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New Approach to Oil Palm Trunk Core Lumber Material Properties Enhancement via Resin Impregnation

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In this study, oil palm trunk core-lumber (OPTCL) producing from oil palm based plywood industries waste materials was studied using microwave drying technique for material optimization. Microwave dried oil palm trunk core part was impregnated with phenol formaldehyde resin as a matrix by using high-pressure vacuum impregnation chamber. Microwave drying optimized the drying conditions, avoided burning, shrinkage and increased the permeability of oil palm trunk (OPT). OPTCL impregnated in different times and compared with kiln dried OPTCL and rubber wood (RW). Impregnation of microwave dried core part of oil palm trunk was carried out first time. The microwave dried impregnated OPTCL exhibited higher mechanical properties as compared to microwave dried. Results indicated that OPTCL impregnated for 60 min shows lower mechanical properties as compared to RW. The morphology of resin loaded oil palm trunk core cell wall or lumen ultra structure was analyzed by scanning electron microscope (SEM) and it clearly showed full penetration of resin into OPTCL cell. The mechanical properties of impregnated samples were analyzed according to BS and ASTM standards.

Keywords: Reutilization, Oil Palm Trunk, Mechanical Properties, Scanning Electron Microscope.

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1. INTRODUCTION

The potential for transforming biomass oil palm trunk waste to an alternative wood lumber material and insufficiency of wood lumber in the near future make the research indispensable to find out alternative lumber material sources including waste materials. It has been studied so far that the oil palm trunk could be engineered into a palm "wood" or solid oil palm trunk. Nevertheless conventional drying methods used in previous studies caused drying defects with low recovery, and the processing cost was too expensive.[1] The oil palm solid waste, particularly the oil palm trunk (OPT), has received little attention from researchers due to lack of scientific information. Although several investigations have already conducted related to OPT utilization but still it required to gather sufficient knowledge in order to design and establish the new wood products from OPT. OPT wood consist of primary tissue and it is not comparable to dicotyledons and gymnosperms in terms of wood developmental because oil palm do not possess cambium.[2] Due to lack of supply of raw materials from traditional sources such as rubber wood and tropical hardwoods give an opportunity to utilize OPT as an alternative lignocellulosic raw material for wood based industry. Oil palm tree is monocotyledon and consists of parenchyma and vascular bundles, which are main obstacle in utilization of OPT as wood materials. In monocotyledon wood, fibers have less strength and irregular in characteristics as compared to the dicotyledonous wood.[3] In fact OPT is not wood as compared to rubber wood and hardwoods which wood-based industries are used to.

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This study utilized the optimized microwave dried OPTCL which was completely dried without burning, shrinkage and swelling. Resin impregnation to wood has applied for dimensional stability enhancement and prevention of biodeterioration as wood-preservation technique.[4] Due to the low mechanical and physical properties of oil palm trunk agro waste, it could be modified with low molecular weight phenol formaldehyde[5] to gain better mechanical properties.[6] Previously few researchers worked to improve the properties of oil palm trunk such as dimensional stability, durability and strength.[7–9] The heartwood of most species resists penetration of preservatives, but for well-dried species it is reasonably easy for resin to penetrate.[10] Proper microwave drying and precise impregnation technique modified the core part in this study whereas new oil palm trunk exhibit superior permeability through modification with microwave technique as compared to kiln dry treatment. For impregnation process phenol formaldehyde resin was suitable to used due to its low viscosity, low volatility, lack of odour, low toxicity, less heat generation at polymerization, and low price.[9,11] The impregnated OPTCL acted as a reinforcement of the polymer matrix that enhanced the mechanical, dimensional stability, wear-proof, chemical proof, surface, and decay properties as compared with ordinary wooden lumber.

The significance of this study to utilize core part of oil palm trunk, which consists of less vascular bundles and more parenchyma. Microwave drying shows more complete drying without defects as compared to other drying methods. In the preliminary study on microwave drying, the moisture content of OPT core part reduces from 294% to 12–15%, which is within the optimum moisture content.[12] The modification of OPT with phenolic resin also has been done to improve the dimensional stability and biological exposure. Moreover, using low molecular weight of phenol formaldehyde[5] has been studied to gain better wood characteristics. In this study different impregnation times applied for OPTCL were 15, 30, 60, 90 and 120 min. The mechanical test results of microwave dried oil palm trunk core lumbers were compared with the kiln dried OPTCL. Mechanical properties of impregnated oil palm trunk core lumber were tested for tensile strength and modulus of elasticity (MOE), flexural strength and modulus of rupture (MOR), compressive strength, and impact strength. All the samples were tested as per British standard, BS EN 373:1957 methods of testing small clear specimens of timber except for impact strength, we tested it according to ASTM D256.

2. MATERIALS AND METHOD

2.1. Material Preparation

2.1.1. Oil Palm Trunk Core Lumber (OPTCL)

About 30 logs of 25 years old oil palm trunk (OPT) were obtained from Juru Plantation Sdn Bhd, Malaysia. During the peeling process, the 10 cm diameter core was produced as waste and this central part of the OPT was used in this study. The present study focuses on the core part of OPT which contains less vascular bundles and more parenchyma. Due to the density variation along the oil palm tree, middle part of oil palm trunk was used due to the more uniformity in structure and density at this part. Middle part of oil palm trunk has not been studied by any other researchers as per literature review and it has been considered as waste materials.

The samples were directly cut to desired weight with a tolerance of ± 2 grams (due to the even shape of the sample requirement, dimensions of $5 \times 5 \times 50$ cm for a 1000 g of sample) with a band saw (Model Hitachi A50). The samples were used in a microwave for drying purpose.[12]

2.1.2. Resin for Impregnation

The phenol formaldehyde resin used as impregnation material was obtained from Hexion Specialty Chemicals Sdn. Bhd. The properties of the PF resin used are tabulated in Table I. The resin was kept in the refrigerator to avoid any changes prior to use.

