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Study on Dimensional Stability Properties of Laminated Veneer Lumber from Oil Palm Trunk Bonded with Different Cold Set Adhesives

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Abstract: The study was conducted to determine the dimensional stability properties of Laminated Veneer Lumber (LVL) from Oil Palm Trunk (OPT) bonded with three different cold set adhesives namely Emulsion Polymer Isocyanate (EPI) and polyvinyl acetate (PVAc). Three-ply experimental LVL from OPT veneers were bonded using two adhesive spread levels, 250 and 500 g m^{-2} for single glue line. Laminated veneer lumber from rubberwood was used as control. The dimensional stability properties investigated include dimensional changes associated with changes in relative humidity of 30 to 90%, hysteresis over a range of 30 to 90% and durability against biological attack through soil burial. Amongst the three adhesives, OPT LVL manufactured with EPI (VAc) had the highest Fibre Saturation Point (FSP) and the least was experienced by OPT LVL bonded with PVAc. Totally, the magnitude of hysteresis was below 1.00 which in the average 0.69 to 0.82 for OPT LVL panels while rubberwood LVL, 0.81 to 0.94, respectively. Overall, the dimensional stability properties of LVL from OPT bonded with cold setting adhesives namely EPI (SBR), EPI (VAc) and PVAc were found to be comparable with rubberwood.

Key words: Laminated veneer lumber, oil palm trunk, emulsion polymeric isocyanate, polyvinyl acetate

INTRODUCTION

The oil palm residues can be utilized to produce various types value added products which mean the resources of the substitute's material on wood based industry. Hence, there are intensively research works being carried out for converting Oil Palm Frond (OPF) and Oil Palm Trunk (OPT) into commercially composite panel products by using variable technologies (Sulaiman *et al*., 2008; Ho *et al*., 1985). For example, most of the OPT have been used for making various types of wood such as plywood, lumber or even saw-wood. Furthermore, Laminated Veneer Lumber (LVL) produced from OPT can be used for making furniture and partition walls due to the flexibility that enable designers and manufacturers to create furniture in various shapes and forms by using the mould design (Mohd Ariff *et al*., 2007; Abdul Hamid, 2006).

However, the utilisation of oil palm by-products in wood composites is still limited due to its properties especially low average density and density gradient exist in the radial direction of OPT. And these drawbacks may influence the stability and strength properties of the products (Husin *et al*., 1986). Beside that, formaldehyde-based adhesives such as urea-formaldehyde (UF) and phenol-formaldehyde (PF) were used in most of the laminated products from OPT. Emission of formaldehyde associated to health hazards that are produced from formaldehyde based adhesives. Therefore, substitution material, especially formaldehyde-based adhesives to free formaldehyde, in wood products is vital to reduce pollutants from building materials and to control indoor air quality (Shukla and Kamdem, 2007).

Visual and structural problems in final products may result from the dimensional changes that cause shrinkage and swelling of wood. Various finishes and treatments may be used to slow this process, but, in general they do not stop it. According to Tsoumis (1991), the hygroscopicity properties might be associated with chemic composition which originated from wood. A lot of studied (Hashim *et al*., 1997; Ellis and O`Dell, 1999;

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Uysal, 2005) had been carried out to dimensionally stabilized wood in preventing any problems associated with shrinkage and swelling, however their success has been limited.

In this study, the dimensional stability of LVL made up from OPT bonded with cold setting adhesives made using polyvinyl acetate (PVAc) or Emulsion Polymer Isocyanate (EPI) was emphasized. These adhesives were used to determine the suitability of cold set and free-formaldehyde adhesives in manufacturing LVL. Adhesive that does not emit formaldehyde normally classified under cold setting adhesive. Furthermore, the study on this type of adhesive is very limited.

MATERIALS AND METHODS

Samples preparation: Oil palm trunk veneers measuring, 23 cm long by 23 cm wide by 4.5 mm were supplied by a plywood mill in Kedah and dried to approximately 7 to 10% moisture content. Three types adhesives namely, emulsion polymer isocyanate (1, 3-butadiene-styrene and vinyl acetate based) and polyvinyl acetate (PVAc) which were obtained from Casco Adhesive (Asia) Pte. Ltd were used (Hashim *et al.*, 2011). Emulsion Polymer Isocyanate (EPI) adhesives are two-component adhesives based on reaction of a mixture of water based emulsions polymer type (for example; styrene butadiene rubber, emulsion vinyl acetate and polyvinyl acetate) with an isocyanate hardener (as a crosslinker) forming water resistant bonds. EPI adhesives are cold-setting with very good adhesion to some hardwoods species which might be difficulties to form a bonding. Besides, EPI adhesive are fast curing even at high wood moisture content. EPI can be classified as thermoplastic adhesives with properties very close to thermosetting adhesives. It can be formulated in many ways to give the optimal performance with respect to water resistance, curing speed, type of substrate, strength and viscosity in each bonding operation. Meanwhile, Polyvinyl acetate (PVAc) adhesives are classified as thermoplastics adhesives and are produced by an addition polymerisation of either vinyl acetate alone or in combination (copolymerisation) with various amounts of one or more other monomers which may or may not contain reactive groups. The chemistry of PVAc was started from production of vinyl acetate monomer and further polymerization of vinyl acetate using the conventional polymerization techniques, including mass polymerization, solvent polymerization and emulsion polymerization. In particular, it is capable of producing strong and durable bonds on wood and wood-derived products and this has been a major contributing factor to the tremendous growth of polyvinyl acetate-based adhesives in recent years (Conner, 2001). PVAc, $(CH_2\text{-}CH(OCOCH_3))_n$ was prepared as an emulsion for adhesive applications and is familiar to users as white glue.

