PROPERTIES OF BIO-COMPOSITE LUMBER FROM OIL PALM FRONDS AGRICULTURE WASTE

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ABSTRACT

The physical and mechanical properties of bio-composite lumbers from agricultural residues of oil palm fronds were studied. Phenol and urea formaldehyde were used as the binders. The oil palm fronds were obtained from an oil palm plantation. The fronds were harvested and segregated into matured, intermediate and young grouping. The fronds were then sub-segregated into bottom, middle and top portions. The leaflets and the epidermis were removed from the fronds before they were sliced longitudinally into thin layers. The layers were then compressed into uniform thickness of 2 - 3 mm. The layers were air-dried and later mixed with resins using 12-15% of phenol and urea formaldehyde and recompressed with other layers forming bio-composite lumbers. The bio-composite lumbers were then tested for their physical and mechanical properties. Testing was conducted according to the standards of the International Organization for standardization (ISO). The result on the physical and mechanical properties shows that the compressed oil palm fronds bio-composite lumbers is better than composite lumbers from oil palm trunks and slightly lower than the rubberwood. Statistical analysis indicated significant differences between bio-composite lumbers made from each groups and portion, but no differences were observed in the type of resin used. The bio-composite lumbers from compressed oil palm fronds agricultural residues has potential to be used as an alternative to wood to overcome the shortage in materials in the wood industry.

Keyword: Oil palm fronds; bio-composite lumbers; physical properties; mechanical properties

1. INTRODUCTION

Increasing in timber prices and the shortage of timber supply has affected the wood-based industries in the world. The ever increasing manufacturing costs and uncertainty in the supply of timber in some region due to restrictions on logging and inadequate forest resources have caused increasing concerns over future timber supplies. The rapid increased in the world's population has further increased the demand for timber. The forest could no longer supply the timber in a huge amount anymore. Research and development activities, in many parts of the world have now focus on the bio-composites non-wood resources from agriculture residues as the alternative source for raw material. Non-wood lignocelluloses composites are becoming attractive in both commercial and non-commercial applications. Organic natural fibres are increasingly being investigated for various usages in many structural and non-structural applications. Malaysia produced large quantity of agricultural residues such as rice (*Oryza sativa*) husk, coir (*Cocos nucifera*) fibre, and oil palm (*Elaeis guinnesis*) fibre (Zulkifli *et al.*, 2008). These fibres are considered renewable, non-abrasive, cheaper, abundance and show less health and safety concern during handling and processing. The properties of other composites products combined between agro-residues and other lignocelluloses material, metals, plastics, glass and synthetic fibres are currently under studied (Hill *et al.*, 1998).

Oil palm fronds which can be obtained all the year round can be answer on to overcome this problem because of its biomass appears to be the most viable alternative to be utilized as value added product as well as future wood-based industry (Mohamad *et al.*, 2003). Malaysia is currently the world's largest producer and exporter of palm oil. Malaysia produces about 47% of the world's supply for palm oil (Wahid *et al.*, 2004). Malaysian palm oil industry generates huge quantity of oil palm biomass including oil palm trunk, oil palm frond, empty fruit bunch, shell and fibre in the production of palm oil. Numerous research and development efforts undertaken to utilize empty fruit bunches contemplated mainly on the production of pulp for paper making (Astimar *et al.*, 2002; Tanaka *et al.*, 2002) while a handful can also be found on the production of medium density fibreboard (Ridzuan *et al.*, 2002), oil palm fibre mattress and agricultural mats, high quality organic fertilizer, charcoal briquette and roof tiles (Mohamad *et al.*, 2002). The production of medium density fibreboard (Laemsak and Okuma, 2000), particleboard (Chew, 1987), cement-bonded particleboard (Kochummen *et al.*, 1990), fibre reinforced cement board (Abraham *et al.*, 1998; Schwarz, 1985), fibre plastic composite (Liew *et al.*, 2000) and plywood (Ho *et al.*, 1985; Othman *et al.*, 2008) from oil palm trunk beside laminated veneer lumbers (Razak *et al.*, 2008) and oil palm frond have shown to be technically feasible. Not many researches however are currently focusing on the potential uses of oil palm fronds as future alternative to woods. The oil palm fronds can be found in abundant all the year round

The objectives of these investigations were to investigate the properties of compressed oil palm fronds composite lumbers. These were achieved by assessing the physical and mechanical properties of the bio-composite lumbers from different maturity and portion grouping.

1. MATERIALS & METHODOLOGY

2.1 Oil Palm Fronds Preparation: The oil palm fronds were obtained from a private plantation in Kota Belud, in Sabah. The oil palm fronds were selected based on decay-free and no defect trees. The selected oil palm fronds were divided into three (3) groups of matured, intermediate and young oil palm fronds. Within these groups they were further sub-divided into bottom, middle and top portions. Leaflets were removed from the selected fronds. A part like disc about 10 cm in the middle were cut from every portion for the physical properties study for the raw oil palm frond and the rest were peeled of their skin and sliced in longitudinal direction. The fronds were then transport to Universiti Malaysia Sabah for subsequent processing. The fronds were then sliced longitudinally of thickness 2-4 mm, and later compressed using rollers compressed machine to increase their density before undergoing sun-drying.

2.2 Air Drying: All the compressed oil palm fronds then were air-dried for 12 hours to remove moisture in them. The air drying process was done to prevent the fungi and insects attacks. The drying process ends once the moisture content of these compressed fronds reached the equilibrium moisture content (14% in Malaysia).

2.3 Resin: Two (2) types of resin were used in this study to produce the bio-composite lumbers. They were phenol formaldehyde (PF) and urea formaldehyde (UF) resin. Both types of resin were obtained from Sepanggar Chemical Sdn. Bhd.