2.2. Impregnation Technique

Impregnation of the oil palm trunk core was done by using high-pressure vacuum impregnation chamber (Fig. 1). The excess air and water in intercellular cavities of the samples inside the chamber was removed under vacuum. The impregnation process was performed under 5 bar pressure. After the desired time, resin was evacuated from the vacuum chamber and vacuum process was imposed under 3 bar pressure for five minutes. It was done to optimize use of resin and remove excess resin from the oil palm trunk. Finally, the PF resin-impregnated oil palm trunk core lumbers were cured at 150 °C for 2 h. The impregnation of OPTCL carried out at different time interval (15, 30, 60, 90, 120 min).

3. CHARACTERIZATION OF IMPREGNATED OPT

3.1. Mechanical Properties

Mechanical properties of impregnated oil palm trunk core lumber were tested for tensile strength and modulus of

Table I. Properties of resin phenol formaldehyde.

Characteristic	Phenol formaldehyde
Viscosity (cp)	50–100
pH	13–15
Solid content	44–45
Specific gravity	1.20–1.21
Molecular weight	4000

Fig. 1. Impregnation chamber utilized for impregnation of resin in OPTCL.

elasticity (MOE), flexural strength and modulus of rupture (MOR), compression strength and impact strength. All the samples were tested based on BS EN 373:1957 methods of testing for small clear specimens of timber except impact strength tested according to ASTM D256. The characteristics of impregnated oil palm trunk core at different time interval were compared to each other and also compared it with kiln dried OPTCL. Finally the optimum impregnated OPTCL was compared with green and kiln dried OPTCL as well as with rubber wood.

3.1.1. Tensile Properties

Tensile properties (strength and modulus) based on BS EN 373:1957 were performed by using Gotech Universal Tester-GT-A1-7000L. The tensile test was conducted on rectangular strips with dimensions of 300 mm × 20 mm × 6 mm. The samples were tested at a cross-head speed of 1.27 mm/min and a gauge length of 160 mm. All the specimens were conditioned at ambient temperature (25 ± 3 °C) and at relative humidity of 30% (± 2%) before testing.

3.1.2. Flexural Properties

The flexural test (strength and modulus of rupture) was performed according to BS EN 373:1957 by using Gotech Universal Tester-GT-A1-7000L. Rectangular sample strips with dimensions of 300 mm × 20 mm × 20 mm were prepared for testing. Sample is tested with movable crosshead speed of 10 mm/min. Span of supporting beam is 280 mm and load is applied at centre of the testing sample. All the specimens were conditioned at ambient temperature (25 ± 3 °C) and at relative humidity of 30% (±2%) before testing.

3.1.3. Compression Strength

Compression test was carried out based on BS EN 373:1957 with sample dimensions of 60 mm × 20 mm × 20 mm. This test was conducted using Instron machine 4204 with moveable head speed of 0.635 mm/min.

3.1.4. Impact Properties

The Charpy impact test was performed using a Model CS-1370 Impact Pendulum Tester (Zwick). Impact test is conducted by using Gotech impact tester model GT-7045-MDL according to ASTM D256. Sample of impact test was 60 mm × 20 mm × 12 mm. Before impact testing, V-notch was made on the samples by using Gotech V-notch machine. Depth of V-notch was 2 mm and angle of V-notch is 90°. Energy of impact pendulum was 2.715 J and speed 3.46 m/s. All the specimens were conditioned at ambient temperature (25 ± 3 °C) and at relative humidity of 30% (±2%) before testing.

3.2. Scanning Electron Microscope (SEM)

Morphological studies of the samples were carried out by using scanning electron microscope (Leo Supra, 50 VP, Carl Ziess, SMT, Germany). A thin section of the sample was mounted on an aluminum stub using a conductive silver paint and was sputter-coated with gold prior to morphological examination. The SEM micrographs were obtained under conventional secondary electron imaging conditions with an acceleration voltage of 5 kV.

3.3. Microwave Dried OPT

The samples were cut to achieve a weight of 1000 g and placed into the microwave (model WKS-4, Taiwan). The microwave power was set at level 5 corresponding to a power of 3300 w. The initial moisture of the samples was measured to be 294% w/w. The drying condition of the samples were optimized at 6.89 min of time with a microwave power set at level 4 which reduced the moisture content to 14%. The microwave dried OPTCL showed acceptable appearance, strength and permeability with improved mechanical and physical properties compared to fresh OPTCL and oven dried ones.[12]

3.4. Impregnation of Oil Palm Trunk Core Lumber

Microwave and kiln dried OPTCL were impregnated with phenol formaldehyde to conduct a comparison study on the effect of microwave drying on the mechanical and physical properties of the sample. In this section each property has been studied individually. Table II demonstrates the amount of resin loaded in varying times. It can be clearly noticed that the amount of the resin impregnated to the OPT increases with impregnating time. The more

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Table II. Resin loading variation with time.

Time, min	Resin loading (%)
0	0
15	57
30	75
60	102
90	123
120	126

impregnating time, more the cell cavities of OPT will be filled and it show that 90 min of impregnating time do loading of around 123% wt. It attributed to the saturation of OPT as all the cavities have been fully occupied by the resin and indicated maximum capacity of OPT for impregnation. The calculation was based on the sample weight before and after impregnation.

4. RESULTS AND DISCUSSION

4.1. Mechanical Properties

The mechanical properties i.e., tensile strength, tensile modulus, flexural strength, flexural modulus, and impact strength of microwave and kiln dried samples of OPTCL were studied in this section.

