Dimensional Stability Properties of Laminated Veneer Lumber Made From Oil Palm Trunk Bonded With Different Cold Set Adhesives

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ABSTRACT

Dimensional stability properties of laminated veneer lumber (LVL) from oil palm trunk (OPT) bonded with three different cold set adhesives namely emulsion polymer isocyanate (1, 3-butadiene-styrene and vinyl acetate based) and polyvinyl acetate were investigated. Three-ply experimental LVL from OPT veneers were bonded using two adhesive spread levels; 250g/m² and 500g/m² 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 percent, hysteresis over a range of 30 to 90 percent and durability against biological attack through soil burial. 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. 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. Through the eight weeks 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 produced using EPI (SBR) was exhibited the highest percentage of weight loss compared to LVL bonded EPI (VAc) and PVAc respectively.

Keyword: *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. Intensive research work is ongoing using variable technologies to convert oil palm fronds (OPF) and oil palm trunk (OPT) for the manufacture of commercially viable composite panel products (Sulaiman et al., 2008; Laemsak and Okuma, 2000; Chew, 1987; Ho et al., 1985). Most of the OPT is converted into various types of wood such as saw-wood and plywood or lumber. Research has found that the OPT can be used in the making of laminated veneer lumber (LVL), to produce various products including furniture and partition walls. It provides the flexibility of shape and form, enabling designers and manufacturers to create furniture in varied shapes and forms using the mould design (Mohd Ariff et al., 2007; Abdul Hamid, 2006).

The utilisation of oil palm by-products in wood composites is still limited in case of its properties. Some of the problems were low average density and density gradient exist in the radial direction of OPT. This could have influenced the stability and strength properties of the products (Husin et al., 1986). Most of the laminated products from OPT studied were carried out based on formaldehyde adhesives like UF and PF. 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, 2007).

The dimensional changes that accompany the shrinkage and swelling of wood are major sources of both, visual and structural problems in final products of wood-based. 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; Dale Ellis and O'deal, 1999; 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, we are emphasise on the dimensional stability of LVL made up from OPT bonded with cold setting adhesives.

Materials & Methods

Samples Preparation

Oil palm trunk veneers measuring, 23cm long by 23cm wide by 4.5mm 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 which were obtained from Casco Adhesive (Asia) Pte. Ltd were used. Three layers of laminated veneer lumber were bonded together using two different adhesive spread; 250g/m² and 500g/m² 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 (10.197kg/cm²) for different duration; 30 minutes at 30°C for both EPI adhesives and 60 minutes 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 hours. 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 & 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 than 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 hours 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;

$$b\,(\%) = [(l_1 - l_2) / l_1] \times 100$$

And

$$a\,(\%) = [(l_1 - l_2) / l_2] \times 100$$

Where;

b – shrinkage (%)

a – swelling (%)

l_1 – green (initial) dimension (mm)

l_2 – dry (final) dimension (mm)

Soil Burial Test

In this study, the soil burial test was conducted according to BS 1982: Part 2 (1990) 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 hours 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. Based on the BS 1982: Part 2 (1990), the sampling area should have the turf or the top 50mm 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;

$$loss\ in\ mass\ (\%) = [(m_1 - m_2) / m_2] \times 100$$

Where;

loss in mass – weight of loss (%)

m_1 – initial oven dried weight (g)

m_2 – final oven dried weight (g)

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

Result & Discussion

Density and Moisture Content

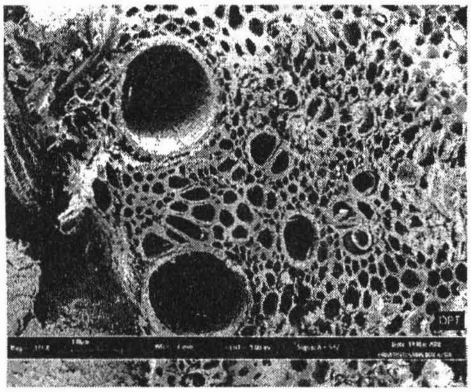
Air-dry density and moisture content of LVL from OPT and control sample were produced by using different adhesives are indicated in Table 1. The air-dried densities values of the solid veneers of OPT and control sample were also calculated. From the result, it reveals that the air-dry density of OPT 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 250g/m² of spread level) and 18.87 to 27.12% (for 500g/m² of spread level). Density of panels bonded at 500g/m² of glue spread were slightly higher compared to panels bonded at 250g/m² 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 (Figure 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.