2.4 Compressed Oil Palm Frond Bio-composite Lumbers: After undergoing dried in sunlight, the compressed oil palm fronds were then glued together with 12-15% of resins adding 1% of hardener (NH_4Cl) forming layers manually using a forming box of compressed oil palm fronds into 350 x 350 mm. After forming layers, the compressed oil palm fronds were pre-pressed by hand and then transferred to single-opening hydraulic hot-pressed machine with a platen temperature of 125±5°C for phenol formaldehyde resin, meanwhile 100±5°C for urea formaldehyde resin and pressed into desire shape for testing products making to form the compressed oil palm fronds bio-composite lumbers. The compressed oil palm fronds bio-composite lumbers were manufactured 20 mm in thickness from these three types of portion from three types of maturity groups using two different types of resin which are PF and UF. The compressed oil palm fronds bio-composite lumbers were pressed by means of a three-step-down method of pressing among 40 sec/mm for phenol formaldehyde resin, meanwhile 30 sec/mm for urea formaldehyde resin. Distances bars 20 mm in thickness were inserted between the hot platens during hot pressing. All this bio-composite lumbers were trimmed and cut into various size test specimens and then conditioned at 20±3°C and 65±3% relative humidity (RH) for 72 hours prior for testing to produce an equilibrium moisture content of about 12±1%.

2.5 Physical Properties of Oil Palm Frond and Compressed Oil Palm Fronds Bio-composite Lumbers: Physical properties were tested and evaluated in accordance with International Organization for Standardization (ISO) standards. Physical properties of oil palm fronds studied were the density and basic density.

2.5.1. Density: The density was determined by measuring the mass at 12% of moisture content and volume of each sample. Weight each test samples to an accuracy of 0.01 g by using analytical balance, meanwhile the volumes were determined by using water displacement method. The determination of density of each samples test was done in accordance ISO 3131-1975. The initial weight of specimens was taken and then oven-dried at 103±2°C until their moisture content reaches to 12%. The oven-dried weight at 12% was determined and the specimens were slightly into the melting wax. By using water displacement method, initial level of volumetric cylinder was recorded and the weighting equipment was setup at two decimal places. The specimens were then immersed in the water. The weight and the latest water level of volumetric cylinder were recorded.

2.5.2 Basic Density: The basic density was determined by measuring the oven-dry weight and green volume of each sample. Weight each test samples to an accuracy of 0.01 g by using analytical balance, meanwhile the volumes were determined by using water displacement method. The determination of basic density of each test samples was done in accordance ISO 3131-1975. The initial weight of specimens were take before undergoing to oven-dried at 103±2°C until its weight were constant. After the oven-dried weight was determined, the specimens were dip slightly into the melting wax. By using water displacement method, initial level of volumetric cylinder was recorded and the weighing equipment was setup at two decimal places. The specimens were then immersed in the water. The weight and the latest water level of volumetric cylinder were recorded.

2.6 Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Lumbers

Evaluation of mechanical properties was just doing on compressed oil palm fronds bio-composite lumbers. This evaluation was conducted according to International Organization for Standardization (ISO) standard (ISO 3349-1975, ISO 3133-1975 and ISO 3787-1976). Mechanical properties of compressed oil palm fronds bio-composite lumbers were tested through the following method; static bending strength including modulus of elasticity (MOEb) and modulus of rupture (MORb) besides compression strength for modulus of rupture (MORc).

2.6.1. Static Bending Strength: The static bending tests were conducted using A Universal Testing Machine. The dimensions of composite lumber sample for static bending test were according to ISO 3349-1975 for MOE and ISO 3133-1975 for MOR. The specimen was supported on a span of 280 mm and the force applied at the mid-span using a loading head. The tests were stopped when the samples started to break. The proportional limit with ultimate load and deflection were recorded, the MOEb and MORb were calculated automatically by the computer connected to the machine.

2.6.2 Compression Strength: The compression strength test was performed according to ISO 3787-1976 for MORc using a Universal Testing Machine. This test had been done with a constant rate of loading or constant rate of movement of the loading head of the machine till the test piece is broken.

3. RESULTS AND DISCUSSIONS

3.1 Physical Properties of Compressed Oil Palm Fronds Bio-composite Lumbers

The density and basic density were determined for the compressed oil palm fronds bio-composite lumbers as they greatly influenced the mechanical properties of the lumbers. The investigations were done on the basic of the maturity groups, portions and resin types of the compressed oil palm fronds bio-composite lumbers.

3.1.1 Density of Compressed Oil Palm Fronds Bio-composite Lumbers: Density is an excellent indicator of the amount of substance contained in a piece of wood (Abdullah, 2010). The density of the compressed oil palm fronds bio-composite lumbers will depend on the maturity groups, portions and types of the resin that have been used for bonding this bio-composite lumbers. This density value that had been evaluated on the compressed oil palm fronds bio-composite lumbers were similar to the oil palm fronds density where their density value were determined at moisture content equal to 12%. Table 1 shows the results of mean value for density these bio-composite lumbers for each maturity group, portion and resin type. The highest density for these bio-composite lumbers was coming from the bottom portion for each maturity group followed by the middle and then top portions. Meanwhile, the old maturity group possessed the highest density values for every portion compared to others follow by the intermediate and young maturity groups. It showed that all the density values decreased from the bottom to top portions for each maturity group, meanwhile the old maturity group possessed the highest density values for every portion compared to others follow by the intermediate and young maturity groups.

The density values were affected by the anatomical structure in the oil palm fronds by its population of vascular bundles and parenchymatous tissues. The ANOVA in Table 4.11 show that there was a significant difference between density with maturity groups and portions, but no significant difference for the resins that had been used to produce the bio-composite lumbers. The resin types has no influenced on the density of the bio-composite lumbers. However, the density of the compressed oil palm fronds bio-composite lumbers more higher compared to the oil palm frond's density by the effect of resin penetration that have been used in producing this bio-composite lumbers. It was found that, the presence of both resins could increase the density of the compressed oil palm fronds bio-composite lumbers that cause the increasing in material substance per unit volume in these bio-composite lumbers.