In sample preparation, three layers of laminated veneer lumber were bonded together using two different adhesive spread; 250 and 500 g m^{-2} on single bonding surface of the veneers (single glue line). Cold pressing was carried using GOTECH Testing Machine Inc. Model GT-7014 and were pressed at 1MPa (10.197 kg cm^{-2}) for different duration; 30 min at 30°C for both EPI adhesives and 60 min at 30°C for PVAc. For each adhesive type, 10 panel samples were prepared for OPT LVL and controls samples.

Density and moisture content: The moisture content of panel was determined based on oven dried weight. For moisture content determination, about ten replicates, in sizes 20.5 mm long by 20.5 mm wide were used of each board type. The moisture content of test piece is determined by weighing the samples and then placing them in an oven set at 103±2°C for 24 h. Each test piece was weighed after constant mass was achieved. Density of the samples was measured based on initial weight and volume. Ten replicates from each board, 135 mm long by 25 mm wide by based on each LVL thickness were used for air dry density evaluation. The air dry densities were computed based on the air dry weights divided by the volume of the samples in air dry condition.

Adsorption and desorption properties: For dimensional study properties in different level of Relative Humidity (RH), the study was carried out in adjustable RH chamber; GOTECH Testing Machine Model GT-7005-T. This study was run based on Hashim *et al.* (1997) and literature journals with some modification on sample's size. Twenty replicates of test panels were taken from each type of board with 60 mm long by 20 mm width by the thickness of the board for each specimen's size. The specimens were exposed to different level of RH to evaluate the absorption and desorption properties. For oil palm panels, the first cycle started at 90-75-60-50-30% and increased at 50-60-65-75-80%, while for the rubberwood panels, the first cycle were started at 50-30% and increased at 50-60-65-75-80-90% and decreased at 75-65%.

Before the exposure, the specimens were treated with anti-blue solution to avoid any fungal attack. The specimens were then exposed in the RH chamber for a month before being shifted to the next level of RH. After a month, the specimens were removed and measurement of weight and dimension (length, width and thickness) were obtained. The same procedure was repeated until the cycle level of RH was completed. Finally, after the last level of RH, specimens were oven dried at 105±2°C for 24 h and the measurement was obtained. Shrinkage is calculated on the basis of dimensions in the green condition (above fibre saturation point); inversely, swelling is calculated on the basis of dimensions in the dry condition. The values are expressed per unit of the initial dimensions (green or dry) or in (%) of the original dimension (Tsoumis, 1991). Calculations are made by using of the following relationships:

$$b\,(\%) = \frac{l_1 - l_2}{l_1} \times 100$$

And:

$$a\,(\%) = \frac{l_1 - l_2}{l_2} \times 100$$

where, b is the shrinkage (%), a is the swelling (%), l_1 is the green (initial) dimension (mm) and l_2 is the dry (final) dimension (mm).

Soil burial test: In this study, the soil burial test was conducted according to standard with some modification on size of the tested panel. Sixty replicates test samples of size 20 mm width by 20 mm length by the LVL panel thickness were prepared from each panel of each spread level. Each of the tested samples was sealed using the polyester cloth to prevent any lost of decaying samples and to allow the micro fungi to attack the samples.

Since the determination of the weight lost was based on the oven dried weight, all the tested panels need to be oven dried for 24 h at 105±2°C before and after the sampling. The natural soil substrate used in this study contained pH 6 to 8 and do not containing added agrochemicals. The sampling area should have the turf or the top 50 mm removed and shall not be taken from a depth below 200 mm from the surface. It should pass through a sieve of nominal aperture size 12.5 mm to remove stones and larger soil particles. In this study, samples were buried in 1 ft (30.48 cm) under the ground.

After the sample was sealed, they were exposed to garden soil for eight weeks. Every two weeks, the tested samples were removed and cleaned from the soil properly before weighed for air and oven dried weight. The same procedure was repeated for eight weeks. The mass loss based on oven dry weight of the samples was then measured using the formula below:

$$\text{Loss in mass}\ (\%) = \frac{m_1 - m_2}{m_1} \times 100$$

where, loss in mass is the weight of loss (%), m_1 is the initial oven dried weight (g) and m_2 is the final oven dried weight (g).

The average and the standard deviation were than calculated for both, oil palm and control (rubberwood) samples.