Table 1: The physical properties of laminated veneer lumber panels from OPT and rubberwood using 250 and 500g/cm² spread level of EPI (VAc), EPI (SBR) and PVAc

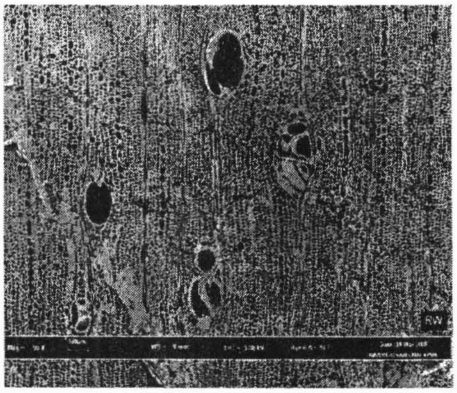
Adhesives	Spread Level (g/m²)	Oil Palm Trunk		Rubberwood	
		Moisture Content (%)	Density (g/cm³)	Moisture Content (%)	Density (g/cm³)
Solid Veneer		10.91 (0.04)	0.43 (0.04)	9.82 (0.02)	0.62 (0.02)
EPI (VAc)	250	7.32 (0.15)	0.55 (0.08)	8.90 (0.65)	0.64 (0.02)
EPI (SBR)	250	8.36 (0.11)	0.52 (0.05)	9.71 (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)

*(Value in parenthesis indicates the standard deviation. n = 10 for moisture content and density)



100 µm

(a)



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(b)

Figure 1:Scanning electron micrograph of (a) oil palm trunk at 127x magnification and (b) rubber wood at 50x magnification

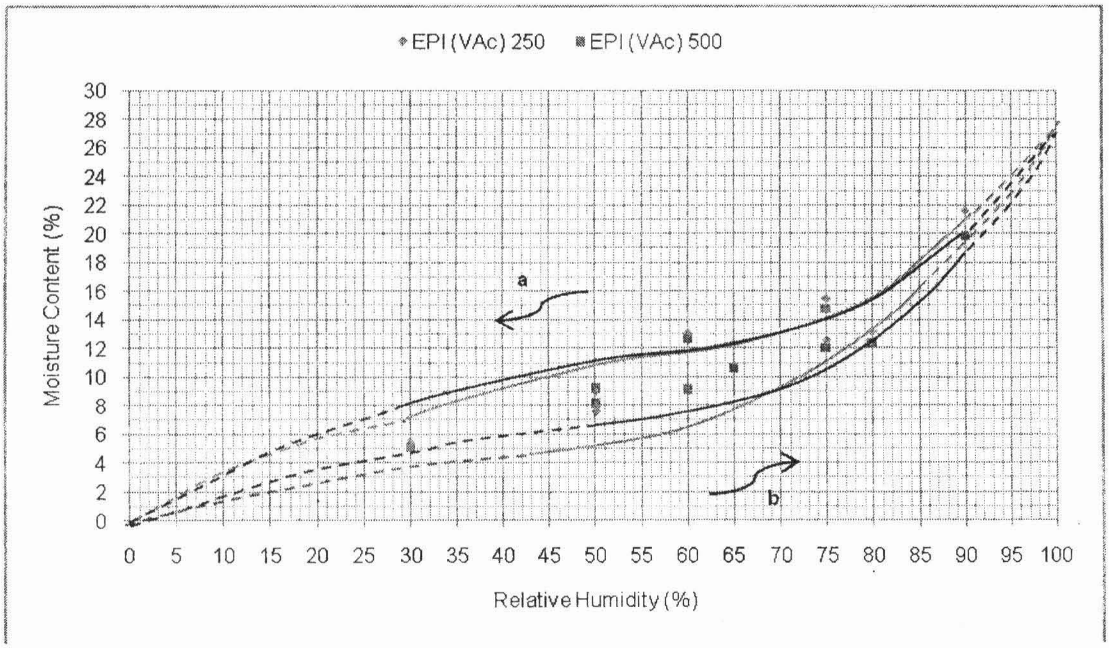
Hysteresis and FSP over an RH range

According to the data obtained; moisture content (MC) at different RH level was computed. It follows that for each level of RH, 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 500g/m^2. From the figure, 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) (Figure 3) and PVAc (Figure 4) adhesives. This was called hysteresis. 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.

Table2representsthevaluemagnitudeofhysteresisforOPTLVLandrubberwoodLVLforbothadhesivespread.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). From Table 5, it is shown that the value region of FSP for OPT LVL was higher for 250g/m^2 adhesives spread level compared with 500g/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 500g/m^2. Extractives content affected the value region of FSP. As had been observed by Julien et al. (1972); Liese and Parameswaran (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.