3.1.2: Basic Density of Compressed Oil Palm Fronds Bio-composite Lumbers

The measuring basic density value for compressed oil palm fronds bio-composite lumbers were similar to basic density value evaluation for the oil palm fronds where the different between calculating density value and basic density value based on weight at moisture content equal to 12% percent for density value, meanwhile pure oven-dry weight for basic density value which were according to Organization for Standardization (ISO) standard (ISO 3131-1975).

The mean values of basic density for the compressed oil palm fronds bio-composite lumbers for each maturity group, portion and resin type were shown in Table 2. The results showed that all the basic density values decreased from the bottom to top portions for each maturity group, meanwhile the old maturity groups possessed the highest basic density values for every portion compared to others follow by the intermediate and young maturity groups. Their trend was similar to the density value, just different in number value because of its way calculation has been done. According to the obtained results in Table 2, the decreased summarized compressed oil palm fronds bio-composite lumbers basic density from the bottom to top portions for each maturity group and from the old to young maturity groups for each portion were same situation with the basic density value of the oil palm fronds. The high concentration of fibrous vascular bundles, especially at the bottom portion of the oil palm fronds possessed higher in basic density value compared to other portions (Mohamad *et al.*, 1985). Rowell (1994) stated that basic density values for wood were differently according to their cell size, cell wall thickness and relative amount of solid cell wall material. He mentioned that more mature and thickly cells were have been on bottom part of wood, thus cause the higher basic density values than others part. This statement agreement with basic density values that had been recorded in this study where the compressed oil palm fronds bio-composite lumbers from the bottom portion got higher in basic density value than other portions. This is supported by Haygreen and Bowyer (1930), where they reported that the basic density values were decreased from bottom part of a wood to top part because of their differences growing that cause the anatomical cell maturity development. The same authors also mentioned that the densities as well as basic density are the main physical properties that will affected the mechanical properties of wood. They noted that at the same moisture content of wood, the higher value in densities as well as basic density possessed the higher in mechanical properties and this will be discussed on the next subtopic.

Analysis of variance in Table 6 showed that there was a significant difference between basic density with maturity groups and portions, but there was no significant difference for the resin types that had been used to produce the bio-composite lumbers. It means that, the types of resin were not influenced to the basic density value of the bio-composite lumbers. However, the basic density of compressed oil palm fronds bio-composite lumbers more higher compared to the oil palm frond basic density by the effect of resin that have been used in producing this bio-composite lumbers. The increasing of compressed oil palm fronds bio-composite lumbers basic density probably related to resin penetration into the bio-composite lumbers. Previous study by Paridah and Anis (2008) report that parenchyma behaves like a sponge and can easily absorb moisture. Therefore, the bio-composite lumbers could easily absorb phenol and urea formaldehyde resin during producing process and leads to increase in the basic density of the compressed oil palm fronds bio-composite lumbers. It is assumed that the resin penetrations possessed higher density as well as basic density and enhance the strength of the bio-composite lumbers.

3.2 Mechanical Properties of Compressed Oil Palm Fronds Biocomposite Lumbers

The mechanical properties of wood are measures of its resistance to exterior forces which tend to deform its mass (Erwinsyah, 2008). The resistances of wood to such forces depend on their magnitude and the manner of loading (bending, compression, shear, tension, etc.). Due to the mechanical properties, Tsoumis (1991) stated that wood exhibits different mechanical properties in different growth directions, therefore it is mechanically anisotropic. According to Bowyer *et al.* (2004), mechanical properties are usually the most important characteristics of wood product to be used in structural applications. A structural application is any use for which strength is one of the primary criteria for selection of the material. Structural uses of wood product include floor joint and rafters, wall sheathing and sub flooring (Erwinsyah, 2008).

Regarding the mechanical properties of the compressed oil palm fronds bio-composite lumbers, several mechanical properties were tested in this study, including static bending strength (MOE and MOR) and compression strength (MORc). The testing was carried out on the basis of International Organization for Standardization (ISO) standard for the mechanical properties evaluation. The analysis of mechanical properties of the compressed oil palm fronds bio-composite lumbers were particularly investigated the effect of maturity groups, portions and types of resin. The resins that have been used in producing the bio-composite lumbers were phenol and urea formaldehyde.

In addition, due to the original unit of force during the testing material, all the force-unit for mechanical testing is in Newton-force, for example unit for modulus of elasticity in N/mm^2, but in order to have the value in kg/cm^2, the force value can be converted into International System of Unit (Walker *et al.*, 1993).

3.2.1: Static Bending Strength of Compressed Oil Palm Fronds Biocomposite Lumbers

The static bending strength refers to tests performed in which a bending stress is applied to the specimen to determine the stiffness or MOEb of the specimen as well as the amount of force required to cause the specimen to fail, expressed as the MORb (Erwinsyah, 2008). Bending strength of wood is usually expressed in term of the MORb (Erwinsyah, 2008). These properties are the most important parameters which usually are used for engineering purposes.

In order to investigate the static bending of the compressed oil palm fronds bio-composite lumbers, the analysis data was conducted to examine the effect of maturity groups (mature, intermediate and young), portions (bottom, middle and top) and resins (phenol and urea formaldehyde) to the MOEb and MORb. The summarized mean result of static bending test including MOEb and MORb strength is presented in Tables 3 and 4. It showed that the bottom portion got the highest value for both MOEb and MORb strength in static bending for every maturity group, meanwhile the old maturity group possessed the highest value for each portion compared to the intermediate and young maturity groups. It was clearly observed that the values of the compressed oil palm fronds bio-composite lumbers both from phenol and urea formaldehyde resin for MOE and MOR in static bending were decrease from the bottom to top portions for every maturity group and from the old to young maturity groups for each portion respectively.