4.1.1. Tensile Properties

4.1.1.1. Tensile Strength. Figure 2 shows the tensile strength of impregnated OPTCL dried by microwave and kiln method at different time interval. It can be obviously clear from the figure that both methods of drying followed the same trend with significantly lower tensile strength in kiln drying. Microwave drying is low temperature drying method that could result in less damage in structure and dimension of wood.[13] Figure 3(a) and Figure 3(b) shows the cross view of the impregnated OPTCL dried with microwave and kiln method, respectively. It can be noted that the microwave dried OPTCL shows significantly more uniform shape as compared to kiln dried OPTCL. Uniform shape of microwave dried samples helps to spread glue properly throughout the lumber and improve mechanical properties as compared to kiln dried samples. Initially stage tensile strength rises drastically within the 15 min of impregnation for both drying methods. After the 60 min of impregnation, the tensile strength reduces significantly and reaches the peak at 27.64 MPa and 23.63 MPa for microwave and kiln dried, respectively. Enhancement of tensile strength may be due to the formation of chemical bonding between OPT structure and the matrix. Previous study reported that chemical reactions can occur between fiber and matrix as a result of high bonding strength.[14,15]

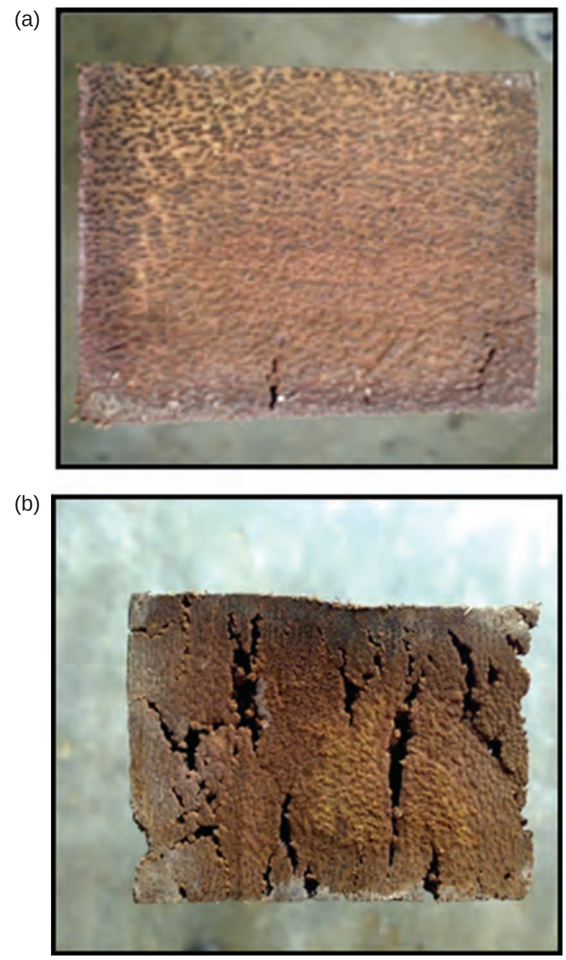

Fig. 3. Cross cut view of impregnated OPTCL dried with (a) microwave and (b) kiln.

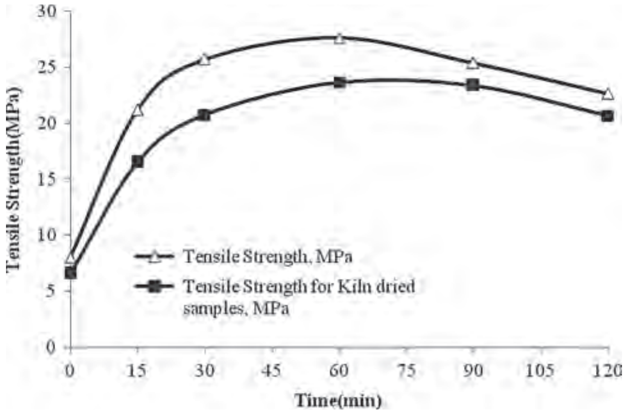

Fig. 2. Tensile strength of OPT in varying times of impregnation.

60 min of impregnation of OPTCL shows optimum tensile strength due to better adhesion between the fiber and matrix as compared to other impregnation times. From the results, it is obvious that the optimum resin loading (102% wt) can be penetrated properly into the OPTCL and form a better bonding between the fiber and parenchymatous tissue. Beyond this point the ratio of the resin to OPTCL increases which could be the reason of the drop in the tensile strength as the properties shift to the

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resin side. After the impregnation time exceeds 60 min, the tensile strength slightly decreased due to incomplete cure of resin and poor fibre/resin bonding in OPTCL. This drop was observed afterwards until impregnation time of 120 min. Tensile strength may be associated with strengths and weaknesses of OPTCL such as the nature of the resin and interaction between the fiber-matrix. In addition, the effective fiber-to-matrix stresses transfer to improve the performance of mechanical properties.

4.1.1.2. Tensile Modulus. Figure 4 demonstrates the tensile modulus of impregnated OPTCL at various time intervals. The tensile modulus of OPTCL shows similar trend like tensile strength, showing higher results for the microwave dried OPTCL. It clears from Figure 4 that initially the tensile modulus of microwave and kiln dried OPTCL reach peak at 2.97 GPa and 2.66 GPa, respectively within the 60 min of impregnation. A moderate drop is observed afterwards until impregnation time of 120 min. As the result shows, impregnation of resin into microwave and kiln dried OPTCL revealed a significant increment in tensile modulus. The OPTCL of 102% wt resin loading (60 min impregnation) exhibited the optimum resin penetration into OPTCL and leads to improvement in stiffness. These results revealed that higher resin loading reduced the OPTCL ability to resist breaking under tensile stress due to inability of the resin to transfer the stress and increase the brittleness of the OPTCL. Since, the oil palm fibers exhibit micro pores on their surface, the resin penetrates into the pores and forms a mechanically interlocked coating on its surface. This attributes to its superior tensile properties by withstanding the fiber failure even after the major internal failure.[14, 15] The better results from microwave drying can be attributed to the uniformity of the dried lumber leading to a uniform impregnated resin in the lumber (Fig. 3). Results shows improvement in tensile properties due to microwave drying at low temperature leads to less damage to the lumber as compared to conventional kiln drying method.