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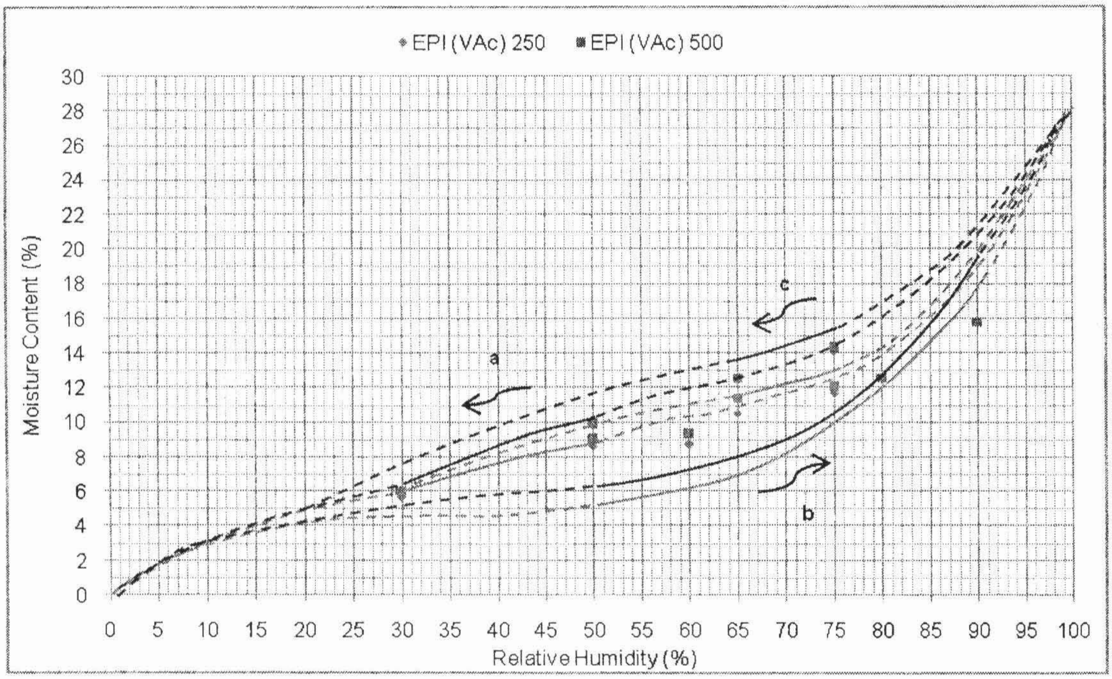
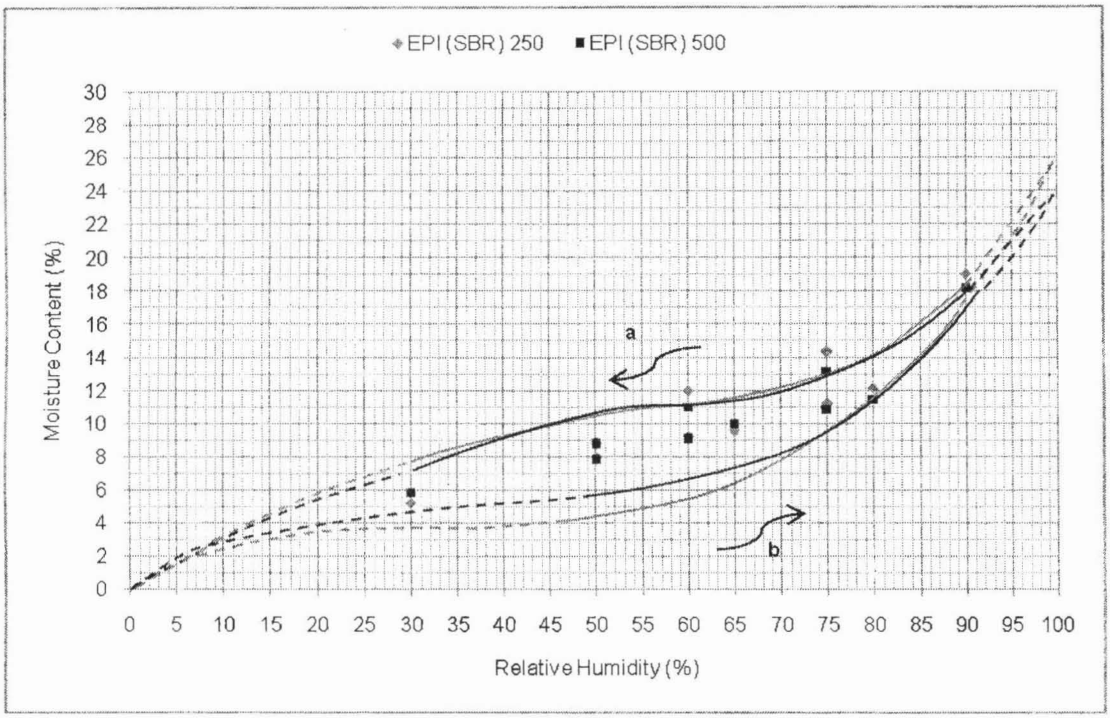


(b)

Figure 2: Adsorption and desorption curves for LVL panels produced using EPI (VAc) (a) OPT and (b) Rubberwood. desorption (a); absorption (b); initial desorption (c)



