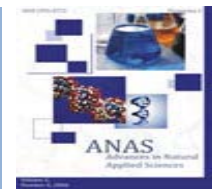




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Physical And Mechanical Properties Of Bio-Composite Board From Compressed Oil Palm Fronds

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ABSTRACT

Investigations were conducted on physical and mechanical properties of the bio-composite boards made from compressed oil palm fronds. The bio-composites boards consist of young, intermediate and mature fronds, which were divided to three portions respectively. They were the bottom, middle and top portions for each maturity age group of the fronds. The fronds were sliced longitudinal into the thin sheet after their skins were removed. The sheets were later compressed by running them through a flattening machine. Two types of resins namely phenol formaldehyde and urea formaldehyde were used to bind the fronds' sheets together forming parallel bio-composite board from compressed oil palm fronds. The physical and mechanical properties of this bio-composite board were later studied. The physical properties such as density and basic density were investigated. The mechanical properties such as static bending for modulus of elasticity and modulus of rupture as well as the compression strength for modulus of rupture were studied in order to investigate their strength properties in structural application. All tests were made in accordance to the International Organization for standardization (ISO) standards. The results indicate that the bio-composite boards with higher basic density possess higher bending and compression strength compares to those with lower values. The bio-composite board from bottom portion oil palm frond shows to have the higher basic density follows by the middle and top portion for each maturity age group, meanwhile matured maturity group possess the higher basic density for each portion compare to the intermediate and young maturity group. Thus, the bending and compression strength show to have higher results for bio-composite board from bottom portion and decrease for the middle and top portion for each maturity age group, while the matured maturity group possess the higher strength result for each portion follows then by intermediate and young maturity group.

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INTRODUCTION

The increasing in timber prices and the shortage of timber supply has affected the wood-based industries in the world including Malaysia (Uysal, 2005). The ever increasing manufacturing costs and uncertainty in wood supply in some region due to restrictions on logging and inadequate forest resources have caused increasing concerns over future fiber supplies. However, the forest could not supply the woods in a huge amount anymore due to depletion of the natural forest. As the results, the wood industry are facing shortage of wood required for their operations and many plants producing wood based products, especially plywood and lumber had to cease or close down operations.

This phenomenon has prompted an immediate research and development by most countries around the world to look for an alternative material to replace natural wood. Sustainable lignocelluloses resources are available in different forms of non-wood based fibers and agriculture residues. Oil palm especially the fronds has a high potential to be used in overcoming this problem. It appears to be the most viable alternative to be

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utilized as value added product as well as future wood-based industry (Mohamad *et al.*, 2003). Unlike other plants, the oil palm fronds can be obtained at anytime. With the expansion in the cultivation of oil palm, oil palm fronds can be obtained in large quantity. Cultivation of the oil palm has expanded tremendously in recent years such that it is now second only to soybean as a major source of the world supply of oils and fats (Wahid *et al.*, 2004). Oil palms by products are available in large quantity sufficient for industrial raw materials in agro-based industries. The endless and consistent supply of lignocelluloses materials from oil palm industry should be considered as new resources. New products from oil palm are now at their stage of research to be developed later on.

One of the major attentions is converting them into a higher value added product such as the bio-composite. In Malaysia oil palms are abundant and be planting in commercial plantation. The oil palm which is mainly growth for its oil production and its economic life spans is about 25 years and would be planted after 25 to 30 years old and this process would contributed to a high amount of agricultural waste (Ismail *et al.*, 1990). During the replanting process, the waste would be generated in the form of felled trunks and fronds. As the world's leading exporter of oil palm, Malaysia had at least 4 million ha of oil palm plantation and it has been estimated that about 23 million mt of waste will be available during replanting (Kamarulzaman *et al.*, 2004). These residues would be great new sources of economy if we can maximally convert them into value added product and thus, this study seems to be relevant and important.

In this study, the bio-composite board made from the compressed oil palm fronds was introduced as an alternative to future wood composite and had been investigated for their physical and mechanical properties. The result of the study hopefully will contribute to optimizing the use of the biomass by products especially from oil palm as well as giving better understanding and knowledge in non-wood materials for a sustainable tomorrow.