RESULT AND DISCUSSION

Density and moisture content: Air-dry density and moisture content of LVL from OPT and control sample were produced by using different adhesives are indicated in Table 1. The air-dried densities values of the solid veneers of OPT and control sample were also calculated. From the result, it reveals that the air-dry density of OPT LVL showed slight improve compared to solid veneers. However, the density varied among the adhesives used. The air-dry density of OPT panels were increased around 17.31 to 21.81% (for 250 g m^{-2} of spread level) and 18.87 to 27.12% (for 500 g m^{-2} of spread level). Density of panels bonded at 500 g m^{-2} of glue spread were slightly higher compared to panels bonded at 250 g m^{-2} spread level. The amounts of glue lines between the veneers help distribute more uniform throughout the panel during pressing, giving a better compaction to the piece. Compared to OPT LVL panels, the density of rubberwood LVL panels as a control sample was higher. However, the increment density of rubberwood LVL panels from solid veneer was lower; 3.13 to 7.46% for both glue spread. Greater density experienced by rubberwood may be associated with wood density itself and its cell wall structure (Fig. 1).

All the specimens were in a conditioning chamber maintained at a temperature of 20±2°C with 65±5% relative humidity for about a week prior testing. The moisture content of the panel samples was found in the range of 7.3 to 9.7%, for both OPT and rubberwood LVL, respectively.

Hysteresis and FSP over an RH range: According to the data obtained; Moisture Content (MC) at different RH level was computed. It follows that for each level of RH,

Table 1: Physical properties of laminated veneer lumber panels from OPT and rubberwood using 250 and 500 g cm^{-2} spread level of EPI (VAc), EPI (SBR) and PVAc

		Oil palm trunk		Rubberwood	
Adhesives	Spread level (g m^{-2})	Moisture content (%)	Density (g cm^{-3})	Moisture content (%)	Density (g cm^{-3})
Solid veneer		10.91±0.04	0.43±0.04	9.82±0.02	0.62±0.02
EPI (VAc)	250	7.32±0.15	0.55±0.08	8.90±0.65	0.64±0.02
EPI (SBR)	250	8.36±0.11	0.52±0.05	9.71±0.36	0.64±0.05
PVAc	250	8.18±0.17	0.55±0.06	7.53±0.17	0.65±0.03
EPI (VAc)	500	7.89±0.06	0.57±0.04	8.84±1.02	0.67±0.02
EPI (SBR)	500	7.48±0.16	0.53±0.03	7.86±0.28	0.67±0.04
PVAc	500	8.30±0.15	0.59±0.03	7.62±0.19	0.65±0.02

Values are as Mean±SD, n: 10 for moisture content and density

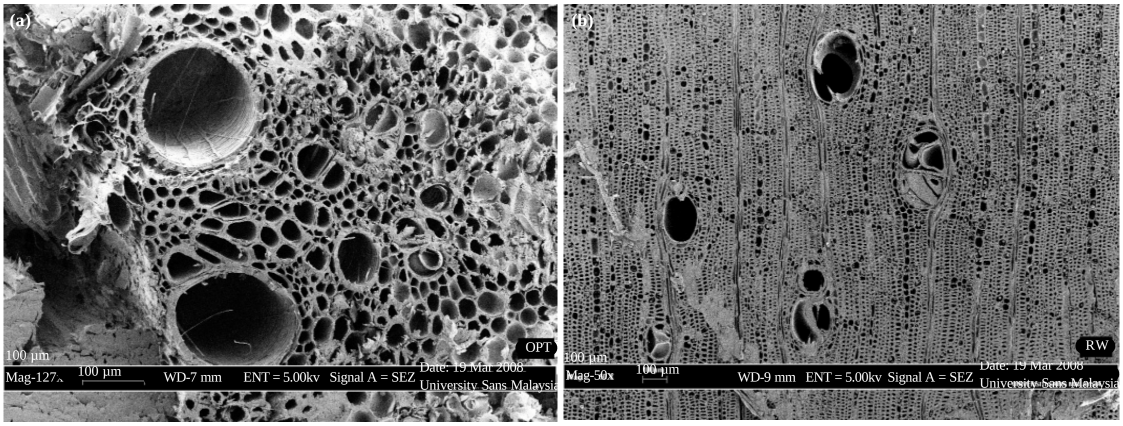

Fig. 1(a-b): Scanning electron micrograph of (a) Oil palm trunk at 127x magnification and (b) Rubber wood at 50x magnification