4.1.2. Flexural Properties

4.1.2.1. Flexural Strength. Flexural strength of impregnated OPTCL dried with microwave and kiln at different time interval shown in Figure 5. Microwave and kiln drying method show similar trend but microwave dried OPTCL shows a better resistance towards flexural forces. This is also attributed to the uniform thickness of microwave dried sample which make it more tolerant against flexural forces. As can be noted from the Figure that initial stage flexural strength of OPTCL rises and it achieve optimum value at 60 min of impregnation, After the 60 min of impregnation the rising rate of the flexural strength reduces significantly. Optimum flexural strength value of microwave and kiln dried samples was 39.76 MPa and 33.78 MPa, respectively. A moderate drop is observed afterwards until impregnation time of 120 min, it may be attributed to the hydrogen bonding between OPT fiber and PF resin.

High polarity of PF resin caused the formation of strong hydrogen bonds with hydroxyl groups.[16] As a result, strong dipole–dipole and van der waals forces are developed between the fibers and the resin leading to higher flexural strength in OPTCL. The excess resin beyond 60 min impregnation leads to decrease in flexural strength of OPTCL and hence makes the OPTCL more brittle. OPTCL (0 min) exhibited the lowest flexural strength. This can be explained by the high amount of resin content in the OPTCL makes the samples more brittle because of properties of thermoset resin. The OPTCL with high resin content is unable to withstand greater loads and decreases the flexural strength. The excess resin during the impregnation process may change the structure of OPT when resin was forced to fill up the porous components.[9, 17]

4.1.2.2. Flexural Modulus. As plotted in Figure 6, flexural modulus shows the same trend as the flexural strength for both the microwave and kiln dried samples. An upward trend was noticed within the first 60 min of impregnation followed by slight decrease in flexural modulus with further impregnation time interval. After being impregnated more than 60 min, samples with high resin contents are

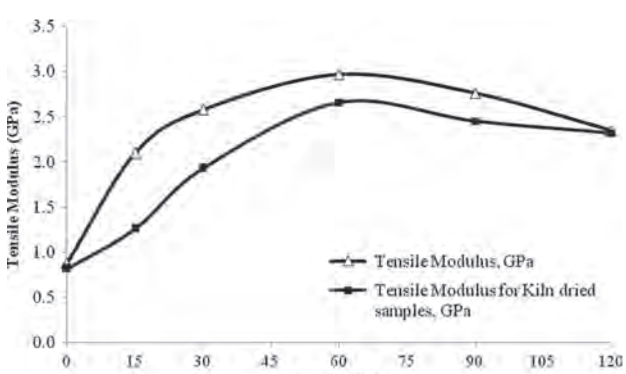

Fig. 4. Tensile modulus of OPT in varying times of impregnation.

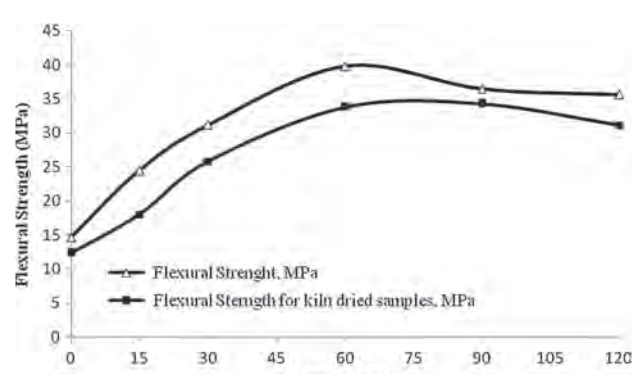

Fig. 5. Flexural strength of OPT in varying times of impregnation.

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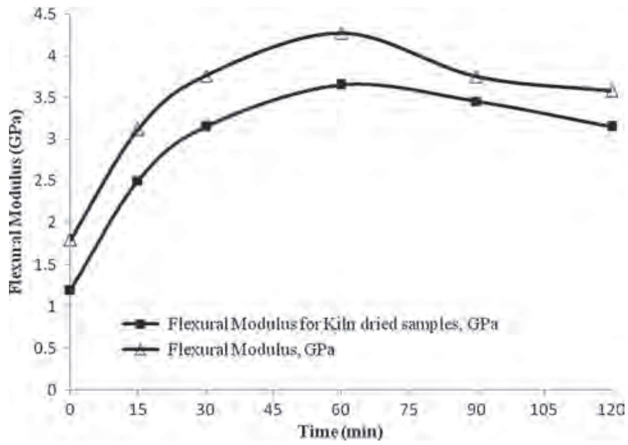

Fig. 6. Flexural modulus of OPT in varying times of impregnation.

unable to withstand greater flexural loads. The optimum flexural modulus was found to be 4.27 GPa and 3.65 GPa for microwave and kiln dried OPTCL, respectively. Thus, the higher the resin content in OPTCL sample, the less the sample was able to withstand greater loads; this may be because of the increase in brittleness of the thermoset resin with increasing content.[11] However, the untreated kiln-dried OPTCL exhibited the lowest flexural modulus.