According to the obtained results of static bending test which is summarized in Table 3 for modulus of elasticity (MOEb) strength, it showed that the average values of the old maturity group from the bottom, middle and top portions for phenol formaldehyde bio-composite lumbers were 999.61, 952.29 and 844.18 N/mm^2. Meanwhile, the average values MOEb for urea formaldehyde bio-composite lumbers were 980.31, 949.40 and 840.40 N/mm^2 respectively from the bottom, middle and top portions for old maturity group. It was observed that the MOEb strength were decrease from the bottom to top portion for old maturity group both of phenol either urea formaldehyde bio-composite lumbers and the same situation were done for others two maturity groups which were the intermediate and young maturity groups. Looking at the average values of MOEb for maturity groups, the values for the bottom portion were having been discussing as a comparison. According to the result, the average value of MOEb strength for the bottom portion from the old, intermediate and young maturity groups of phenol formaldehyde bio composite lumbers were 999.61, 979.15 and 935.36 N/mm^2 respectively. Further, the mean value of MOEb strength for the bottom portion of urea formaldehyde bio composite lumbers were 980.31, 953.93 and 936.24 N/mm^2 from the old, intermediate and young maturity groups. Based on this distribution result, it showed that the average value of MOEb strength was a decrease from the old to young maturity groups for the bottom portion either for phenol or urea formaldehyde bio-composite lumbers and there were happened to the middle and top portions too according from the old, intermediate and young maturity groups. Beside the MOEb, the wood strength when the specimen reached the breaking point and then it was not able to recovery its shape, where the load achieves its maximum value, it's called MORb. This mechanical property is one of the important parameter which usually used for engineering purposes. Relating to the result test of MORb of the compressed oil palm fronds bio-composite lumbers at the different maturity groups, portions and resin types, the summarized data of mean values is presented in Table 4.

Based on the result in Table 4, the MORb of the compressed oil palm fronds bio-composite lumbers was gradually decreasing from the bottom to top portions for each maturity group and from old to young maturity groups for every portion. This including for both two types of the resin that have been used in producing this bio-composite lumbers which were phenol and urea formaldehyde resins. The MORb strength for the old maturity group from the bottom, middle and top portions were 16.66, 12.55 and 11.72 N/mm^2 respectively for the compressed oil palm frond bio-composite lumbers used phenol formaldehyde resin, while the MORb values for urea formaldehyde bio-composite lumbers were 15.40, 12.38 and 11.63 N/mm^2 respectively. This trend was also similar to the intermediate and young maturity groups according from the bottom towards top portions. Furthermore, in order to investigate the effect of maturity groups of oil palm fronds in producing this bio-composite lumbers to MORb in static bending strength, the data was carried out to examine the distribution of MORb values like shown in Table 4 based on mean value. From the obtained result, it showed that for the bottom portion for each maturity group which was the old, intermediate and young maturity groups from phenol formaldehyde bio-composite lumbers, the values was 16.66, 14.38 and 12.16 N/mm^2, meanwhile the MORb value for urea formaldehyde bio-composite lumbers was 15.40, 12.62 and 12.25 N/mm^2 respectively. This strength values respectively decreased from the old towards maturity groups for bottom portion either both of resin types that have been used in this bio-composite lumbers. The MORb value were decreasing too to others two portions which was the middle and top portions towards maturity groups from old, intermediate and young maturity groups. This trend was also similar to MOEb value effect by portions where the MORb values were decreasing from bottom to top portions for each maturity group as well as from old towards young maturity groups for every portion.

It is clearly observed that the values of both MOEb and MORb for the compressed oil palm fronds bio-composite lumbers were decreasing from bottom, middle and top portions as well as towards the maturity groups from matured, intermediate and young grouping. This happened to both of the bio-composite lumbers made from phenol and urea formaldehyde resin. the trend of variations in MOEb and MORb values along the tree height can be explained by the decrease in maturity of wood and fibre length from bottom to top of the tree (Rulliarty and America, 1995). This is due to the presence of vascular bundles which decreases from bottom to top portions along the oil palm fronds as well as from the matured to young grouping. The presence of vascular bundle affected the quantity of fibre cell that causes higher values in the density and basic density. High values in density and basic density influences the mechanical properties of wood (Haygreen and Bowyer, 1930). Based on Haygreen and Bowyer statement, it can be indentified why the bottom portion got higher value both for MOEb and MORb strength compare than the middle and top portions for each maturity group as well as matured group than the intermediate and young groups for every portion. The strength properties of wood have a close and significant correlation with density and basic density (Desch, 1968). The MOE and MOR strength of the compressed oil palm fronds bio-composite lumbers from the bottom portion produced higher result than middle and top portions for each maturity group as well as towards old, intermediate and young maturity groups for every portion. This reinforced by the ANOVA in Table 6, there was a significant difference between MOE and MOR of static bending with maturity groups and portions.

The result showed that the bio-composite lumbers from phenol formaldehyde resin possessed the higher value both of MOEb and MORb test than urea formaldehyde resin. Due to the factor of urea formaldehyde resin, it has high amount of solid content compared to phenol formaldehyde resin. Therefore, the distribution of phenol formaldehyde resin was located irregularly in the bio-composite lumbers structures (Abdullah, 2010). In addition, when the stress was applied, the stress could not be transferred consistently between the fibre and matrix. Besides this, the penetration of high viscosity of urea formaldehyde resin probably breaks the cell wall of the compressed oil palm fronds bio-composite lumbers (Abdullah, 2010). This action would make the fibre and matrix impossible to withstand greater loads. However, according to the analysis of variance in Table 6, the result of MOEb and MORb of static bending did not show any significant difference in resin types. This means that the types of resin does has influenced in the density value of the bio-composite lumbers. The strength in comparison between composites oil palm lumber from trunk, fronds and rubberwood are shown in Table 5. The strength of the composite made from oil palm fronds is slightly better than the composite made from the oil palm trunks (Razak *et al.*, 2008).