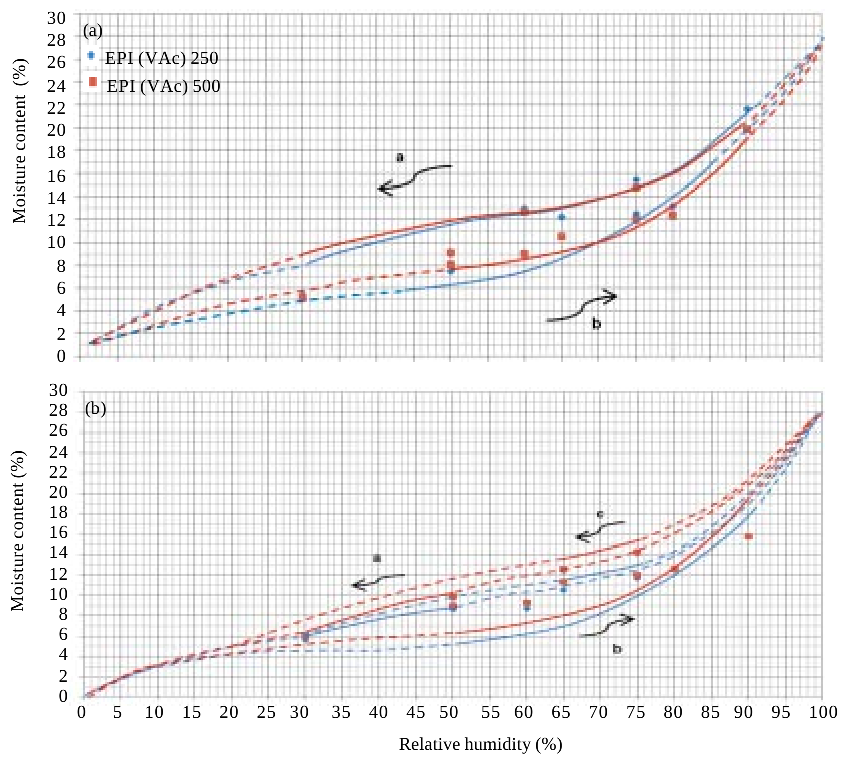

Fig. 2(a-b): Adsorption and desorption curves for LVL panels produced using EPI (VAc) (a) OPT and (b) Rubberwood, a: Desorption, b: Absorption and c: Initial desorption

there is a corresponding MC of the wood which determined the Equilibrium Moisture Content (EMC) of the piece panel. This relationship was illustrated by the adsorption and desorption curve after plotting the MC versus RH graph.

Figure 2 shows the adsorption and desorption curves for OPT and rubberwood panels bonded with EPI (VAc) for both adhesive spread rate; 250 and 500 g m^{-2}. It was obviously showed the EMC is greater in desorption than in adsorption. The same phenomenon was also experienced by panels bonded with EPI (SBR) (Fig. 3) and PVAc (Fig. 4) adhesives. This was called hysteresis. This hysteresis value was calculated by the ratio of adsorption to desorption equilibrium moisture content at the same

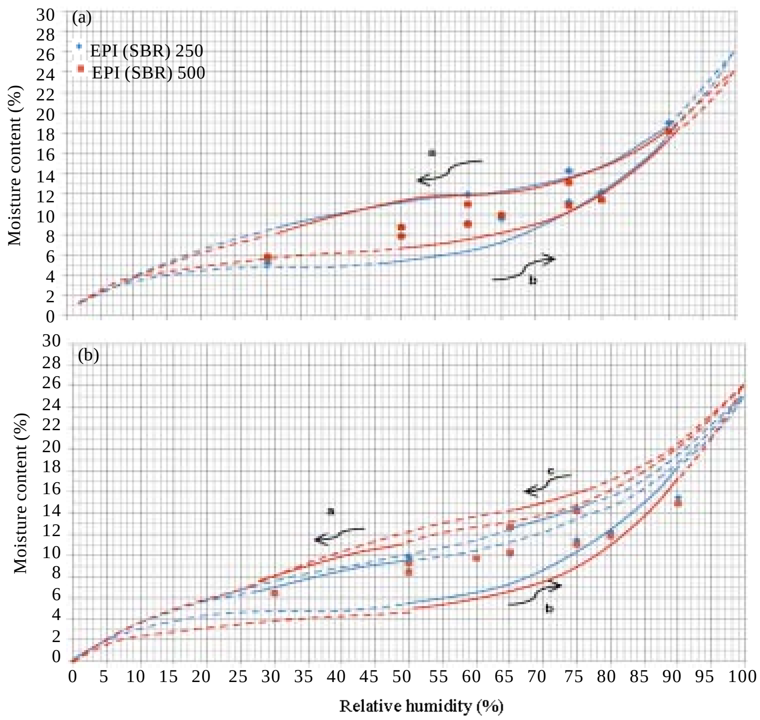

Fig. 3(a-b): Adsorption and desorption curves for LVL panels produced using EPI (SBR), (a) OPT and (b) Rubberwood, a: Desorption, b: Absorption and c: Initial desorption