MATERIALS AND METHODS

Oil Palm Fronds Preparation:

The oil palm fronds from same age tree were obtained from a private plantation in Kota Belud, Sabah. The oil palm fronds were selected based on decay-free and no defect trees. The selected oil palm fronds were divided into three groups according to their maturity. They were matured fronds that have been taken from the below of the fronds crown, meanwhile the intermediate fronds were obtained from the middle of the fronds crown. The third group was the young fronds that have been taken from the above of the fronds crown. Within these groups they were further sub-divided into bottom, middle and top portions. Leaflets were removed from the fronds, and then were peeled of their skin and sliced in longitudinal direction of thickness 2 - 4 mm, and later compressed using rollers compressed machine to increase their density before undergoing sun-drying.

Sun-Drying:

All the compressed oil palm fronds then undergo a sun-drying process for 12 hours until almost the moisture was removed from the fiber. This sun-drying process was done to enhance their durability against fungi and insects attacks. The drying process ends once the moisture content of these compressed oil palm fronds reached the equilibrium moisture content (14% in Malaysia).

Resin:

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

Compressed Oil Palm Fronds Bio-composite Board Manufactured:

The compressed oil palm fronds bio-composite board was made on laboratory scale by standard techniques and controlled conditions. 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 $125\pm 5^\circ\text{C}$ for phenol formaldehyde resin, meanwhile $100\pm 5^\circ\text{C}$ for urea formaldehyde resin and pressed into desire shape for testing products making to form the bio-composite board.

The compressed oil palm fronds bio-composite board was 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 phenol formaldehyde and urea formaldehyde. The bio-composite board was 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 the bio-composite boards were trimmed and cut into various size test specimens and then

conditioned at $20\pm3^{\circ}\text{C}$ and $65\pm3\%$ relative humidity (RH) for 72 hours prior for testing to produce an equilibrium moisture content of about $12\pm1\%$.

Physical Properties of Compressed Oil Palm Fronds Bio-composite Board:

Physical properties were tested and evaluated in accordance with International Organization for Standardization (ISO) standards. Physical properties of compressed oil palm fronds bio-composite board was studied including density and basic density. In order to understand the compressed oil palm fronds bio-composite board behaviors and performances, it is necessary to consider first some of the basic physical properties which are affecting to its mechanical properties furthermore. All of the physical properties studied were investigated on the basis of its maturity groups, portions and resin types of the compressed oil palm fronds bio-composite board.

a) 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 $103\pm2^{\circ}\text{C}$ 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 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.

b) Basic Density:

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 was taken before undergoing to oven-dried at $103\pm2^{\circ}\text{C}$ until its weight was 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.

Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Board:

Evaluation of mechanical properties 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 board was tested through the following method; static bending strength including modulus of elasticity (MOE) and modulus of rupture (MOR) besides compression strength for modulus of rupture (MOR).

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).

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

b) Compression Strength:

The compression strength test was performed according to ISO 3787-1976 for MOR 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. Compression strength is defined as the maximum stress sustained by compression of a specimen with the specimen having a ratio of length to smallest dimension (Thanate *et al.*, 2006). While, Ronald and Gjinoli (1997) reported that the characteristic of the compression load deformation curve were similar to those for static bending strength. The compression strength of composite is strongly dependent on the effectiveness of the matrix in supporting the fiber against buckling (John and Reid, 1969).

RESULTS AND DISCUSSIONS

Physical Properties of Compressed Oil Palm Fronds Bio-composite Board:

Several physical properties of the compressed oil palm fronds bio-composite board was investigated in this study. They were density and basic density evaluation. Physical properties were tested and evaluated in accordance with International Organization for Standardization (ISO) standards.

a) Density:

Table 1 shows the results of mean value for density the bio-composite board for each maturity group, portion and resin type. The highest density for the bio-composite board was coming from the bottom portion for each maturity group followed by the middle and then top portions. Meanwhile, the matured 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 matured maturity group possessed the highest density values for every portion compared to others follow by the intermediate and young maturity groups.

Table 1: Mean value for density of compressed oil palm fronds bio-composite board

Oil palm fronds maturity groups	Resin used	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

Note: Number of replicates for each parameter = 5

Total number of replicates = 90

The density values were affected by the anatomical structure in the oil palm fronds by its population of vascular bundles and parenchymatous tissues. This reinforced by the Analysis of Variance (ANOVA) in Table 6, there was a significant difference between density with maturity groups and portions, but there was no significant difference for the resins that had been used to produce the bio-composite board. It means that, the types of resin were not influenced to the density value of the bio-composite board.