3.2.2: Compression Strength of Compressed Oil Palm Fronds Bio-composite Lumbers

Testing on mechanical property was conducted in accordance to the ISO 3787-1976. The obtained data was examined using statistical analysis to define the effect of three parameters like static bending strength test, which were based on maturity groups (mature, intermediate and young), portions (bottom, middle and top) including types of resin (phenol and urea formaldehyde) to the compression strength of the compressed oil palm fronds bio-composite lumbers. Table 6 showed the compression strength value of old maturity group from bottom to top portions were 473.17, 395.93 and 260.22 N/mm^2 for phenol formaldehyde bio-composite lumbers, while for the urea formaldehyde bio-composite lumbers, the result were 459.52, 344.60 and 260.00 N/mm^2 respectively. It can be observed that the compression strength were decrease from bottom portion towards to middle and top portions for old maturity group. The similar decrement distribution data have been done too for intermediate and young maturity groups towards from bottom, middle and top portions. In order to investigate the effect of maturity groups to compression strength of compressed oil palm fronds bio-composite lumbers, the data in Table 6 showed that the trend for each portion towards old, intermediate and young maturity groups were similar to portion factor from bottom to top portions. The result of bottom portion according from old, intermediate and young maturity groups were 473.17, 453.67 and 301.49 N/mm^2 for phenol formaldehyde bio-composite lumbers, meanwhile the obtained result 459.52, 431.88 and 312.94 N/mm^2 respectively for urea formaldehyde bio-composite lumbers. It is clearly showing the decrement towards old, intermediate and young maturity groups for the bottom portion and this was happen to others two portions which were middle and top portions.

The decreasing trend in the compression strength shows a similar trend of MOEb and MORb in static bending strength. This is caused by the differences vascular bundles population along the oil palm fronds, thus affected the value of density as well as basic density. The differences of density and basic density value encourage the distribution result of compression strength for the maturity groups and portions, where the bottom portion got higher result in compression strength than middle and top portions for each maturity group as well as for old maturity group follow by intermediate and young maturity groups for every portion. Significant difference exist between the compression strength with maturity groups and portions (see Table 7). Oyagade and Fasulu (2005) reported that generally each of the wood species, density and mechanical properties decrease with increment in the tree height. This also applied to the oil palm fronds from bottom, middle and top portions and from matured to young grouping. The compression strength in some wood show failure typically occurs in wood with low density (Nordahlia, 2008). The obtained result showed that the average value for each part of phenol formaldehyde bio-composite lumbers possessed higher result in compression strength than urea formaldehyde bio-composite lumbers. Higher compression strength of compressed oil palm fronds bio-composite lumbers with phenol formaldehyde resin as compared to urea formaldehyde bio-composite lumbers can be due to the fact that phenol formaldehyde resin, when properly cured, is often tougher that the wood itself as stated by Baldwin (1995). The effectiveness of the phenol and urea formaldehyde resin in enhancing the compression strength showed a similar trend to that of the static bending, where the phenol formaldehyde bio-composite lumbers possessed higher value compared to urea formaldehyde bio-composite lumbers. The differences, however shows no significant difference (see Table 7).

3.3 Analysis of Variance on Physical and Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Lumbers: Table 7 shows the analysis of variance (ANOVA) for physical and mechanical properties of the compressed oil palm fronds bio-composite lumbers. The analysis was conducted to determine whether there exist any significance difference between physical properties (density and basic density) and mechanical properties (MOEb for static bending strength and MORb for static bending including compression strength) with maturity groups, portions and types of resin of the compressed oil palm fronds bio-composite lumbers.

Based on the ANOVA in Table 7, there were significant differences between physical properties (density and basic density) and mechanical properties (static bending strength (MOEb and MORb) and compression strength (MORc) with the maturity groups and portions factors. It possessed that the significant differences between them were at P-value ≤ 0.01. The obtained result shows that for all physical and mechanical properties that have been investigate towards compressed oil palm fronds in this study show the significant differences with the maturity groups as well as the portions. It means that maturity groups and portions were affected and influenced for the result of physical and mechanical properties values of the bio-composite lumbers. There was no significant difference between physical properties (density and basic density) and mechanical properties (static bending strength (MOEb and MORb) and compression strength (MORc)) with the types of resin factors. According to the ANOVA in Table 7, there was no encouragement of resin types to the physical and mechanical properties of the compressed oil palm fronds bio-composite lumbers, although there was differences in value for the testing result for each part which were the testing result from phenol formaldehyde bio-composite lumbers possessed more higher value than urea formaldehyde bio-composite lumbers and has been discussed before this. It means whether using phenol or urea formaldehyde resin in producing this bio-composite lumbers will give quite similar in values testing result.

3.4 Correlation Coefficient between Physical and Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Lumbers: The correlation among physical and mechanical properties of the compressed oil palm fronds bio-composite lumbers is presented in Table 8. There was a correlation between physical properties (density and basic density) of compressed oil palm fronds bio-composite lumbers with maturity groups and portions. Negative correlations were observed between density and maturity groups ($r = -0.3657$) and portions ($r = -0.3748$). The basic density ($r = -0.4435$, $r = -0.6588$) however, were negatively correlated with maturity groups and portions. These correlations of compressed oil palm fronds bio-composite lumbers were similar to correlation coefficient of oil palm fronds, where from old to young maturity groups for each portion and towards bottom, middle and top portions for every maturity group, there were decreasing in density as well as basic density values. These were supported by negative correlation between them as been shown in Table 8 and have significant differences in ANOVA displayed in Table 7. There was also a correlation coefficient between density with basic density ($r = 0.5611$). A positive correlation was observed between of them and significant difference at P-value ≤ 0.01. A positive correlation relationship exist between resin types with density value ($r = 0.0411$), while negative correlation was shown among the resin types and basic density value ($r = -0.0668$). However, these correlation relationship were not significant (Table 7).

The correlation between the strength properties (MOEb for static bending strength and MORb for static bending including compression strength) with others compressed oil palm fronds bio-composite lumbers properties are presented in Table 8. There was a correlation between maturity groups factor with the mechanical properties values. Negative correlation were obtained between maturity groups with MOEb of static bending strength (r = -0.4321), MORb of static bending strength (r = -0.4927) and MOR for compression strength (r = -0.5029). While, similar trend correlation were obtained too between portions with MOEb of static bending strength (r = -0.7862), MORb of static bending strength (r = -0.6939) and last but not least MORc for compression strength (r = -0.7481). The negative correlation between maturity groups and portions with strength properties (MOEb and MORb for static bending strength and MORc for compression strength) means that the strength of compressed oil palm fronds bio-composite lumbers decreases towards bottom, middle and top portions for each maturity group as well as from old to young maturity groups for every portion. The ANOVA presented in Table 7 shows significant difference at P-value ≤ 0.01.