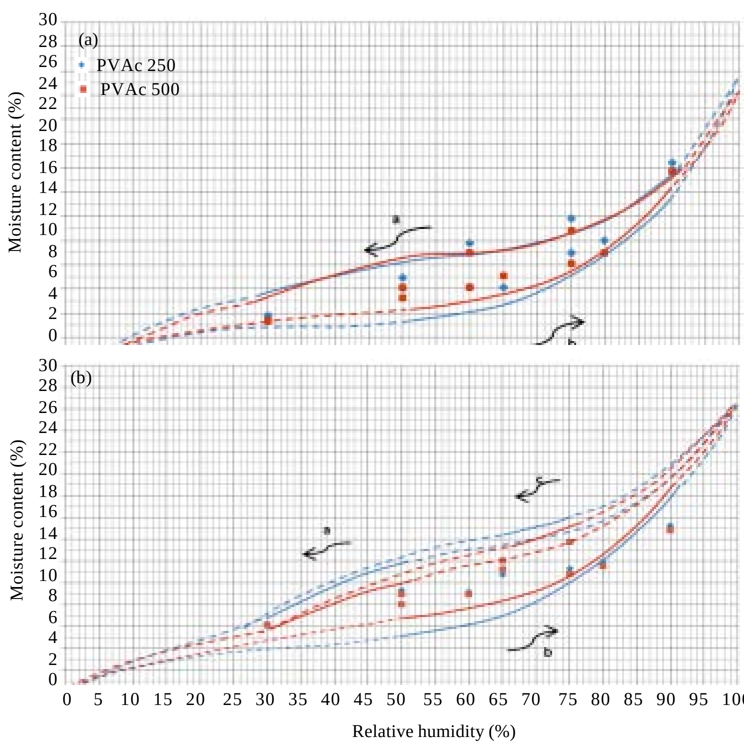

Fig. 4(a-b): Adsorption and desorption curves for LVL panels produced using PVAc, (a) OPT and (b) Rubberwood, a: Desorption, b: Absorption and c: Initial desorption

Table 2: Magnitude value of hysteresis for OPT LVL and rubberwood LVL bonded with EPI (Vac), EPI (SBR) and PVAc for 250 and 500 g m^{-2} adhesives spread rate

Adhesives	Spread level ($g\ m^{-2}$)	Magnitude of hysteresis	
		OPT	Rubberwood
EPI (VAc)	250	0.69	0.84
	500	0.71	0.90
EPI (SBR)	250	0.76	0.81
	500	0.82	0.81
PVAc	250	0.69	0.89
	500	0.74	0.94

Table 3: Region value of fibre saturation point for OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc at 250 and 500 g m^{-2} adhesives spread rate

Adhesives	Spread level ($g\ m^{-2}$)	Region of fibre saturation point (°C)	
		OPT	Rubberwood
EPI (VAc)	250	27.5	28
	500	27	28
EPI (SBR)	250	26	25
	500	24	26
PVAc	250	25	26
	500	24	26

relative humidity. At the equilibrium point, when desorption was greater compared to adsorption, the phenomenon was called hysteresis and is a characteristics property of all cellulosic materials. According to Tsoumis (1991), the phenomenon occurred when the hygroscopicity of panels is permanently reduced at high RH after the initial desorption. The magnitude of hysteresis was expressed by the ratio of adsorption to desorption at the same RH and the ratio is practically constant. Overall, higher trends were observed for rubberwood as compared to OPT for each treatment when specimens were exposed to different level of RH to evaluate the absorption and desorption properties as shown in Fig. 2 to 4.

Table 2 represents the value magnitude of hysteresis for OPT LVL and rubberwood LVL for both adhesive spread. Generally, the magnitude of hysteresis was below 1.00 which was in the average 0.69 to 0.82 for OPT LVL while 0.81 to 0.94 rubberwood LVL, respectively. Various theories have been proposed to explain moisture hysteresis. Howard (1973) and Isenbrands *et al.* (1979) reported from their study that the phenomenon is due to linkage of free hydroxyls of wood constituents when there is no moisture or very little moisture in wood. During the next adsorption, the number of available hydroxyls is smaller.

From the results analysis, region of Fibre Saturation Point (FSP) for each different type of panels could be predicted. Table 3 tabulated the region of FSP that was found by extrapolation from the curves. The concept of FSP is useful because most properties are changed when the moisture content of wood is below this point (Tsoumis, 1991). The results showed that the value region of FSP for OPT LVL was higher for 250 g m^{-2} adhesives spread level compared with 500 g m^{-2} adhesive spread level. Amongst the three adhesives, OPT LVL bonded with EPI (VAc) performed the highest and the least was experienced by OPT LVL bonded with PVAc. In comparison, rubberwood LVL performed higher value of FSP compared to OPT LVL in both adhesive spread level; 250 and 500 g m^{-2}. Extractives content affected the value region of FSP. As had been observed by Liese and Paramewaran (1971) indicated that the presence of extractives reduces the FSP. Other factor includes rise of temperature of RH chamber has a reducing effect of FSP (Tsoumis, 1991) as well.

Dimensional changes associated with changes in RH: Figure 5 and 6 show the percentage rate of thickness swelling in different RH for LVL panels bonded with EPI (VAc), EPI (SBR) and PVAc. The percentage of Thickness Swelling (TS) increased as the value of RH was shifted. However, the percentage varied among the adhesives types. This indicated that the rate of TS appeared to depend on the adhesive type instead of wood. It is obviously seen in Fig. 5; both OPT LVL and rubberwood LVL produced from EPI (SBR) showed the rapid increase in TS compared with OPT LVL and rubberwood LVL produced from EPI (VAc) and PVAc.