The density of the compressed oil palm fronds bio-composite board more higher compared to the oil palm fronds density by the effect of resin penetration that have been used in producing the bio-composite board. It was found that, the presence of both resins could increase the density of the compressed oil palm fronds bio-composite board that cause the increasing in material substance per unit volume in the bio-composite board.

b) Basic Density:

Table 2 shows the mean values of basic density for the compressed oil palm fronds bio-composite board for each maturity group, portion and resin type. The results showed that all the basic density values decreased from the bottom to top portions for each maturity group, meanwhile the matured maturity groups possessed the highest basic density values for every portion compared to others follow by the intermediate and young maturity groups. Its trend was similar to the density value, just different in number value because of its way calculation has been done.

Table 2: Mean value for basic density of compressed oil palm fronds bio-composite board

Oil palm fronds maturity group	Resin used	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

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

According to the obtained results in Table 2, the decreased summarized the compressed oil palm fronds bio-composite board basic density from the bottom to top portions for each maturity group and from the matured to young maturity groups for each portion. 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 the basic density values that had been recorded in this study where the compressed oil palm fronds bio-composite board from the bottom portion recorded 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.

ANOVA 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 board. It means that, the types of resin were not influenced to the basic density value of the bio-composite board. However, the basic density of compressed oil palm fronds bio-composite board more higher compared to the oil palm fronds basic density by the effect of resin that have been used in producing this bio-composite board. The increasing of the compressed oil palm fronds bio-composite board basic density probably related to resin penetration into the bio-composite board. Previous study by Paridah and Anis (2008) report that parenchyma behaves like a sponge and can easily absorb moisture. Therefore, the bio-composite board 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 board. It is assumed that the resin penetrations possessed higher density as well as basic density and enhance the strength of the bio-composite board.

Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Board:

Regarding the mechanical properties of the compressed oil palm fronds bio-composite board, several mechanical properties were tested in this study, including static bending strength (MOE and MOR) and compression strength (MOR). 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 board were particularly investigated the effect of maturity groups, portions and types of resin.

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/mm², but in order to have the value in kg/cm², the force value can be converted into International System of Unit (Walker *et al.*, 1993).

a) Static Bending Strength:

In order to investigate the static bending of the compressed oil palm fronds bio-composite board, the analysis data was conducted to examine the effect of maturity groups (matured, intermediate and young), portions (bottom, middle and top) and resins (phenol and urea formaldehyde) to the MOE and MOR. The summarized mean result of static bending test including MOE and MOR strength is presented in Table 3 and 4. It showed that the bottom portion got the highest value for both MOE and MOR strength in static bending for every maturity group, meanwhile the matured maturity group possessed the highest value for each portion compared to the intermediate and young maturity groups.

It is 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 matured 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 (MOE) strength, it showed that the average values of the matured maturity group from the bottom, middle and top portions for phenol formaldehyde bio-composite board were 999.61, 952.29 and 844.18 N/mm². Meanwhile, the average values MOE for urea formaldehyde bio-composite board were 980.31, 949.40 and 840.40 N/mm² respectively from the bottom, middle and top portions for matured maturity group. It was observed that the MOE strength were decrease from the bottom to top portion for matured maturity group both of phenol either urea formaldehyde bio-composite board and the same situation were done for others two maturity groups which were the intermediate and young maturity groups.

Table 3: Modulus of elasticity (MOE) static bending strength of compressed oil palm fronds bio-composite board

Oil palm fronds maturity group	Resin used	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

Note: Number of replicates for each parameter = 5

Total number of replicates = 90

Looking at the average values of MOE for maturity groups, the values for the bottom portion were having been discussing as a comparison. According to the result, the average value of MOE strength for the bottom portion from the matured, intermediate and young maturity groups of phenol formaldehyde bio-composite board were 999.61, 979.15 and 935.36 N/mm² respectively. Further, the mean value of MOE strength for the bottom portion of urea formaldehyde bio-composite board were 980.31, 953.93 and 936.24 N/mm² from the matured, intermediate and young maturity groups. Based on this distribution result, it showed that the average value of MOE strength was a decrease from the matured to young maturity groups for the bottom portion either for phenol or urea formaldehyde bio-composite board and there were happened to the middle and top portions too according from the matured, intermediate and young maturity groups.

Relating to the result test of MOR of the compressed oil palm fronds bio-composite board at the different maturity groups, portions and resin types, the summarized data of mean values is presented in Table 4.