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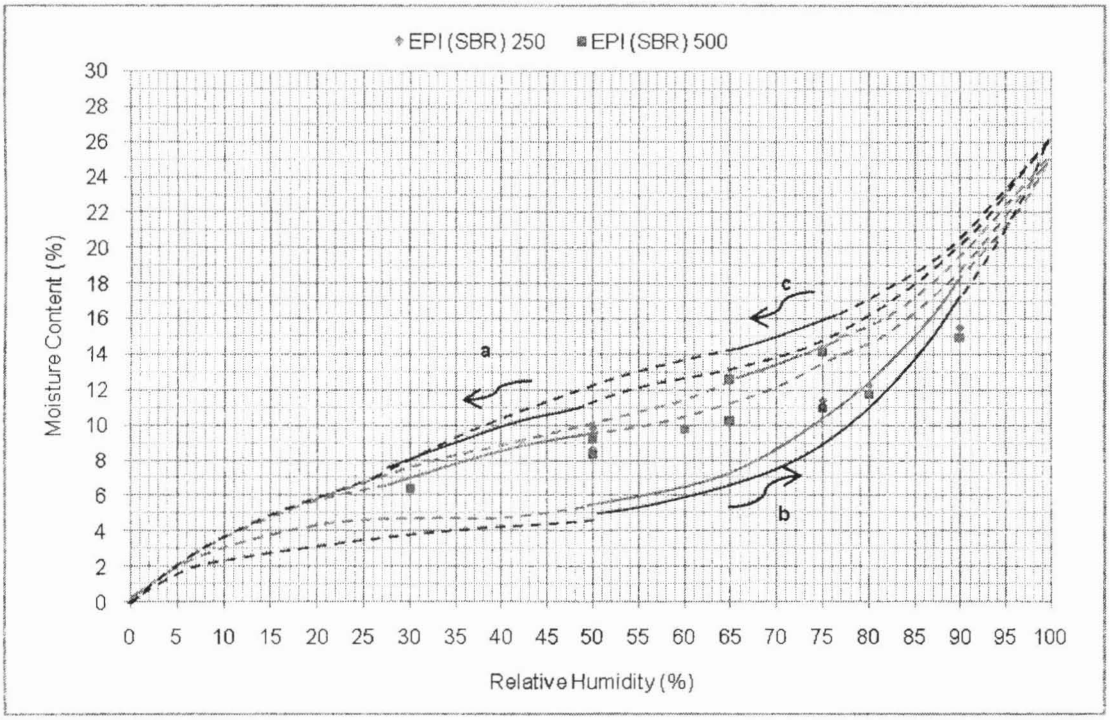
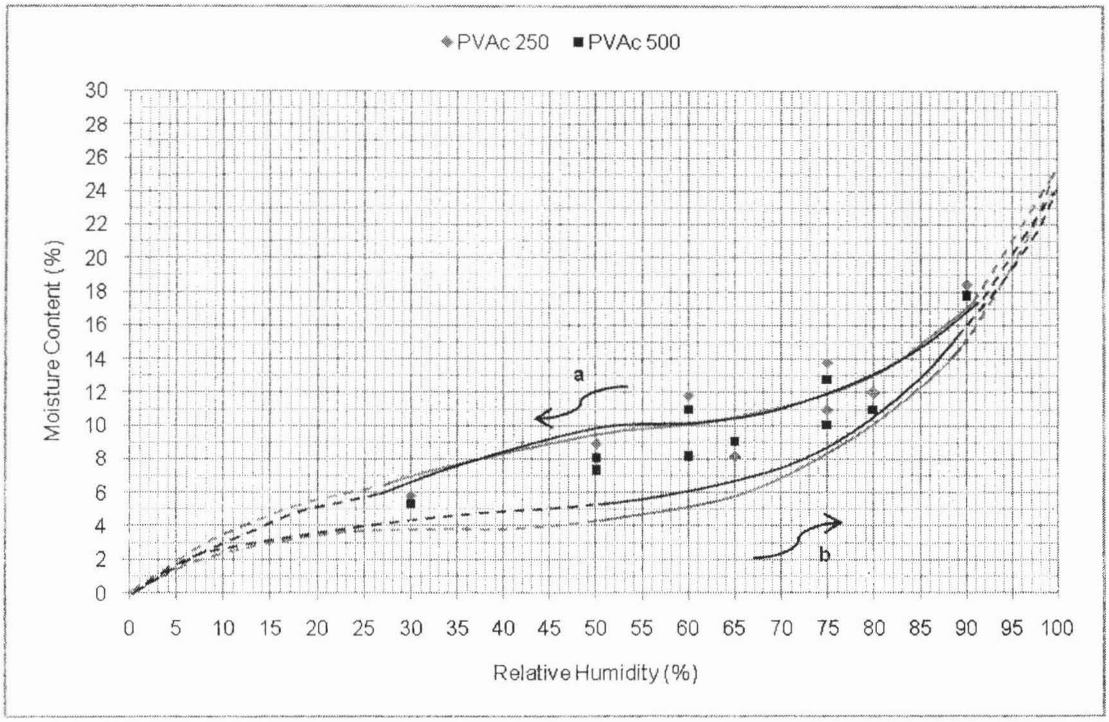


