International Journal of Sciences
(ISSN 2305-3925)
http://www.ijSciences.com

Research Article
Volume 2, Issue Mar 2013

COMPRESSED OIL PALM FRONDS COMPOSITE: A PRELIMINARY STUDY ON MECHANICAL PROPERTIES

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Abstract: The mechanical properties of composites consisting of compressed oil palm fronds have been investigated. Three maturity groups at different portion were bind together using two types of formaldehyde resin which were phenol and urea. Modulus of rupture (MOR) for bending strength of the compressed oil palm fronds composite increase from young to intermediate and mature maturity group for each portion, meanwhile decrease from bottom to middle and top portion for each maturity group. Same results trend have been recorded for modulus of elasticity (MOE) for bending strength and modulus of rupture (MOR) for compression strength. Statistical analysis indicated significant differences between compressed oil palm fronds composite made from each maturity group and portion, but no differences were observed in the type of resin used.

Keywords: Compressed oil palm fronds composite, phenol and urea formaldehyde, mechanical properties.

Introduction

Shortage of wood as a raw material has forced wood-based industries to find alternative local raw materials. Many plants that produce wood-based products, especially plywood and lumber, have already closed down (Uysal, 2005). 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. Therefore, wood-based industries must find alternative sources of local raw materials, and oil palm biomass currently appears to be the most viable alternative. Currently, oil palm biomass is undergoing research and development (R&D) and appears to be the most viable alternative. Oil palm is produced in 42 countries worldwide on about 27 million acres. Production has nearly doubled in the last decade, and oil palm has been the world's foremost fruit crop, in terms of production, for almost 20 years.

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 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). The current status of oil palm biomass in Malaysia during the year 2006 as stated by Anis *et al.* (2007) showed that the total area of oil palm trees planted was 4.17 million hectares. Oil palms by products are available in large quantity sufficient for industrial raw materials in agro-based industries. This residue can be considered as an alternative material for wood-based industries reported by Mohamad *et al.* (2003). 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 composite. 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 over 4 million hectares 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

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product and thus, this study seems to be relevant and important.

This work examines the conversion of compressed oil palm fronds to an alternative future wood composite and had been investigated for their physical and mechanical properties. Currently, there is no information on the physical and mechanical properties of the compressed oil palm fronds composite. A better understanding will help to develop productive uses for oil palm fronds, mitigating environmental problems from waste biomass while also developing an alternative material to wood.

Materials and Methods

Preparation of Compressed Oil Palm Fronds

The oil palm fronds were obtained from a plantation in Kota Belud, Sabah. The selected oil palm fronds were divided into three groups according to their maturity. 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 before undergoing air-drying.

Air-Drying

All the compressed oil palm fronds then undergo air-drying process for 12 hours until almost the moisture was removed from the fiber. This air-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 formaldehyde resin were used in this study to produce the composite which were phenol and urea formaldehyde. Both types of resin were obtained from Sepanggar Chemical Sdn. Bhd.

Preparation of Compressed Oil Palm Fronds Composite

The compressed oil palm fronds composite was made on laboratory scale by standard techniques and controlled conditions. After undergoing dried in air-drying, 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±5ºC for phenol formaldehyde resin, meanwhile 100±5ºC for urea formaldehyde resin and pressed into desire shape for testing products making to form the composite.

The compressed oil palm composite was manufactured 20 mm in thickness. The composite 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 composite were trimmed and cut into various size test specimens and then conditioned at 20±3ºC and 65±3% relative humidity (RH) for 72 hours prior for testing to produce an equilibrium moisture content of about 12±1%.

Physical Testing

The physical testing was conducted in this study was basic density.

Basic Density

The basic density of the composite was determined by measuring the oven-dry weight and green volume of each sample. Each sample was weighed to an accuracy of 0.01 g by using an analytical balance. The oven-dry weight of each composite was obtained by calculating the arithmetic mean of the oven-dry weight of all test samples taken from the same board. The dimensions of each test sample were measured using a sliding calliper, in accordance with ISO 3131-1975. The volume of the samples was obtained by multiplying the length, width and thickness of the samples. Determination of basic density was done in accordance with ISO 3131-1975, using the following formula:

$$\text{Basic Density } (g/cm^3) = m / v \qquad (1)$$

Where m is the oven-dry weight and v is the green volume of the composite sample.

Mechanical Testing

Two types of mechanical testing were conducted in this study; static bending and compression strength.

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 modulus of elasticity (MOE) and ISO 3133-1975 for modulus of rupture (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.

Compression Strength

The compression strength test was performed according to ISO 3787-1976 for modulus of rupture (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.

Results and Discussions

Physical Properties

Basic Density

Table 1 shows the mean values of basic density for the compressed oil palm fronds composite 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.