Table 4: Modulus of rupture (MOR) static bending strength of compressed oil palm fronds bio-composite board

Oil palm fronds maturity group	Resin used	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 replicates = 90

Based on the result in Table 4, the MOR of the compressed oil palm fronds bio-composite board was gradually decreasing from the bottom to top portions for each maturity group and from matured to young maturity groups for every portion. This including for both two types of the resin that have been used in producing the bio-composite board which were phenol and urea formaldehyde resin. The MOR strength for the matured maturity group from the bottom, middle and top portions were 16.66, 12.55 and 11.72 N/mm² respectively for the compressed oil palm frond bio-composite board used phenol formaldehyde resin, while the MOR values for urea formaldehyde bio-composite board were 15.40, 12.38 and 11.63 N/mm² respectively. This trend was also similar to the intermediate and young maturity groups according from the bottom towards top portions.

Further, in order to investigate the effect of maturity groups of oil palm fronds in producing the bio-composite board to MOR in static bending strength, the data was carried out to examine the distribution of MOR

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 matured, intermediate and young maturity groups from phenol formaldehyde bio-composite board, the values was 16.66, 14.38 and 12.16 N/mm², meanwhile the MOR value for urea formaldehyde bio-composite board was 15.40, 12.62 and 12.25 N/mm² respectively. This strength values respectively decreased from the matured towards maturity groups for bottom portion either both of resin types that have been used in the bio-composite board. The MOR value were decreasing too to others two portions which was the middle and top portions towards maturity groups from matured, intermediate and young maturity groups. This trend was also similar to MOE value effect by portions where the MOR values were decreasing from bottom to top portions for each maturity group as well as from matured towards young maturity groups for every portion.

It is clearly observed that the values of both MOE and MOR for the compressed oil palm fronds bio-composite board were decrease towards the portions from bottom, middle and top portions as well as towards the maturity groups from matured, intermediate and young maturity groups. These were happen to both of the bio-composite board made from phenol and urea formaldehyde resin.

According to Rulliarty and America (1995), the trend of variations in MOE and MOR values along the tree height can be explained by the decrease in maturity of wood and fiber length from bottom to top of the tree. This statement was logically accepted due to the presence of vascular bundles decrease from the bottom to top portions along the oil palm fronds as well as from the old to young maturity groups. It is because the presence of vascular bundle will affect the quantity of fiber cell that cause the density and basic density values in higher results. According to Haygreen and Bowyer (1930), the higher result in density and basic density values are the main physical properties that will affected the mechanical properties of wood. Based on Haygreen and Bowyer statement, it can be indentified why the bottom portion got higher value both for MOE and MOR strength compare than the middle and top portions for each maturity group as well as matured maturity group than intermediate and young maturity groups for every portion.

The strength properties of wood have a close and significant correlation with density and basic density (Desh, 1968). The MOE and MOR strength of the compressed oil palm fronds bio-composite board from the bottom portion produced higher result than middle and top portions for each maturity group as well as towards matured, 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 obtained result showed that the bio-composite board from phenol formaldehyde resin possessed the higher value both of MOE and MOR 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 board structures (Abdullah, 2010). In addition, when the stress was applied, the stress could not be transferred consistently between the fiber 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 board (Abdullah, 2010). This action would make the fiber and matrix impossible to withstand greater loads. However, according to ANOVA in Table 6, the result of MOE and MOR of static bending did not show significantly difference with resin types. It means that, the types of resin were not too much influenced to the density value of the bio-composite board.

b) Compression Strength:

Table 5 showed the compression strength value of matured maturity group from bottom to top portions were 473.17, 395.93 and 260.22 N/mm² for phenol formaldehyde bio-composite board, while for the urea formaldehyde bio-composite board, the result were 459.52, 344.60 and 260.00 N/mm² respectively. It can be observed that the compression strength were decrease from bottom portion towards to middle and top portions for matured maturity group. The similar decrement distribution data have been done too for intermediate and young maturity groups towards from bottom, middle and top portions.

Table 5: Modulus of rupture (MOR) compression strength of compressed oil palm fronds bio-composite board

Oil palm fronds maturity group	Resin used	Compression MOR (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 replicates = 90

In order to investigate the effect of maturity groups to compression strength of compressed oil palm fronds bio-composite board, the data in Table 5 showed that the trend for each portion towards matured, intermediate and young maturity groups were similar to portion factor from bottom to top portions. The result of bottom portion according from matured, intermediate and young maturity groups were 473.17, 453.67 and 301.49 N/mm² for phenol formaldehyde bio-composite board, meanwhile the obtained result 459.52, 431.88 and 312.94 N/mm² respectively for urea formaldehyde bio-composite board. It is clearly showing the decrement towards matured, intermediate and young maturity groups for the bottom portion and this was happen to others two portions which were middle and top portions.