The strength properties of wood have a close and significant correlation with density as well as basic density (Desch, 1968). Increment of density and basic density value increases the mechanical properties of wood including static bending and compression strength. This statement is supported in the correlation analysis shown in Table 7. The positive correlation coefficient occurred between density and basic density value with strength properties (MOEb and MORb of static bending strength and MORc of compression strength) of compressed oil palm fronds bio-composite lumbers towards maturity groups (old to young maturity groups) and portions (bottom to top portions). Positive correlation were obtained between density with MOEb of static bending strength (r = 0.3750), MORb of static bending strength (r = 0.4045) and MORc of compression strength (r = 0.5339), while correlation between basic density with these three mechanical testing that has been done in this study were r = 0.7241 and r = 0.6669 for MOEb and MORb of static bending strength and r = 0.7356 for MORc of compression strength. All of these correlations possessed significant differences at P-value ≤ 0.01 according to the ANOVA in Table 7.

The effect of resin types on the mechanical properties of compressed oil palm fronds bio-composite lumbers, there posses negative correlation among of them, where r = -0.1196 and r = -0.1592 for MOEb and MORb of static bending strength, while r = -0.0867 for MORc of compression strength. It was similar trend to correlation relationship between physical properties (density and basic density) of compressed oil palm fronds bio-composite lumbers with types of resin. Although, they possessed a correlation relationship, but there were not significant between of them according to ANOVA in Table 6. It means that the types of resin not affected too much to mechanical properties of this bio-composite lumbers strength similar to physical properties. Positive correlation were observed among of these three mechanical properties, where r = 0.7673 and r = 0.7870 between MOEb of static bending strength with MORb of static bending and compression strength, while r = 0.7889 between MORb of static bending strength with MORc of compression strength and these correlation coefficient were possessed significant differences at P-value ≤ 0.01.

4. CONCLUSIONS

The bio-composite lumbers made from matured oil palm fronds possessed high values in density and basic density within the oil palm fronds maturity. This is followed by the intermediate and young fronds. The same trends were observed in the bottom, middle and top portions of the oil palm fronds. The high density of the bio-composite lumber were those produced from the matured bottom portion having 0.42 to 0.46 g/cm^3 followed by the intermediate middle and young top portions having 0.40 to 0.44 g/cm^3 and 0.40 to 0.42 g/cm^3 respectively. Matured bottom portion of oil palm fronds have the highest basic density of 0.32 to 0.39 g/cm^3, followed by the intermediate middle and young top portion having 0.32 to 0.37 g/cm^3 and 0.30 to 0.34 g/cm^3 respectively.

In the static bending, the matured bottom portion possesses the highest strength in modulus of elasticity (MOEb) of 840.40 to 999.61 N/mm^2 followed by the intermediate middle and young top portions having 776.04 to 979.15 N/mm^2 and 666.30 to 936.24 N/mm^2 respectively. The highest modulus of rupture (MORb)) in static bending for the bio-composite lumber were those produced from the matured bottom portion having 11.63 to 16.66 N/mm^2 followed by the intermediate middle and young top portions having 10.51 to 14.38 N/mm^2 and 9.10 to 12.25 N/mm^2 respectively.

The highest strength in modulus of rupture (MORc) for compression of the bio-composite lumber were those produced from the matured bottom portion having 260.00 to 473.17 N/mm^2 followed by the intermediate middle and young top portions having 190.70 to 453.67 N/mm^2 and 181.06 to 312.94 N/mm^2 respectively.

REFERENCES

Abdullah, C. K. (2010). *Impregnation of Oil Palm Trunk Lumber (OPTL) using Thermoset Resins for Structural Applications*. Master Thesis. Universiti Sains Malaysia.