(b)

Figure 3: Adsorption and desorption curves for LVL panels produced using EPI (SBR) (a) OPT and (b) Rubberwood. desorption (a); absorption (b); initial desorption (c)



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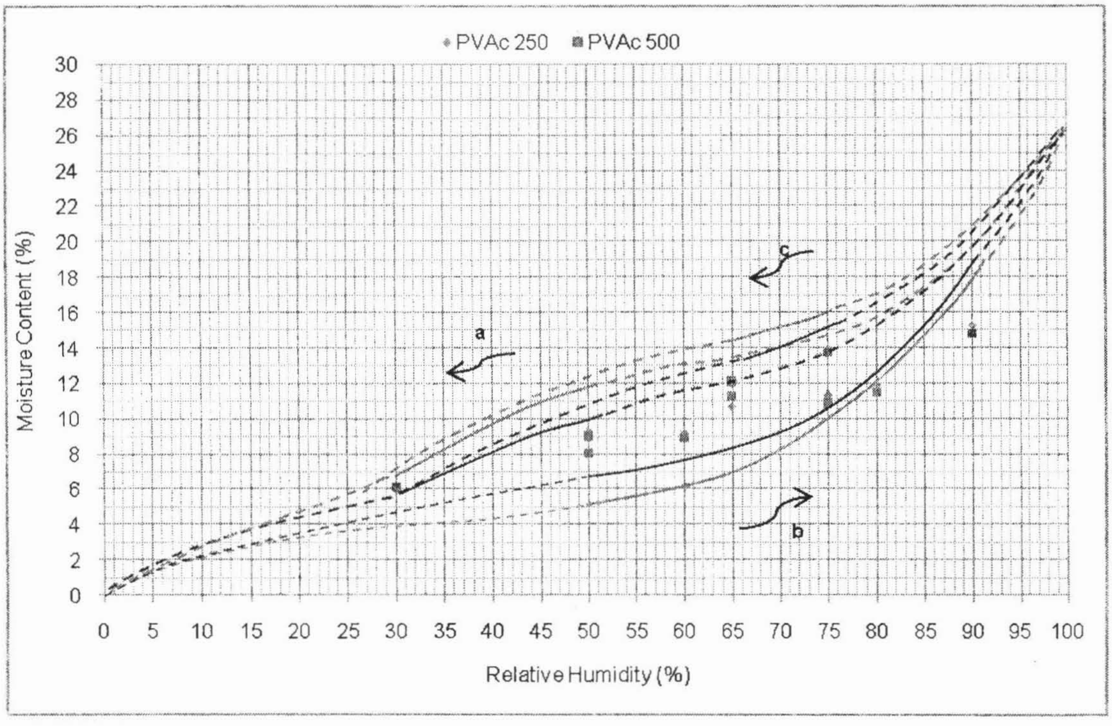


(b)

Figure 4:Adsorption and desorption curves for LVL panels produced using PVAc (a) OPT and (b) Rubberwood. desorption (a); absorption (b); initial desorption (c)

Table 2:Magnitude value of hysteresis for OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc for 250 and 500g/m² adhesives spread rate

Adhesives	Spread Level	Magnitude of Hysteresis	
	(g/m²)	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 500g/m² adhesives spread rate

Adhesives	Spread Level	Region of Fibre Saturation Point (°C)	
	(g/m²)	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

Dimensional Changes Associated With Changes in RH

Figure 5 and Figure 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. From the previous investigations by Seifert, (1972) on hygroscopicity of plywood glued with phenol-formaldehyde resin, it was show that the hygroscopic curves changed their character above 90% of RH. This certainly does not come from the wood, but from the glue line. It is obviously seen from Figure 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 500g/m² adhesive spread level, the percentage of TS for OPT LVL bonded with EPI (SBR) and EPI (VAc) was nearly similar through the RH (Figure 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 Kolmann et al., (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.

