Coconut + Rubberwood	743.34 (14.35)

[a]Values in parenthesis are standard deviations.

Bending properties

Bending test results were obtained for hybrid plywood using PF and PVAc. Tests were performed to investigate the effects of hybrid coconut veneer with rubberwood veneer on the mechanical properties of the plywood. Table 3 showed the bending strength and bending modulus of hybrid plywood as compared to different adhesive. Clearly, the bending strength of hybrid plywood using PF is higher than that of

PVAc. Overall, the results showed that hybrid plywood using PF exhibited higher bending strength than hybrid plywood using PVAc.

As shown in table 3, hybrid plywood using PF possesses a higher bending modulus than hybrid plywood using PVAc. Higher values of bending modulus were found for panels made using PF compared to panels made using PVAc. This can be because of the fact that PF resin, when properly cured, often is tougher than the wood itself and results in a higher bending modulus as stated by (Richard, 1995).

Table 3: The result of bending strength of hybrid plywood

Adhesive	Sample	MOR (MPa)	MOE (MPa)
PF	Coconut + Rubberwood	34.58 (18.43)[a]	5567.13 (2660.62)
PVAc	Coconut + Rubberwood	22.17 (7.50)	3664.18 (821.26)

[a] Values in parenthesis are standard deviations.

Shear properties

The shear properties of hybrid plywood were also studied. Table 4 shows the shear properties for samples with same glue spreads using PF and PVAc. It can clearly be seen that the bond strength of plywood panels decreased when using PVAc; the highest mean bond strengths were found in the hybrid plywood using PF.

Poor wettability is considered an indicator of poor bond durability. Wettability is recognised as an mportant criterion in evaluating the bondability of wood, and contact angle reflects the physical and chemical affinity between a wood surface and an adhesive.

The glue resin used for bonding also plays an important role in the wettability of the plywood. From table 4, it can be seen that hybrid plywood using PVAc has lower shear strength. PF adhesive showed poor wettability and a hydrophobic surface; consistent with findings by (Ismail and Gursel, 2007).

Table 4: The result of shear strength of hybrid plywood

Adhesives	Sample	Shear (MPa)
PF	Coconut + Rubberwood	3.39 (0.36)[a]
PVAc	Coconut + Rubberwood	2.34 (1.59)

[a] Values in parenthesis are standard deviations.

Water absorption and thickness swelling

Table 5 shows the water absorption percentage of hybrid plywood with different adhesive with same spread levels. The results showed that hybrid plywood using PVAc has higher water absorption capacity than PF. Greater water resistance properties were seen for hybrid plywood using PVAc adhesive at 180g/m^2 glue spread levels, compared to panels made using PF. PF gives better moisture stability to plywood than PVAc does due to greater cross-linking density and the higher methylene content. The hydroxyl group will absorb moisture or water through the formation of hydrogen bonds as reported by (Abdul Khalil et al.,2007).

Study carried out by Sreekala et al., (2002) showed that the weak compatibility between the fibre surface and the adhesive could lead to the formation of void structures within the composites, which facilitates water absorption.Many physical properties of plywood are affected by the amount of moisture present in the plywood. Plywood exhibits greater dimensional stability than most other wood-based building products. Thickness swelling is independent of panel size and thickness of veneer by as stated by (Kelly, 1994).

Table 6 showed that the hybrid plywood for PVAc exhibited more thickness swelling than hybrid plywood for PF.This test also showed that the thickness swelling values of composites increased with lengthier periods of exposure to water. By increasing the exposure time of plywood in water, a significant amount of water was absorbed, resulting in the swelling of the fibres. The type of resin used may also affect the thickness swelling of the plywood. In the case of amino resins, bond deterioration takes place upon exposure to water and moisture due to the hydrolysis of their aminomethylenic bond as reported by (Pizzi, 1994), whereas fibres are hydrophilic in nature because of an abundance of hydroxyl groups that are not compatible with the hydrophobic matrices of PF as mentioned by (Abdul Khalil et al., 2008).This incompatibility leads to low fibre–matrix interfacial bond strength, poor wetting of the fibres by the matrix resin, and a reduction of mechanical performance when exposed to moisture.

Table 5: The water absorption of hybrid plywood

Adhesives	0 Hour	2 Hour	4 Hour	6 Hour	8 Hour	10 Hour	24 Hour
PF	0	32.74	47.43	49.46	56.67	61.68	72.72
	(0.00)[a]	(3.79)	(4.13)	(4.07)	(4.93)	(4.99)	(7.43)
PVAc	0	36.61	42.17	42.77	43.75	46.68	56.38
	(0.00)	(4.79)	(6.59)	(4.98)	(4.49)	(4.92)	(6.15)

[a]Values in parenthesis are standard deviations.

Table 6: The thickness swelling of hybrid plywood

Adhesives	0 Hour	2 Hour	4 Hour	6 Hour	8 Hour	10 Hour	24 Hour
PF	0	32.74	47.43	49.46	56.67	61.68	72.72
	(0.00)[a]	(3.79)	(4.13)	(4.07)	(4.93)	(4.99)	(7.43)
PVAc	0	36.61	42.17	42.77	43.75	46.68	56.38
	(0.00)	(4.79)	(6.59)	(4.98)	(4.49)	(4.92)	(6.15)

[a]Values in parenthesis are standard deviations.

CONCLUSIONS

This research reported on the use of hybrid coconut and rubberwood as promising raw materials for plywood. The aim of this study, as mentioned above, was to determine the physical and mechanical properties of hybrid plywood. From the research, it can be concluded that hybridisation of coconut with rubberwood improved some properties of plywood, such as bending strength, tensile shear strength, water absorption and thickness swelling, and density. The tensile shear strength was higher in panel bonded with PF at 180g/m^2 compare with PVAc. The panels glued with PF using 180g/m^2 spread level showed better in MOR and MOE compare with plywood bonded using PVAc. Density of panel manufactured using PVAc using 180g/m^2 spread level was higher compare with panel bonded with PF. Water absorption and thickness swelling rate were slightly lower for plywood manufactured using PVAc at 180g/m^2. In conclusion, coconut can be used to substitute raw materials to produce plywood, which will eventually increase the added value of these residues for use as interiors or exteriors.

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