Abraham, J. M., Zakaria, M. A., Mohd Nor, M. Y. and Simatupang, M. H. 1998. Suitability of kraft pulp from oil palm trunk for cellulose fibre reinforced cement boards. *Journal of Tropical Forest Product.* 4 (2): 65-159.
Astimar, A. A., Mohamad, H. and Anis, M. (2002). Preparation of cellulose from oil palm empty fruit bunches via ethanol digestion: Effect of acid and alkali catalysts. *Journal of Oil Palm Research.* 14 (1): 9-14.
Baldwin, R. F. (1995). *Adhesives and Bonding Techniques. In: Plywood and Veneer-based Products Manufacturing Practuces.* California: Miller Freeman Inc.
Bowyer, J. L., Shmulsky, R. and Haygreen, J. G. (2004). *Forest Product and Wood Sciences – An Introduction* (4th Edition). Blackwell Publishing Company.
Chew, T. L. (1987). Particleboard manufactured from oil pal stems: A pilot scale study. *FRIM Occasional Paper No. 4.* Kepong: Forest Research Institute Malaysia (FRIM). 8.
Desch, H. E. (1968). Timber, Its Structure, properties and utilization. New York: London and Basingstoke Associated companies.
Erwinsyah. (2008). *Improvement of Oil Palm Wood Properties Using Bioresin.* PhD Thesis. Technische Universität Dresden.
Haygreen, J. G. and Bowyer, J. L. (1930). *Introduction to Forest Product and Wood Science.* Subtitled by Suhaimi Muhammed and Sheikh Abdul Karim Yamani Zakaria. Kuala Lumpur: Ampang Press Sdn. Bhd.
Hill, C. A. S., Abdul Khalil, H. P. S. and Hale, M. D. (1998). A study of the potential of acetylation to improve the properties of plan fiber. *Journal of Industrial Crops and Products.* 8: 53.
Ho, K. S., Choo, K. T. and Hong, L. T. (1985). Processing, seasoning and protection of oil palm lumber. *Proceedings of the National Symposium on Oil Palm by-products for Agrobased Industries,* November 5-6, 1985, Kuala Lumpur, Malaysia. 43-51.
International Organization for Standardization 3131-1975. (1975). Switzerland: Wood Determination of Density for Physical and Mechanical Tests.
International Organization for Standardization 3133-1975. (1975). Switzerland: Wood Determination of Ultimate Strength in Static Bending.
International Organization for Standardization 3349-1975. (1975). Switzerland: Wood Determination of Modulus of Elasticity in Static Bending.
International Organization for Standardization 3787-1976. (1976). Switzerland: Wood Determination of Ultimate Compression Stress Parallel to Grain.
Kochummen, A. M., Wong, W. C. and Killmann, W. (1990). Manufacture of cement board using oil palm stems. Unpublished IDRC Final Report.
Laemsak, N. and Okuma, M. (2000). Development of boards made from oil palm frond II: Properties of binderless boards from steam-exploded fibres of oil palm. *Journal of Wood Science.* 46 (4): 322-326.
Liew, K. C., Jalaluddin, H., Paridah, M. T., Khairul Zaman, M. D. and Mohd Nor, M. Y. (2000). Properties of oil palm frond-polypropylene composite. *Proceedings of the Utilization of Oil Palm Tree-Oil Palm Biomass: Opportunities and Challenges in Commercial Exploitation.* 8-116.
Mohamad, H., Anis, M. and Wan Hasamudin, W. H. (2003). Energizing the wood-based industry in Malaysia. *Proceedings of the 6th National Seminar on The Utilisation of Oil Palm Tree,* December 15-17, 2003, Oil Palm Tree Utilisation Committee (OPTUC), Kuala Lumpur, Malaysia. 6-13.
Mohamad, H., Ridzuan, R., Anis, M., Wan Hasamudin, W. H., Kamaruddin, H., Ropandi, M. and Astimar, A. A. (2002). Research and development of oil palm biomass utilization in wood-based industries. *Journal of Palm Oil Developments.* 36: 1-5.
Mohamad, H., Zin, Z. Z. and Abdul Halim, H. (1985). Potentials of oil palm by products as raw materials for agro-based industries. *Proceedings of National Symposium on Oil Palm by-product for Agro-based Industries,* Kuala Lumpur, Malaysia.
Nordahlia, A. S. (2008). *Wood Quality of 10-Year-Old Sentang (Azadirachta excelsa) Grown from Seedlings and Rooted Cuttings.* Master Thesis. University Putra Malaysia.
Othman, S., Rokiah, H., Razak, W., Hashim, W. S. and Azmy, M. (2008). Evaluation on somefinishing properties of oil palm plywood. *Journal of Holz Roh Werkst.* 66: 5-10.
Oyagade, A. O. and Fasulu, S. A. (2005). Physical and Mechanical Properties of *Trilepisium madagascariense* and *Funtumia elastica* Wood. *Journal of Tropical Forest Science.*17(2): 258-264.
Paridah, M. T. and Anis, M. (2008). Process optimization in the manufacturing of plywood from oil palm trunk. *Proceedings of 7th National Seminar on the Utilization of Oil Palm Tree,* Oil Palm Tree Utilization Committee, Kuala Lumpur, Malaysia. 12-24.
Razak, W., Hashim, W. S., Aminuddin, M., Othman, S. and Rafidah, S. (2008). Properties of laminated veneer lumbers from oil palm trunks. *Journal of Plant Sciences.* 3 (4): 255-259.
Ridzuan, R., Stephen, S. and Mohd Ariff J. (2002). Properties of medium density fibreboard from oil palm empty fruit bunch fibre. *Journal of Oil Palm Research.* 14 (2): 34-40.

Rowell, R. M. (1994). *Chemical of Solid Wood.* Subtitled by Suhaimi Muhammed and Halimathon Hj Mansor. Kuala Lumpur: Dewan Bahasa dan Pustaka.

Rulliarty, S. and America, W. A. (1995). Natural Variation in Wood Quality Indicators of Indonesian Big Leaf Mahogany(*Swietenia macrophylla.* King). *Proceedings of XX IUFRO World Congress*, Tampere.

Schwarz, H. G. (1985). Cement-bonded boards in Malaysia. *Proceedings of the fibre and particleboards bonded with inorganic binders*, Forest Research Soc, USA. 91-93.

Tanaka, R., Peng, L. C. and Wan Rosli, W. D. (2002). Preparation of cellulose pulp from oil palm empty fruit bunches (EFB) by processes including pre-hydrolysis and ozone bleaching. *Proceedings of the USM-JIRCAS Joint International Symposium-Lignocellulose-Material of the Millenium: Technology and Application*, March 20-21, 2001, Penang, Malaysia. 33-8.

Tsoumis, G. (1991). *Science and Technology of Wood – Structure, Properties and Utilization.* New York: Van Nostrand Reinhold.

Wahid, M. B., Abdullah, S. N. A. and Henson, I. E. (2004). Oil palm: Achievements and potential in new directions for a diverse planet. *Proceedings of the 4th International Crop Science Congress*, September 26 – October 1, 2004. Brisbane, Australia.

Walker, J. C. F., Butterfield, B. G., Langrish, T. A. G., Harris, J. M. and Uprichard, J. M. (1993). *Primary Wood Processing* (1st Edition). London: Chapman and Hall.

Zulkifli, R., Mohd Nor, M. J., Mat Tahir, M. F. Ismail, A. R. and Nuawi, M. Z. (2008). Acoustic properties of multi-layer coir fibres sound absortion panel. *Journal of Applied Sciences.* 8 (20): 3709-3714.