For 500 g m^{-2} adhesive spread level, the percentage of TS for OPT LVL bonded with EPI (SBR) and EPI (Vac) was nearly similar through the RH (Fig. 6) and there were still remains amongst the highest. Unlike EPI adhesives', OPT LVL bonded with PVAc performed the least percentage of TS through the RH. The phenomenon was also experienced by rubberwood LVL. PVAc adhesive was less resistant to moisture and humidity and tend to creep under a sustained load (Conner, 2001). Due to the compression duration during pressing, PVAc adhesive was able to fill the voids of wood and decreased the space available to hold water. Furthermore, the viscosity of PVAc is lower compared to EPI adhesives which was easily to penetrate the cell wall of the veneer.

It is obvious that OPT LVL panels had higher percentage of TS rate compared to rubberwood LVL within the different cycle of RH. According to Kollman and Cote (1975), the interrelationships between the adhesives, species materials and processing are very complicated because of the very fine (even submicroscopic) capillaries in the system wood/glue line.

Soil burial: From the observation within the eight weeks of soil burial test, there were many organisms found after

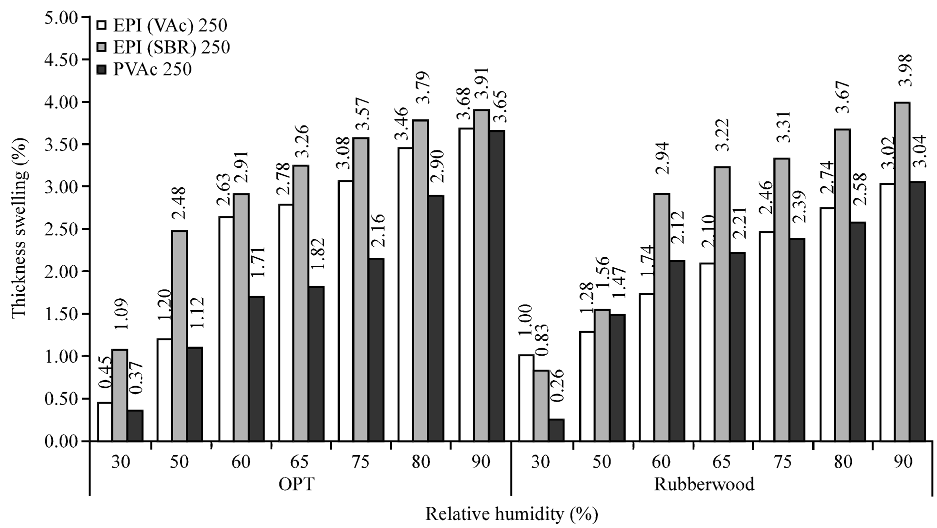

Fig. 5: Percentage of thickness swelling for OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc at 250 g m^{-2} adhesive spread rate

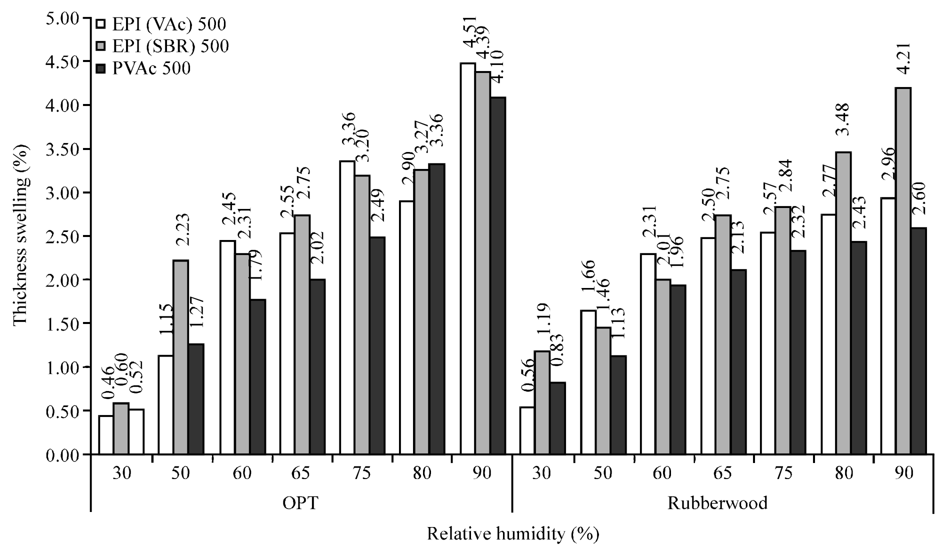

Fig. 6: Percentage of thickness swelling for OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc at 500 g m^{-2} adhesive spread rate

the samples were buried at the site. The organisms such as bugs, termites, ants and worms were found around the site and their traces of trails were around the samples site. OPT LVL was found to be easily degraded compared to rubberwood LVL. This is expected because OPT contains a high amount of readily available food such as starch. This food easily promotes growth of biodetrioration agents such as fungal, bacteria as well as insects.