4.1.3. Compression Strength

Compressive strength is defined as the maximum stress sustained by compression of a specimen with the specimen having a ratio of length to smallest dimension.[18] In this property, only compression strength could be obtained showing a tolerance under a force of 13.87 MPa for microwave drying followed by 12.88 MPa for kiln dried OPTCL. Figure 7 illustrates the compression strength of OPTCL samples at different impregnation time, the first 60 min impregnation shows increasing trend in compression strength. Afterwards, it started to decreasing in compression strength until 120 min imgrenation time. Previous researchers were also reported similar compressive load-deformation curve for the bending.[19]

4.1.4. Impact Strength

Figure 8 demonstrates the impact strength of microwave and kiln dried OPTCL impregnated at various time interval and it is showing almost the same trend for both microwave and kiln dried OPTCL. Enhancement in impact strength noticed until 60 min of impregnation of OPTCL due to PF resin was sufficient to locate in the OPTCL structures. It is observed that, impact strength was the highest in 60 minutes of impregnation time (15.8 kj/m^2 for microwave dried OPTCL and 14.75 kj/m^2 for kiln dried OPTCL). The enhancement of interfacial friction stress and chemical bond between fiber and matrix may cause the strength to improve. The decrease in the impact strength of OPTCL after 60 min impregnation was more related to the matrix fracture. The matrix fracture occurred when the fiber and the resin were not bonded during the curing process.[15] From the Figure 8, it can be observed that the impact strength of microwave dried OPTCL were higher than kiln dried OPTCL. This may be PF resin associated with proper interfacial adhesion between the fiber and matrix.[20] The increase of impact strength is attributed by the physical and chemical bonding between adhered filler and matrix which cause effective stress transfer in OPTCL after being impregnated.[21]

Over all, it was noticed that the mechanical performance of the OPTCL enhanced by impregnation in all aspects and increased up to the ratio of 1:1 corresponding 102% wt. in 60 min of time. Slight reduction of mechanical properties after 60 min impregnations may be attributed to the more effectiveness of PF resin due to thermoset properties. The microwave dried OPTCL showed better resistance in all the mechanical properties. As a result at the optimum point of the impregnation, microwave dried OPTCL showed an enhancement of 6.65% (impact strength) and 15.04% (flexural strength). Even before impregnation the pure OPTCL dried with microwave demonstrated a better tolerance among the forces as compared to kiln dried samples. This was due to the uniformly drying and less damage caused by the microwave drying method.

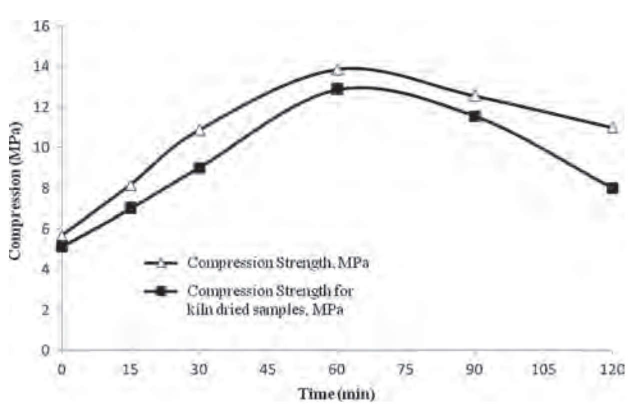

Fig. 7. Compression strength of OPT in varying times of impregnation.

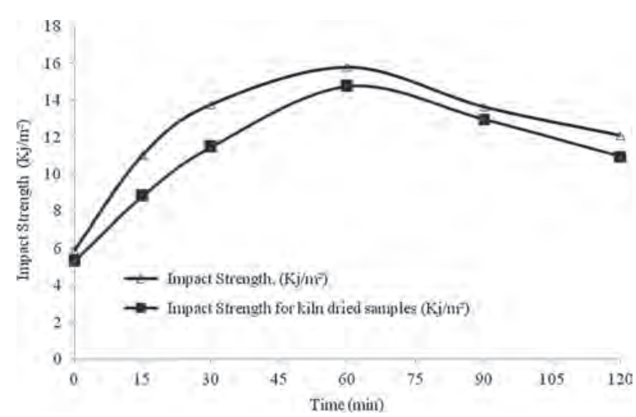

Fig. 8. Impact strength of PF impregnated OPT.

4.2. Mechanical Properties of Un-Impregnated OPTCL Versus Rubber Wood

The comparison of mechanical properties among green OPT, microwave dried, impregnated OPTCL, and kiln dried Rubber wood were studied in this section. Figure 9 illustrates the tensile strength of green OPT, microwave dried OPTCL, 60 min impregnated OPTCL and kiln dried Rubber wood. In case of tensile strength, fiber plays an important role to determine the tensile properties of the wood. The OPTCL contains high amount of parenchyma tissues and less fiber compared with Rubber wood. Therefore, dried OPTCL could not transfer stress effectively between the fibers. However, in case of OPTCL with 60 min impregnation time (102% resin loading) the effective fiber-to-matrix stress transfer leads to improvement and the performance of mechanical properties are enhanced. OPTCL with 60 min impregnation was the most effective resin capacity in improving stiffness among OPTCLs and dried OPT.

The kiln dried Rubber wood still exhibited the highest tensile strength followed by microwave dried OPTCL with 102% of resin loading, and kiln dried OPTCL. It shows that microwave drying, and impregnation can significantly improve the OPTCL tensile properties as compared to Rubber wood but still it requires more improvement. It should be noted that impregnation of OPTCL with proper resins in conjunction with microwave drying method makes the OPTCL a potential waste material to replace the Rubber wood. Microwave drying method of OPTCL could significantly increase the properties as compared to green OPTCL.