Table 1: Mean value for density of Compressed Oil Palm Fronds bio-composite lumbers

Oil palm fronds grouping	Type of Resin	Density (g/cm^3) of portions		
		Bottom	Middle	Top
Matured	Phenol formaldehyde	0.45	0.44	0.42
	Urea formaldehyde	0.46	0.43	0.42
Intermediate	Phenol formaldehyde	0.43	0.42	0.40
	Urea formaldehyde	0.44	0.42	0.41
Young	Phenol formaldehyde	0.42	0.41	0.40
	Urea formaldehyde	0.42	0.41	0.40

Table 2: Mean value for basic density of Compressed Oil Palm Fronds bio-composite lumbers

Oil palm fronds grouping	Type of Resin	Basic density (g/cm^3) of portions		
		Bottom	Middle	Top
Matured	Phenol formaldehyde	0.38	0.36	0.33
	Urea formaldehyde	0.39	0.35	0.32
Intermediate	Phenol formaldehyde	0.36	0.35	0.32
	Urea formaldehyde	0.37	0.34	0.31
Young	Phenol formaldehyde	0.34	0.33	0.30
	Urea formaldehyde	0.34	0.32	0.30

Table 3: Modulus of elasticity (MOE) static bending strength of Compressed Oil Palm Fronds bio-composite lumbers

Oil palm fronds grouping	Type of Resin	Static bending MOE (N/mm^2) of portions		
		Bottom	Middle	Top
Matured	Phenol formaldehyde	999.61	952.29	844.18
	Urea formaldehyde	980.31	949.40	840.40
Intermediate	Phenol formaldehyde	979.15	942.44	817.29
	Urea formaldehyde	953.93	928.34	776.04
Young	Phenol formaldehyde	935.36	837.24	761.14
	Urea formaldehyde	936.24	836.67	666.30

Table 4: Modulus of rupture (MOR) static bending strength of Compressed Oil Palm Fronds bio-composite lumbers

Oil palm fronds grouping	Type of Resin	Static bending MOR (N/mm^2) of portions		
		Bottom	Middle	Top
Matured	Phenol formaldehyde	16.66	12.55	11.72
	Urea formaldehyde	15.40	12.38	11.63
Intermediate	Phenol formaldehyde	14.38	12.37	10.87
	Urea formaldehyde	12.62	12.07	10.51
Young	Phenol formaldehyde	12.16	11.62	10.27
	Urea formaldehyde	12.25	11.19	9.10

Note : Number of replicates for each parameter = 5, Total number of samples for each testing = 90

Table 5. Bending strength between composites oil palm fronds, composite oil palm stem and rubberwood

Bio-Composite Lumbers	Density (kg/m^3)	MORb (N/mm^2)	MOEb (N/mm^2)
Oil Palm Fronds	460.00 (33%)	16.66 (70%)	999.61 (61%)
Oil Palm Stem	486.97 (29%)	15.13 (73%)	480.06 (81%)
Rubberwood	689.15 (00%)	56.57 (00%)	2543.34 (00%)

(value in bracket indicate % lower than rubberwood)

Table 6: Modulus of rupture (MORc) compression strength of Compressed Oil Palm Fronds bio-composite lumbers

Oil palm fronds grouping	Type of Resin	Compression MORc (N/mm^2) of portions		
		Bottom	Middle	Top
Matured	Phenol formaldehyde	473.17	395.93	260.22
	Urea formaldehyde	459.52	344.60	260.00
Intermediate	Phenol formaldehyde	453.67	318.88	196.71
	Urea formaldehyde	431.88	274.90	190.70
Young	Phenol formaldehyde	301.46	235.60	183.48
	Urea formaldehyde	312.94	198.79	181.06

Note: Number of replicates for each parameter = 5, Total number of samples for each testing = 90

Table 7: Analysis of variance on the physical and mechanical properties of Compressed Oil Palm Fronds bio-composite lumbers

Source of Variance	Dependent Variable	Df	Sum of Square	Mean Square	F-Ratio
Maturity	D	2	0.0108	0.0054	7.94 **
	BD	2	0.0180	0.0197	28.75**
	MOEb	2	155675.0000	77837.5000	57.05 **
	MORb	2	79.0218	39.5109	40.39 **
	MORc	2	255794.0000	127897.0000	63.81**
Portion	D	2	0.0112	0.0056	8.26 **
	BD	2	0.0394	0.0090	28.75 **
	MOEb	2	507856.0000	253928.0000	186.12 **
	MORb	2	157.7170	78.8586	80.62 **
	MORc	2	565023.0000	282512.0000	140.95 **
Resin	D	1	0.0001	0.0001	0.20 ns
	BD	1	0.0004	0.0004	1.28 ns
	MOEb	1	11232.8000	11232.8000	8.23 ns
	MORb	1	8.2313	8.2313	8.41 ns
	MORc	1	7538.0100	7538.0100	3.76 ns

** = significant at $p \leq 0.01$, ns = not significant, D = Density, BD = Basic Density, MOEb = Modulus of elasticity for static bending strength, MORb = Modulus of rupture for static bending strength, MORc = Modulus of rupture for compression strength, Total number of samples for each testing = 90

Table 8: Correlation analysis between physical and mechanical properties of Compressed Oil Palm Fronds bio-composite lumbers

	Maturity	Portion	Resin	D	BD	MOEb	MORb	MORc
Maturity	1.0000	0.0000ns	0.0000ns	-0.3657**	-0.4435**	-0.4321**	-0.4927**	-0.5029**
Portion		1.0000	0.0000ns	-0.3748**	-0.6588**	-0.7862**	-0.6939**	-0.7481**
Resin			1.0000	0.0411ns	-0.0668ns	-0.1196ns	-0.1592ns	-0.0867ns
D				1.0000	0.5611**	0.3750**	0.4045**	0.5339**
BD					1.0000	0.7241**	0.6669**	0.7356**
MOEb						1.0000	0.7673**	0.7870**
MORb							1.0000	0.7889**
MORc								1.0000

** = significant at p≤ 0.01, ns = not significant, D = Density, BD = Basic Density, MOEb = Modulus of elasticity for static bending strength, MORb = Modulus of rupture for static bending strength, MORc = Modulus of rupture for compression strength, Note: Total number of samples for each testing = 90