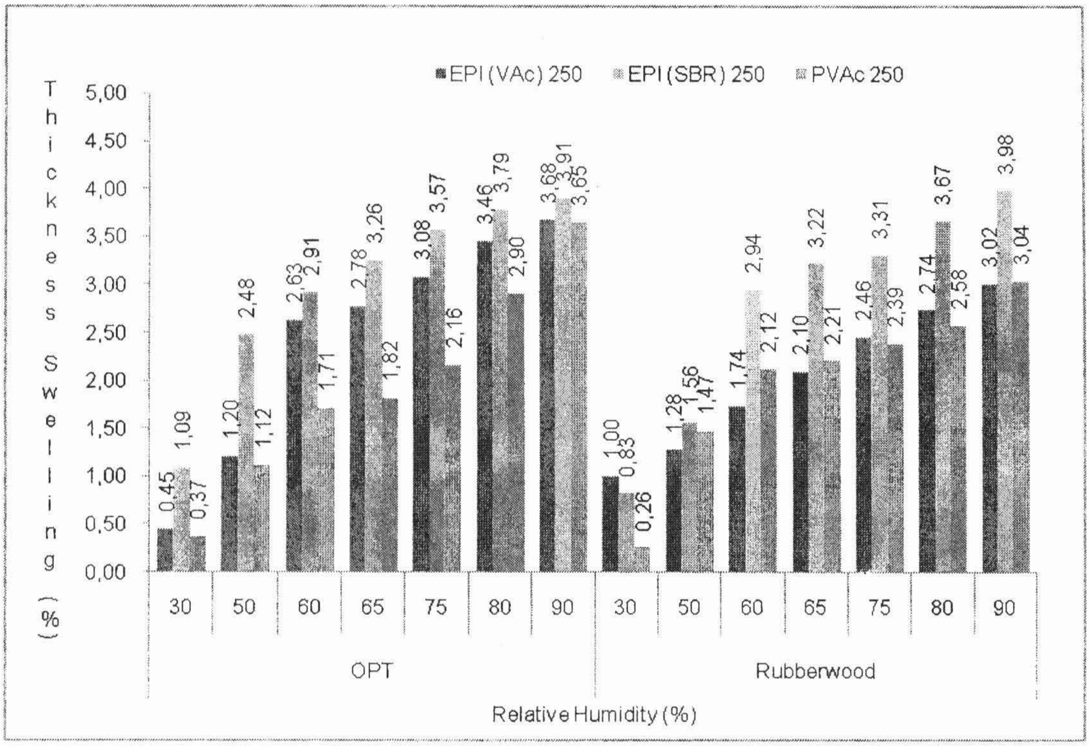


Figure 5:Percentage of thickness swelling for OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc at 250g/m² adhesive spread rate

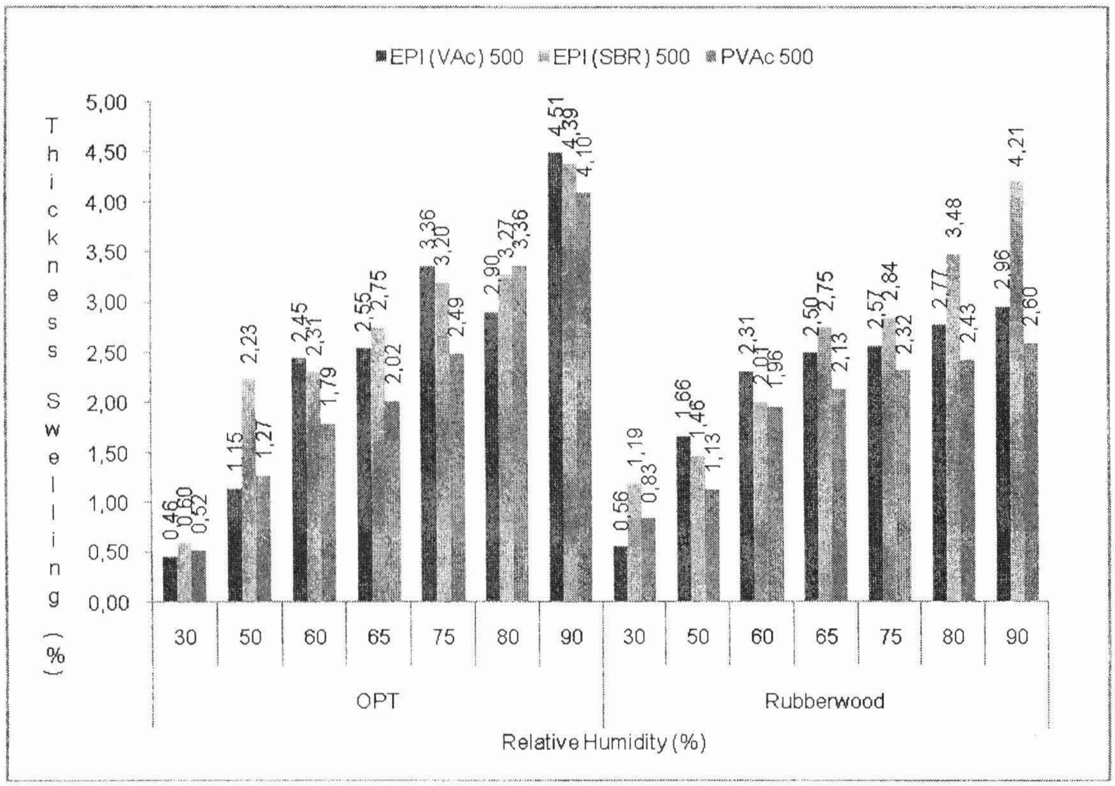


Figure 6:Percentage of thickness swelling for OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc at 500g/m² adhesive spread rate