Figure 10 represents the comparison of flexural strength of green OPT, microwave dried OPT, impregnated OPT, and Rubber wood also demonstrates the same trend as tensile strength. While, there was a significant enhancement of flexural strength of impregnated OPTCL dried with microwave as compared to green OPT lumber due to more uniform drying by use of microwave. Uniform drying of OPTCL by microwave drying method leads to a better resistance on tensile forces. Rubber wood shows higher flexural strength as compared to green and impregnated OPTCL due to chemical composition of the Rubber wood. Rubber wood has more cellulose than OPT and cellulose fiber has high extensibility.[15] The lowest flexural properties of green OPT is due to its high content of parenchyma tissues.[22] Even though, the flexural properties

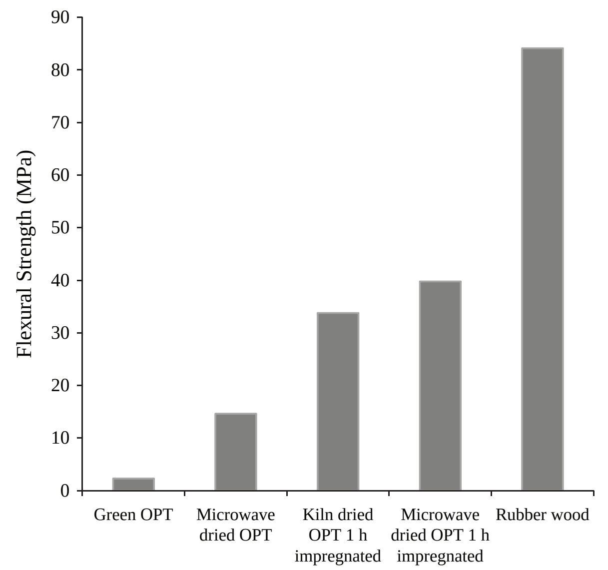

Fig. 10. Comparison of flexural strength of OPT for Rubber wood and impregnated OPT with 2 different drying methods and green OPT (The standard deviation was less than 0.06 and it was negligible in the graphs).

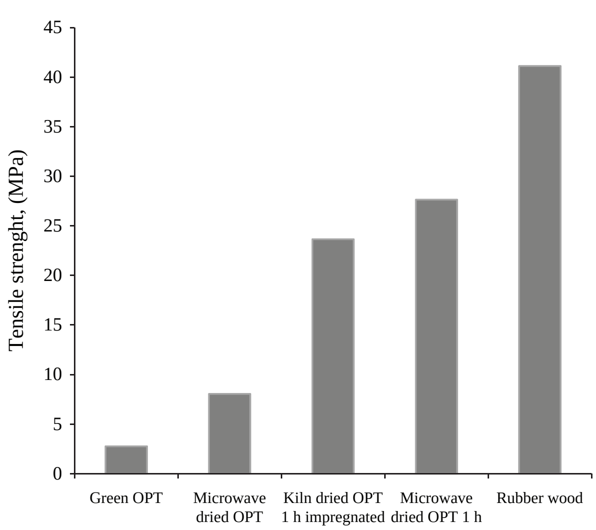

Fig. 9. Comparison of tensile strength of OPT for Rubber wood and impregnated OPT with 2 different drying methods and green OPT (The standard deviation was less than 0.06 and it was negligible in the graphs).

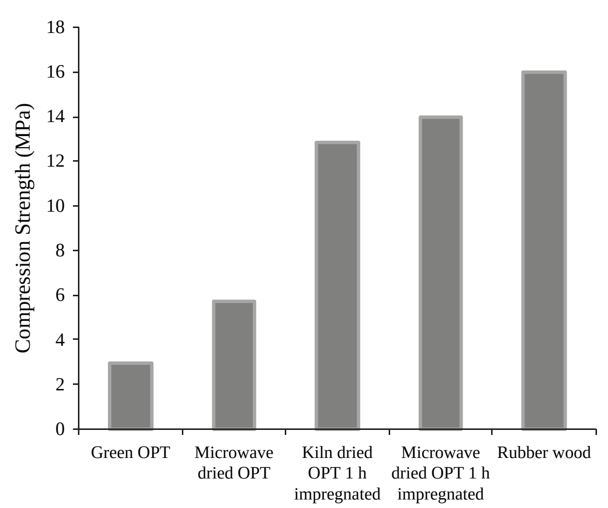

Fig. 11. Comparison of compression strength of OPT for Rubber wood and impregnated OPT with 2 different drying methods and green OPT (The standard deviation was less than 0.06 and it was negligible in the graphs).

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by impregnation after microwave drying has successfully enhanced but lower than Rubber wood. In order to reach the flexural properties similar to Rubber wood, further studies should be carried out on various resins.

For compression strength as presented in Figure 11, the results showed that PF resin enhanced the compression properties of OPT significantly. Rubber wood still exhibited the highest compression strength followed by microwave dried impregnated OPTCL with a slightly lower toleration. This was the property which was found to be more close to the Rubber wood as also reported by other researchers.[23] Figure 12 shows the impact strength which is illustrated in the fourth group of columns, although the PF resin improved the impact properties of OPT. RW and green OPT still exhibited the highest and the lowest impact strength, respectively. Comparing the microwave dried impregnated OPTCL to Rubber wood still a large gap for impact strength is observed.[24] This big gap is attributed to the brittleness of the PF resin which has been fully loaded in the OPTCL.