After eight of weeks observation, the percentage of weight loss was increased for all adhesives types. The OPT LVL bonded with EPI (SBR) was more degradable compared to OPT LVL bonded with EPI (VAc) and PVAc by determining the percentage of weight loss as shown in Fig. 7. The percentage of weight loss was 15.23% for 250 g m^{-2} and 13.94% for 500 g m^{-2} after eight weeks while for rubberwood bonded with EPI (SBR), the percentage of weight loss was 25.68% for 250 g m^{-2} adhesive spread level and 29.49% for 500 g m^{-2} adhesive spread level, respectively for the OPT bonded with EPI (SBR). The OPT LVL bonded with PVAc showed the least of percentage of weight loss among the adhesives used.

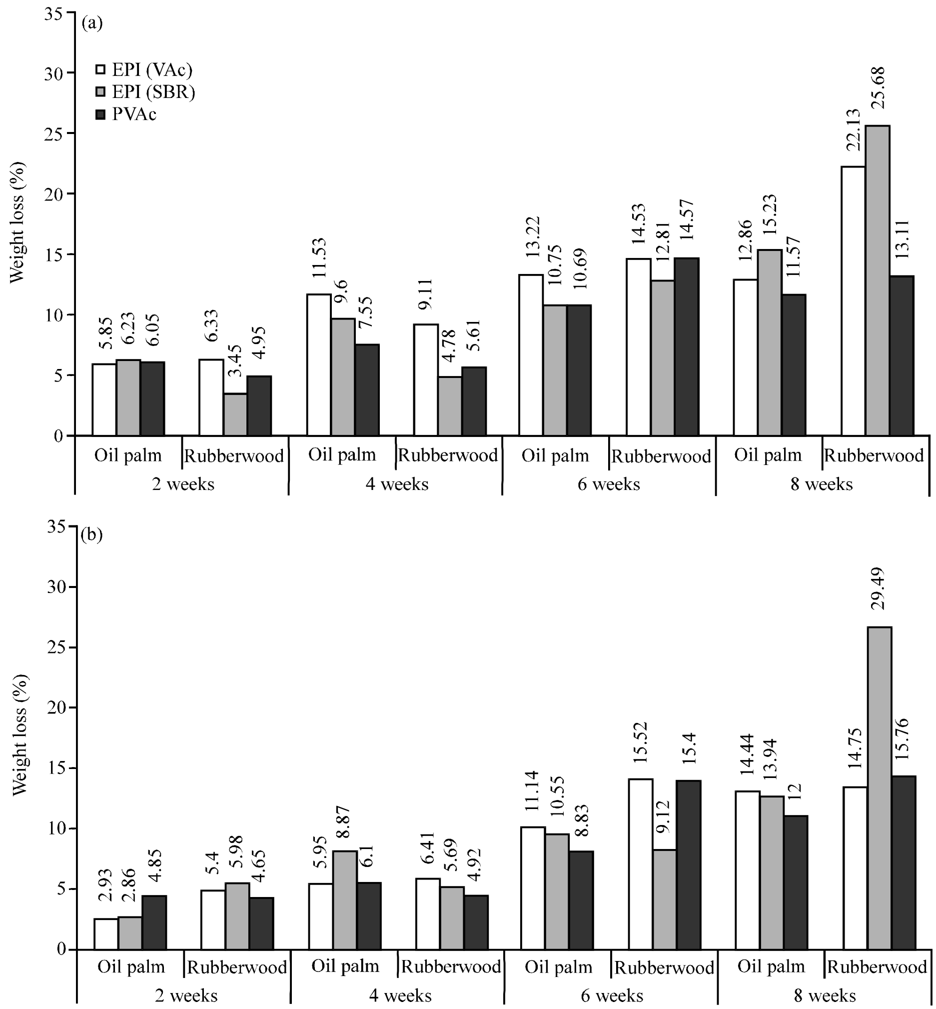

Fig. 7(a-b): Percentage of weight loss between OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc, (a) 250 g m^{-2} and (b) 500 g m^{-2} Adhesive spread rate

The percentage of weight loss was 11.57% for 250 g m^{-2} and 12.00% for 500 g m^{-2} while for rubberwood LVL bonded with PVAc was 13.11% for 250 g m^{-2} and 15.76 for 500 g m^{-2} adhesive spread level after eight weeks.

From percentage of weight loss, the OPT LVL degraded higher compared to rubberwood LVL, almost for all adhesives during the first four weeks as shown in Fig. 7. It was obviously shown that, after four weeks, the percentage of weight loss of rubberwood LVL increased compared to OPT LVL. Rubberwood also contain high amount of starch which provides an easy source of food for organism (Fig. 8). The present of laticifers (latex vessels) in all organs of rubberwood would take a period of time for the organism to attack for the starch content and degrade (Gomez, 1982).