Soil Burial

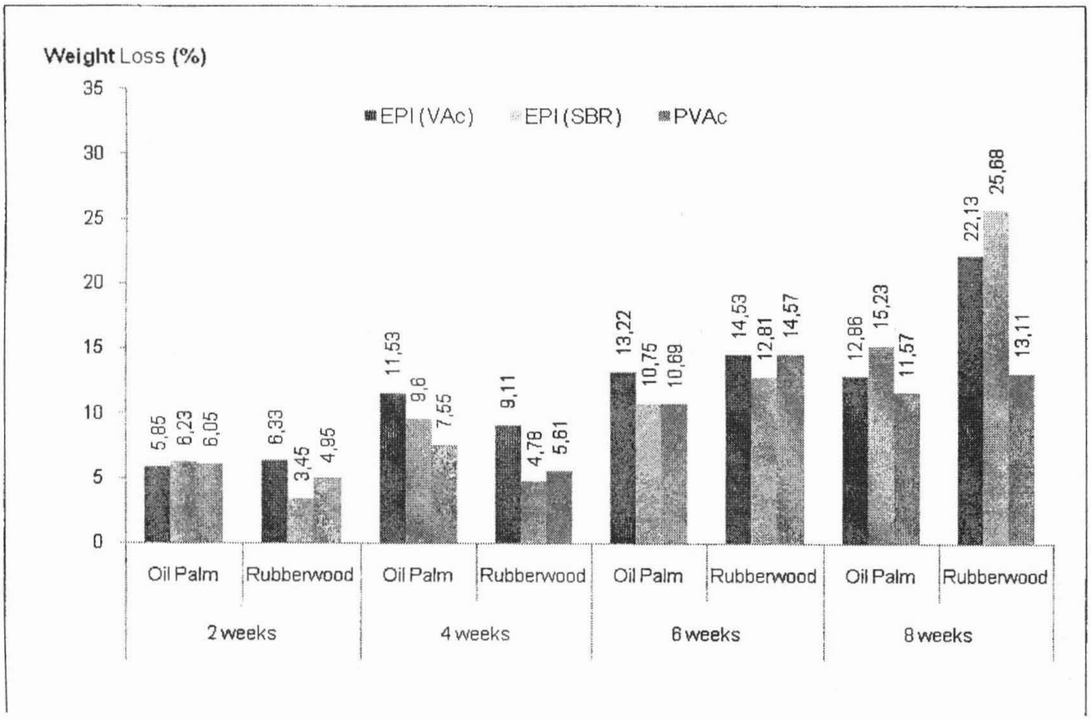
From the observation within the eight weeks of soil burial test, there were many organisms found after the samples were buried at the site. The organisms such as bugs, termites, ants and worms were found around the site and their traces of trails were around the samples site. OPT LVL was found to be 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. From Figure 7, OPT LVL bonded with EPI (SBR) was more degradable compared to OPT LVL bonded with EPI (VAc) and PVAc. OPT bonded with EPI (SBR), the percentage of weight loss was 15.23% for 250g/m^2 and 13.94% for 500g/m^2 after eight weeks while for rubberwood bonded with EPI (SBR), the percentage of weight loss was 25.68% for 250g/m^2 adhesive spread level and 29.49% for 500g/m^2 adhesive spread level respectively. OPT LVL bonded with PVAc showed the least of percentage of weight loss among the adhesives used. The percentage of weight loss was 11.57% for 250g/m^2 and 12.00% for 500g/m^2 while for rubberwood LVL bonded with PVAc was 13.11% for 250g/m^2 and 15.76 for 500g/m^2 adhesive spread level after eight weeks.

From percentage of weight loss, during first four weeks, OPT LVL degraded higher compared to rubberwood LVL, almost for all adhesives as shown in Figure 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 (as can be seen in Figure 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 Figure 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.