4.3. Morphological Properties

Based on the SEM micrograph (Fig. 13), the bowl shaped parenchyma can be observed which can provide a space for resin to fill it up. Physically, parenchyma tissue was spongy, very lightweight, moist in green condition, and and easy to separate one cell to the others. Parenchyma contain high amount of starch and lignin compared to vascular bundles.[25,26] Parenchymatous tissue was very hygroscopic mean easy to evaporate when the temperature rises and also easy to absorb the moisture in high humid condition. The high porous morphology of dried oil palm trunk helps to impregnate resin within the empty space, which will improve the mechanical performance of oil

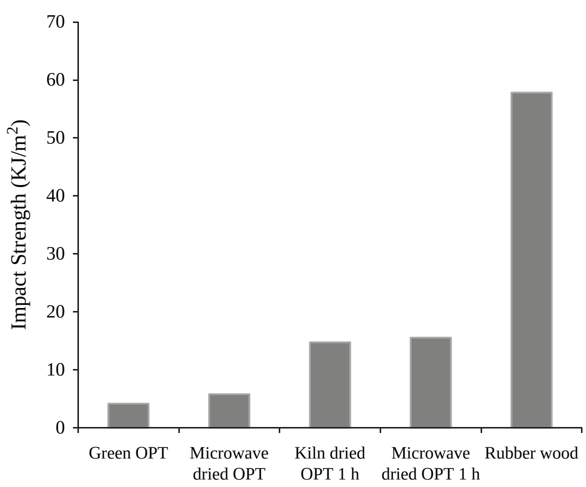

Fig. 12. Comparison of impact strength of OPT for Rubber wood and impregnated OPT with 2 different drying methods and green OPT (The standard deviation was less than 0.06 and it was negligible in the graphs).

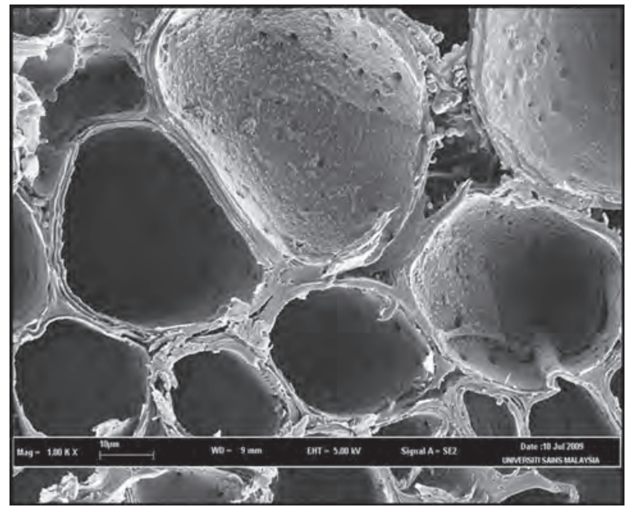

Fig. 13. Scanning electron micrograph (SEM) of parenchyma in dried oil palm trunk (1000x magnification).

palm trunk lumber. After impregnation and curing process, PF resin was seen in the parenchyma tissues. Figure 14 showed the microscopic image of Impregnated OPTCL at 60 min impregnation time, its clear that PF resin incorporates within the parenchyma cell. The parenchyma cells which are fully covered by PF resin were quite similar by attaining elongated shape.

The morphological observation confirmed that the porous morphology of dried OPT has been filled with the PF resin. The micrograph of OPTCL (60 min impregnating) as shown in Figure 14 had better morphology. More interfacial adhesion between the OPTCL fibers and the resin material enhances the mechanical properties. As the impregnation time exceeded 1 hour, the resin started agglomerating and did not embed properly within the pores of the OPTCL, thereby affecting

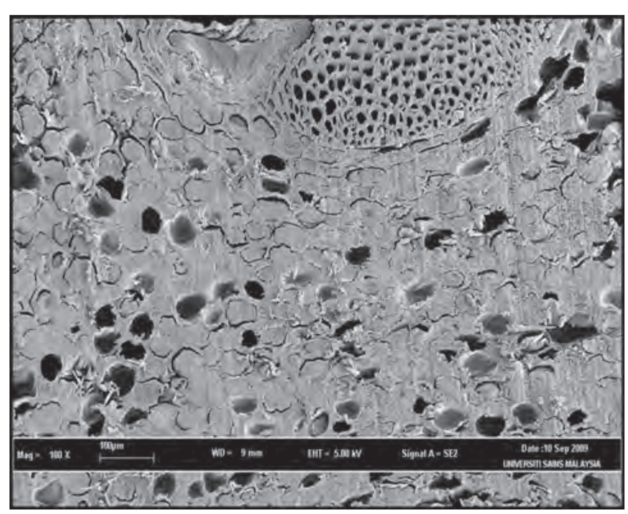

Fig. 14. Scanning Electron micrograph (SEM) of OPTCL after 60 min impregnation (100x magnification).

its mechanical properties. The micrograph of OPTCL as shown in Figure 15 is a critical loading percentage and showed better morphology due to more complete interfacial adhesion between the OPTCL fibers and the resin material and enhnaced the mechanical properties. Loading percentage of the PF resin increased beyond 100%,

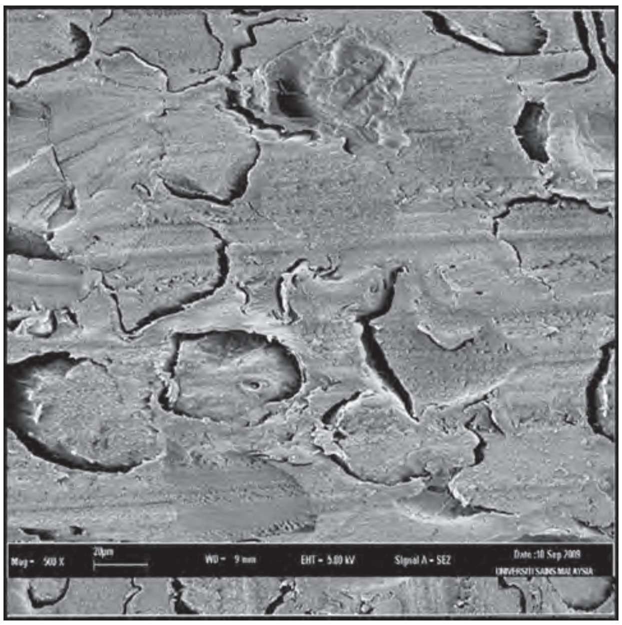

Fig. 15. Scanning 1 Electron micrograph (SEM) of parenchyma fills up with phenol formaldehyde resin, OPTCL after 60 min impregnation (500x magnification).