Table 1: Mean value for basic density of compressed oil palm fronds composite

		Basic density (g/cm^3) of portions		
Oil palm fronds maturity group	Resin used	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 1, the decreased summarized the compressed oil palm fronds composite 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 was agreement with the basic density values that had been recorded in this study where the composite 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 5 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 composite. It means that, the types of resin were not influenced to the basic density value of the composite. However, the basic density of compressed oil palm fronds composite more higher compared to the oil palm fronds basic density by the effect of resin that have been used in producing this composite as shown in Figure 1. The increasing of the compressed oil palm fronds composite basic density probably related to resin penetration into the composite. Previous study by Paridah and Anis (2008) report that parenchyma behaves like a sponge and can easily absorb moisture. Therefore, the composite 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 composite. It is assumed that the resin penetrations possessed higher basic density and enhance the strength of the composite.

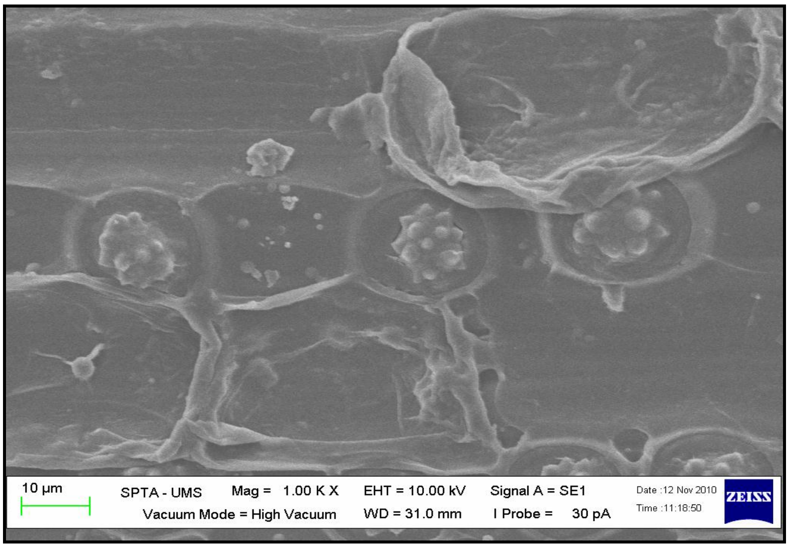

Figure 1: Scanning Electron Micrograph (SEM) of Resin Penetration on Compressed Oil Palm Fronds Composite (1000x magnification)

Mechanical Properties

Static Bending Strength

In order to investigate the static bending of the compressed oil palm fronds composite, 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 2 and 3. 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 composite 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 2 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 composite were 999.61, 952.29 and 844.18 N/mm^2. Meanwhile, the average values MOE for urea formaldehyde composite were 980.31, 949.40 and 840.40 N/mm^2 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 composite and the same situation were done for others two maturity groups which were the intermediate and young maturity groups.

Table 2: Modulus of elasticity (MOE) static bending strength of compressed oil palm fronds composite

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 composite were 999.61, 979.15 and 935.36 N/mm^2 respectively. Further, the mean value of MOE strength for the bottom portion of urea formaldehyde composite were 980.31, 953.93 and 936.24 N/mm^2 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 composite 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 composite at the different maturity groups, portions and resin types, the summarized data of mean values is presented in Table 3.

Table 3: Modulus of rupture (MOR) static bending strength of compressed oil palm fronds composite

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 3, the MOR of the compressed oil palm fronds composite was gradually decreasing from the bottom to top portions for each maturity group and from matured to young maturity groups for every portion including for both two types of the resin that have been used in producing the composite 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/mm^2 respectively for the compressed oil palm fronds composite used phenol formaldehyde resin, while the MOR values for urea formaldehyde composite 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.

Further, in order to investigate the effect of maturity groups of oil palm fronds in producing the composite to MOR in static bending strength, the data was carried out to examine the distribution of MOR values like shown in Table 3 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 composite, the values was 16.66, 14.38 and 12.16 N/mm^2, meanwhile the MOR value for urea formaldehyde composite was 15.40, 12.62 and 12.25 N/mm^2 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 composite. 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 composite 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 composite 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 basic density values in higher results. According to Haygreen and Bowyer (1930), the higher result in 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 mechanical properties of wood have a close and significant correlation with basic density (Desh, 1968). The static bending strength (MOE and MOR) of the compressed oil palm fronds 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 5, there was a significant difference between MOE and MOR of static bending with maturity groups and portions.

The obtained result showed that the composite 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 composite 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 composite (Abdullah, 2010). This action would make the fiber and matrix impossible to withstand greater loads. However, according to ANOVA in Table 5, 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 composite.