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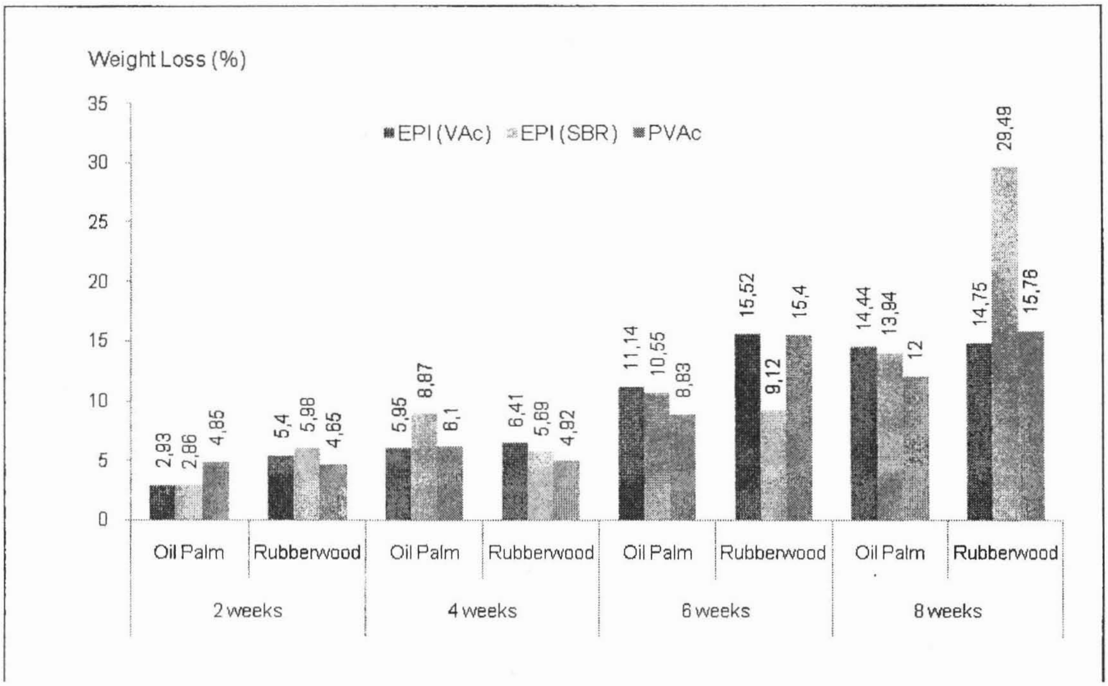
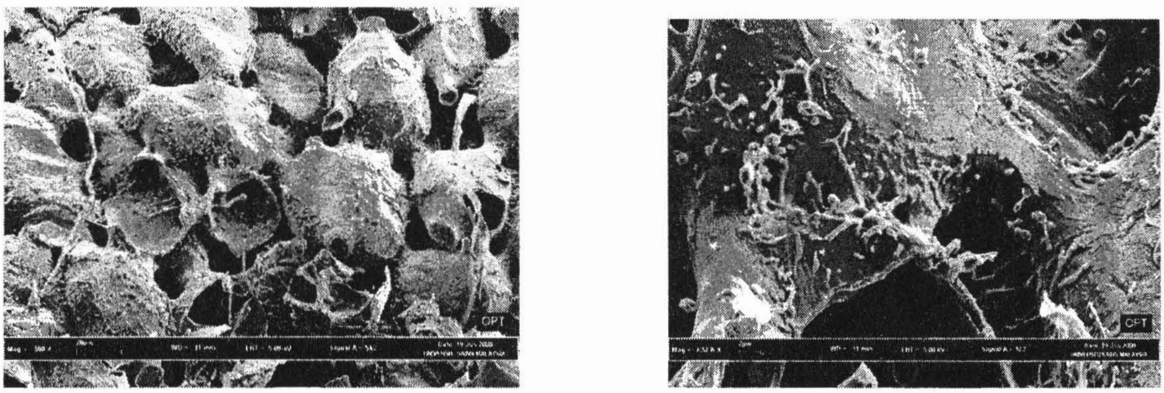


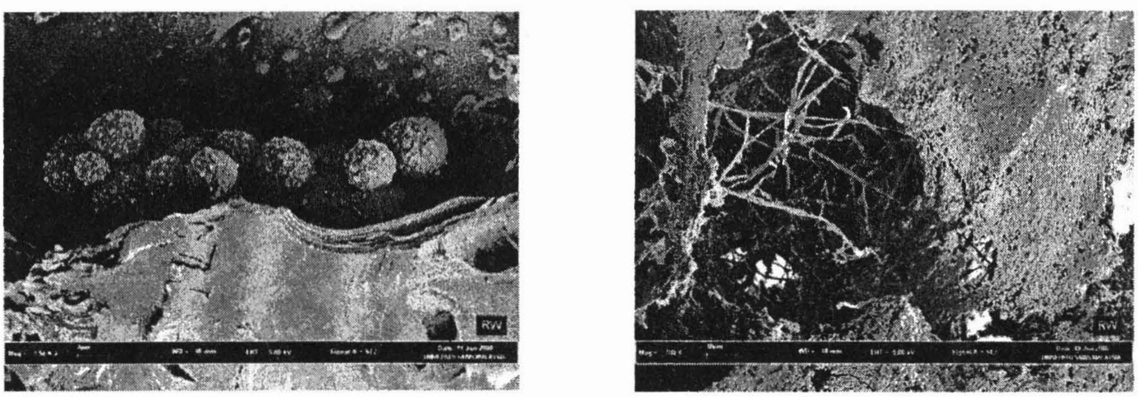
(b)

Figure 7:The percentage of weight loss between OPT LVL and rubberwood LVL bonded with EPI (VAc), EPI (SBR) and PVAc. 250g/m² (a) and 500g/m² (b) adhesive spread rate



20 µm 2 µm

(a)



2 µm 2 µm

(b)

Figure 8:Scanning electron micrographs on LVL samples after soil burial for eight week. (a) Oil palm LVL at 500x and 2.52K x magnification and (b) Rubberwood LVL at 3.54K x and 502x magnification

Conclusions

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 and acceptable. However, it was varied among the adhesives used. 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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