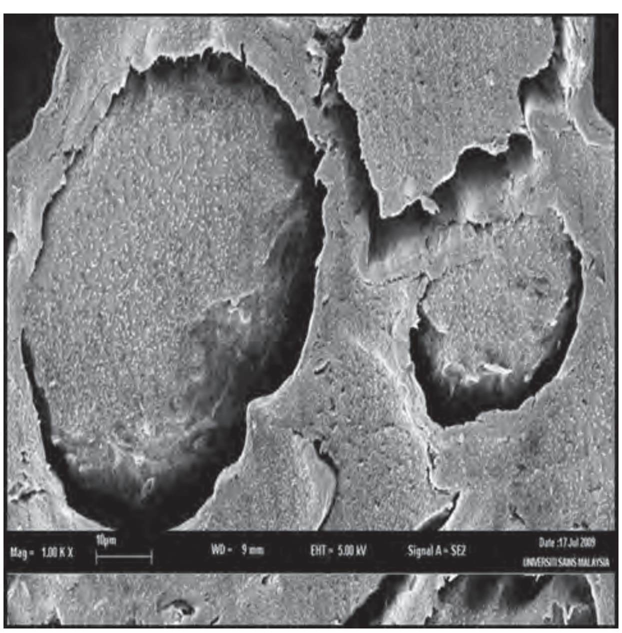

Fig. 16. Scanning Electron micrograph (SEM) of closer view of resin penetration in the parenchyma cells, OPTCL after 60 min impregnation (1000x magnification).

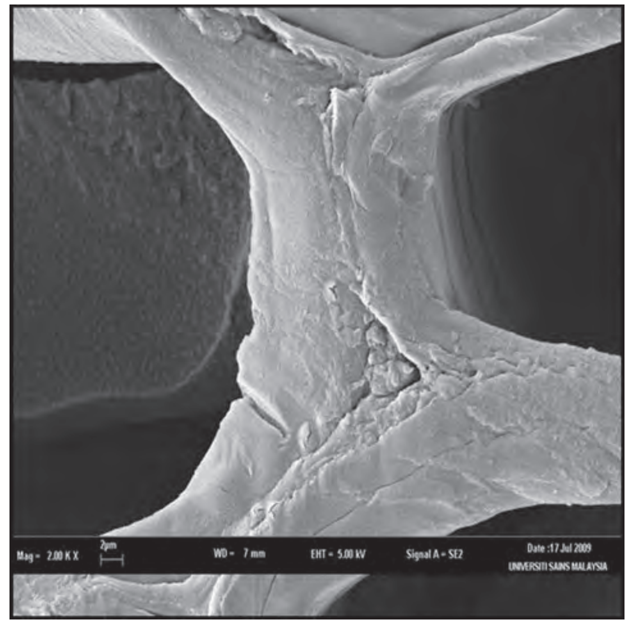

Fig. 17. Scanning electron micrograph (SEM) of cell-wall layers at transverse sectional view (2000x magnification).

the resin started agglomerating and unable to impregnated properly within the pores of OPTCL.

Based on Figures 16 and 17, the PF resin is clearly located in the parenchyma cells. Consequently after dried OPT was impregnated, the porosity of the OPT solid lumber decrease significantly as compared with dried OPT. Moreover, the PF resin was full embedded in parenchyma cell and the pits also filled by cured resin. It is also observed that the resin was not bonded with the cell wall of parenchyma. As high pressure was applied during impregnation process, PF resin penetrated easily into the cell wall. However, closer view in Figure 16 showed that resin located in the cell wall display poor fiber-matrix bonding. The water in PF resin evaporated and the solid content with low adhesion properties remained affecting its mechanical properties.

5. CONCLUSIONS

It was concluded that drying the OPTCL by means of microwave causes less damage to the sample which attributed to the low temperature drying. The microwave dried OPTCL was found to be more uniform as compared to kiln and oven dried samples. Based on the mechanical properties, the microwave dried impregnated OPTCL exhibited higher mechanical properties as compared to unimpregnated microwave dried samples and it also found that duration of 60 min for impregnation was optimum time as compared to other time periods. According to the test results the microwave dried OPTCL gained higher properties as compare to kiln dried samples. Among the different resin loadings, the results of 60 min impregnation were higher than the others. Mechanical properties of rubber wood still maintained the highest values as compared to microwave dried impregnated OPTCL but it demonstrated significant improvement in mechanical properties as compared to green OPT. The impregnated oil palm trunk core lumbers showed better flexural, tensile and compression properties than dried OPT. The impact strength of OPTCL were higher than dried OPT and lower than rubber wood. In most cases OPTCL with 60 min resin loading showed higher impact strength than OPTCL with less and more resin loading time durations. The impregnated OPTCL proved higher ability to resist breaking under compression stress than dried OPT and lower as compared to rubber wood.

From the standpoint of energy saving and conservation of natural resources, the use of alternative constituents in construction materials is now a global concern. Oil palm trunk core lumber is one of the alternative materials which can be utilized as raw materials for different applications. Previous research already reported production of particleboard, cement-bonded particleboard, plywood from OPT and it shown to be technically feasible. Oil palm trunk core lumber can be use in the industrial applications such as transportation pole, home, and recreational sectors. It also possible to fabricate and develop specific products from oil palm trunk core lumber such as wall panel, roof panels, doors, furniture parts etc.

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