Compression Strength

Table 4 showed the compression strength value of matured maturity group from bottom to top portions were 473.17, 395.93 and 260.22 N/mm^2 for phenol formaldehyde composite, while for the urea formaldehyde composite, 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 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 4: Modulus of rupture (MOR) compression strength of compressed oil palm fronds composite

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 composite, the data in Table 4 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/mm^2 for phenol formaldehyde composite, meanwhile the obtained result 459.52, 431.88 and 312.94 N/mm^2 respectively for urea formaldehyde composite. 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.

Decrement trend of the 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 basic density value encourage the distribution result of the 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 5 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 mechanical 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 composite possessed higher result in compression strength than urea formaldehyde composite. Higher compression strength of compressed oil palm fronds composite with phenol formaldehyde resin as compared to urea formaldehyde composite 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 phenol and urea formaldehyde resin in enhancing compression properties showed a similar trend as static bending strength, where the phenol formaldehyde composite possessed more higher value of compression strength compared to urea formaldehyde composite, but the differences result was not observed a significant difference based on ANOVA in Table 5 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 composite.

Analysis of Variance (ANOVA) on Physical and Mechanical Properties

Table 5 shows the ANOVA for physical and mechanical properties of the compressed oil palm fronds composite. The analysis was conducted to determine whether there was exist or not the significance difference between physical properties (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 composite.

Based on the ANOVA in Table 5, there were significant differences between physical properties (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 composite 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 composite.

Table 5: ANOVA on physical and mechanical properties of compressed oil palm fronds composite

Source of Variance	Dependent Variable	Sum of Square	Df	Mean Square	F-Ratio
Maturity	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	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	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≤ 0.01
ns = not significant
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

Meanwhile, there was no significant difference exist between physical properties (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 5, there was no encouragement of resin types to the physical and mechanical properties of the compressed oil palm fronds composite, although there was differences in value for the testing result for each part which were the testing result from phenol formaldehyde composite possessed more higher value than urea formaldehyde composite and has been discussed before this. It means whether using phenol or urea formaldehyde resin in producing the composite will give quite similar in values testing result.

Correlation Coefficient between Physical and Mechanical Properties

The correlation among physical and mechanical properties of the compressed oil palm fronds composite board is presented in Table 6. There was a correlation between physical properties (basic density) of compressed oil palm fronds composite with maturity groups and portions. Negative correlations were observed between basic density and maturity groups (r = -0.4435) and portions (r = -0.6588).

These correlations of compressed oil palm fronds composite were decreasing in 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 6 and have significant differences in ANOVA displayed in Table 5. Besides that, a negative correlation relationship exist between resin types with basic density value (r = -0.0668, however these correlation relationship were not significant between them like stated in ANOVA in Table 5, thus mean that types of resin factor was not affected the basic density value of the compressed oil palm fronds composite because of its correlation coefficient value too small.

The correlation between the mechanical properties (MOE for static bending strength and MOR for static bending including compression strength) with others compressed oil palm fronds composite properties are presented in Table 6. 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).

Table 6: Correlation analysis between physical and mechanical properties of compressed oil palm fronds composite

	Maturity	Portion	Resin	BD	MOEb	MORb	MORc
Maturity	1	0.0000ns	0.0000ns	-0.4435**	-0.4321**	-0.4927**	-0.5029**
Portion		1	0.0000ns	-0.6588**	-0.7862**	-0.6939**	-0.7481**
Resin			1	-0.0668ns	-0.1196ns	-0.1592ns	-0.0867ns
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≤ 0.01
ns = not significant
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 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 composite 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 5 shows significant difference at P-value ≤ 0.01.

The mechanical properties of wood have a close and significant correlation with density as well as basic density (Desh, 1968). Increment of 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 6. The positive correlation coefficient occurred between basic density value with mechanical properties (MOE and MOR of static bending strength and MOR of compression strength) of compressed oil palm fronds composite towards maturity groups (matured to young maturity groups) and portions (bottom to top portions). Positive correlation were obtained between basic density with MOE of static bending strength (r = 0.7241), MOR of static bending strength (r = 0.6669) and MOR of compression strength (r = 0.7356), while correlation. All of these correlations possessed significant differences at P-value ≤ 0.01 according to the ANOVA in Table 5.

The effect of resin types on the mechanical properties of compressed oil palm fronds composite, 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 (basic density) of compressed oil palm fronds composite with types of resin. Although, they possessed a correlation relationship, but there were not significant between of them according to ANOVA in Table 5. It means that the types of resin not affected too much to mechanical properties of this composite 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-value ≤ 0.01.

Conclusions

As conclusion for mechanical properties of the compressed oil palm fronds composite, there was a decrement of MOE in static bending strength of the composite from the bottom, middle and top portions for each maturity group. The same trends also happened to the compressed oil palm fronds composite made from the mature, 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.

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

The compressed oil palm fronds composite can be used to produce quality composite as it possess a good result in mechanical properties, plus as an alternative way for the shortage of wood as raw material in wood-based industries.

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