The decrement trend of compression strength that has been shown absolutely similar to the trend of MOE and MOR 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 matured maturity group follow by intermediate and young maturity groups for every portion. This reinforced by ANOVA in Table 6 that showed there was a significant difference between compression strength with maturity groups and portions.

According to Oyagade and Fasulu (2005), they reported that generally for each of the species, wood density and mechanical properties decrease with increment in tree height and this can be apply along the oil palm fronds toward bottom, middle and top portions plus from old to young maturity groups. Some strength properties of wood according to Nordahlia (2008) noted that compression failure typically occurs in low density of wood.

The obtained result showed that the average value for each part of phenol formaldehyde bio-composite board possessed higher result in compression strength than urea formaldehyde bio-composite board. Higher compression strength of compressed oil palm fronds bio-composite board with phenol formaldehyde resin as compared to urea formaldehyde bio-composite board can be due to the fact that phenol formaldehyde resin, when properly cured, is often tougher than the wood itself as stated by Baldwin (1995).

The effectiveness of phenol and urea formaldehyde resin in enhancing compression properties showed a similar trend as static bending strength, where the phenol formaldehyde bio-composite board possessed more higher value of compression strength compared to urea formaldehyde bio-composite board, but the differences result was not observed a significant difference based on ANOVA in Table 6 between compression strength with the types of resin. Thus, it showed that the effect types of resin not encourage too much of compression strength of this bio-composite board.

Analysis of Variance (ANOVA) on Physical and Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Board:

Table 6 shows the ANOVA for physical and mechanical properties of the compressed oil palm fronds bio-composite board. The analysis was conducted to determine whether there was exist or not the significance difference between physical properties (density and basic density) and mechanical properties (MOE for static bending strength and MOR for static bending including compression strength) with maturity groups, portions and types of resin of the compressed oil palm fronds bio-composite board.

Based on the ANOVA in Table 6, there were significant differences between physical properties (density and basic density) and mechanical properties (static bending strength (MOE and MOR) and compression strength (MOR)) 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 bio-composite board 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 board.

Meanwhile, there was no significant difference exist between physical properties (density and basic density) and mechanical properties (static bending strength (MOE and MOR) and compression strength (MOR)) with the types of resin factors. According to the ANOVA in Table 6, there was no encouragement of resin types to the physical and mechanical properties of the compressed oil palm fronds bio-composite board, although there was differences in value for the testing result for each part which were the testing result from phenol formaldehyde bio-composite board possessed more higher value than urea formaldehyde bio-composite board and has been discussed before this. It means whether using phenol or urea formaldehyde resin in producing the bio-composite board will give quite similar in values testing result.

Table 6: ANOVA on physical and mechanical properties of compressed oil palm fronds bio-composite board

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

Note: Total number of samples for each testing = 90

** = 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

Correlation Coefficient between Physical and Mechanical Properties of Compressed Oil Palm Fronds Bio-composite Board:

The correlation among physical and mechanical properties of the compressed oil palm fronds bio-composite board is presented in Table 7. There was a correlation between physical properties (density and basic density) of compressed oil palm fronds bio-composite board with maturity groups and portions. Negative correlations were observed between density and maturity groups ($r = -0.3657$) and portions ($r = -0.3748$). Meanwhile, basic density value for this bio-composite lumbers ($r = -0.4435$, $r = -0.6588$) were negatively correlated with maturity groups and portions.

These correlations of compressed oil palm fronds bio-composite board were decreasing in density as well as basic density values from matured to young maturity groups for each portion and towards bottom, middle and top portions for every maturity group. These were supported by negative correlation between them as been shown in Table 7 and have significant differences in ANOVA displayed in Table 6. There was also possessed a correlation coefficient between density with basic density ($r = 0.5611$) in this study. A positive correlation was observed between of them and there was a significant difference at $P\text{-value} \leq 0.01$. Besides that, a positive correlation relationship exist between resin types with density value ($r = 0.0411$), while negative correlation was possessed among resin types and basic density value ($r = -0.0668$). However, these correlation relationship were not significant between them like stated in ANOVA in Table 6, thus mean that types of resin factor was not affected the density as well as basic density value of the compressed oil palm fronds bio-composite board because of its correlation coefficient value too small.