As shown by the SEM in Fig. 8, the fibres were mostly intact for both, OPT LVL and rubberwood LVL. The test samples however showed the developing of fungi entwining the fibres, parenchyma and starch granules. This influence of microorganisms as well as the organisms had the ability to consume the fibres, parenchyma and starch for degradation.

Through the eight week study, it was found that most of the samples were degraded by termites and organism and by the end there were mixed together with soil. Soil had played an important role in maintaining life and the environment.

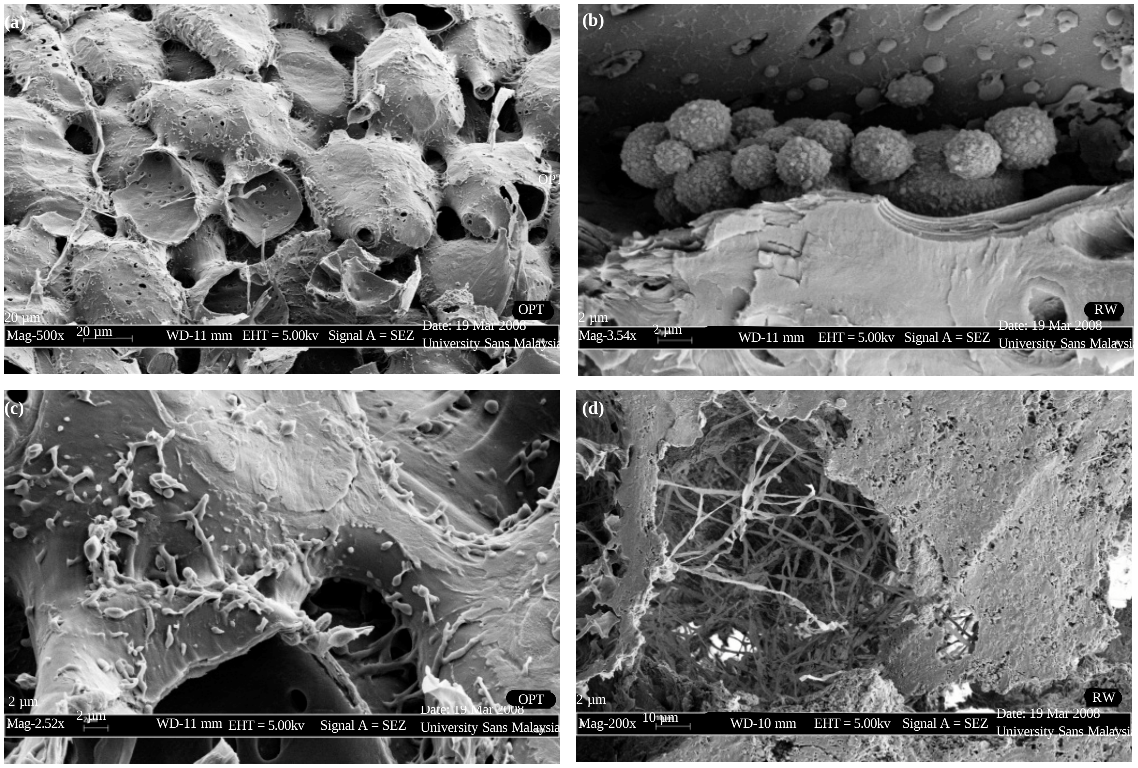

Fig. 8(a-d): Scanning electron micrographs on LVL samples after soil burial for eight week, (a-b) Oil palm LVL at 500x and 2.52Kx magnification and (c-d) Rubberwood LVL at 3.54 Kx and 502×magnification

CONCLUSION

From this study, it can be concluded that the dimensional stability properties of LVL from OPT bonded with cold setting adhesives namely EPI (SBR), EPI (VAc) and PVAc were comparable with rubberwood. However, the average values were varied among the adhesives. The average values of the oven-dry density of OPT LVL have shown slightly higher compared to OPT's solid veneers. The adsorption and desorption of OPT LVL were detected to have a higher dimensional change compared to rubberwood LVL as the relative humidity was shifted. Amongst the three adhesives, OPT LVL manufactured with EPI (VAc) had the highest FSP and the least was experienced by OPT LVL bonded with PVAc. Overall, the magnitude of hysteresis was below 1.00 which in the average 0.69 to 0.82 for OPT LVL panels while rubberwood LVL, 0.81 to 0.94, respectively. The OPT and rubberwood LVL panels were detected to have a dimensional change as the relative humidity was shifted. After eight weeks of observation, the percentage of weight loss increased for all adhesives types, respectively for OPT and rubberwood LVL. OPT LVL showed to be very vulnerable to bio deterioration attack. Through the eight-week study, it was found that most of the samples were degraded by termites and organism and by the end of eight weeks, there were mixed together with soil. LVL panels which produced using EPI (SBR) exhibited the highest percentage of weight loss compared to LVL bonded EPI (VAc) and PVAc, respectively.

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