The correlation between the strength properties (MOE for static bending strength and MOR for static bending including compression strength) with others compressed oil palm fronds bio-composite board properties are presented in Table 7. There was a correlation between maturity groups factor with the mechanical properties values. Negative correlation were obtained between maturity groups with MOE of static bending strength ($r = -0.4321$), MOR 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 MOE of static bending strength ($r = -0.7862$), MOR of static bending strength ($r = -0.6939$) and last but not least MOR for compression strength ($r = -0.7481$).

The negative correlation between maturity groups and portions with mechanical properties (MOE and MOR for static bending strength and MOR for compression strength) means that the strength of compressed oil palm fronds bio-composite board decreases towards bottom, middle and top portions for each maturity group as well as from matured to young maturity groups for every portion. The ANOVA presented in Table 6 shows significant difference at $P\text{-value} \leq 0.01$.

Table 7: Correlation analysis between physical and mechanical properties of compressed oil palm fronds bio-composite board

	Maturity	Portion	Resin	D	BD	MOEb	MORb	MORc
Maturity	1	0.0000ns	0.0000ns	-0.3657**	-0.4435**	-0.4321**	-0.4927**	-0.5029**
Portion		1	0.0000ns	-0.3748**	-0.6588**	-0.7862**	-0.6939**	-0.7481**
Resin			1	0.0411ns	-0.0668ns	-0.1196ns	-0.1592ns	-0.0867ns
D				1	0.5611**	0.3750**	0.4045**	0.5339**
BD					1	0.7241**	0.6669**	0.7356**
MOEb						1	0.7673**	0.7870**
MORb							1	0.7889**
MORc								1

Note: Total number of samples for each testing = 90

** = 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

The mechanical properties of wood have a close and significant correlation with density as well as basic density (Desh, 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 (MOE and MOR of static bending strength and MOR of compression strength) of compressed oil palm fronds bio-composite board towards maturity groups (matured to young maturity groups) and portions (bottom to top portions). Positive correlation were obtained between density with MOE of static bending strength ($r = 0.3750$), MOR of static bending strength ($r = 0.4045$) and MOR 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 MOE and MOR of static bending strength and $r = 0.7356$ for MOR of compression strength. All of these correlations possessed significant differences at $P\text{-value} \leq 0.01$ according to the ANOVA in Table 6.

The effect of resin types on the mechanical properties of compressed oil palm fronds bio-composite board, there posses negative correlation among of them, where $r = -0.1196$ and $r = -0.1592$ for MOE and MOR of static bending strength, while $r = -0.0867$ for MOR of compression strength. It was similar trend to correlation relationship between physical properties (density and basic density) of compressed oil palm fronds bio-composite board 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 board strength similar to physical properties. Positive correlation were observed among of these three mechanical properties, where $r = 0.7673$ and $r = 0.7870$ between MOE of static bending strength with MOR of static bending and compression strength, while $r = 0.7889$ between MOR of static bending strength with MOR of compression strength and these correlation coefficient were possessed significant differences at $P\text{-value} \leq 0.01$.

Conclusions:

The compressed bio-composite board made from matured oil palm fronds possesses the highest values in density and basic density. 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. For the maturity groups factor, there was the decrement resulting in basic density value of compressed oil palm fronds bio-composite board through matured, intermediate and young maturity groups for every portion that have been used in producing this bio-composite board.

For mechanical properties, there was a decrement of MOE in static bending strength of compressed oil palm fronds bio-composite board from the bottom, middle and top portions for each maturity group. The same trends also happened to the compressed oil palm fronds board made from the matured, intermediate and young maturity groups for every portion. This decrement trend happened too in determination MOR in static bending and compression strength towards maturity groups and portions. The MOR values decreased for the compressed oil palm fronds bio-composite board from the bottom, middle and top portions for each maturity group including towards the matured, intermediate and young maturity groups for every portions.

There was a correlation between the fronds maturity group and the portion of the compressed oil palm fronds bio-composite board tested in terms of the physical and mechanical properties of the bio-composite board. Significant differences exist between physical and mechanical properties across varying levels of maturity and different portions of the bio-composite board except for the resin. It means that the resins were not influence to the properties of the bio-composite board with regards to their physical and mechanical properties.

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