Evaluation of Thermal Treatment Effect on the Physical and Mechanical Properties of *Acacia* Hybrid

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Abstract - The palm oil curing thermal treatment of *Acacia* hybrid was investigated. The physical and mechanical properties of the thermal treatment of *Acacia* hybrid were determined through to the different portions (top, middle, and bottom), temperatures (160°C and 200°C), and durations (1, 2, and 3 hrs). The characterization of treated and untreated *Acacia* hybrid was determined according to the ASTM Standard. Untreated samples' overall mean density value was 74.4 kg/m3 and classified under Medium Hardwoods. Furthermore, the mean MOE was 10,712 N/mm2 which fell into the Strength Group 4 category. The thermal treatments results indicated a better impact on physical properties by reducing the moisture content to around 18% to 19% ±1%. The mean density was highest at 200°C temperature 3-hour time duration. Nevertheless, it did not achieve the expected mechanical properties, such as reducing static bending strength at the tangential surface (12.8% to 15.6% of MOE, 22.2% to 30.5% of MOR) compared to the control samples. However, the compression parallel to grain highlighted the value increased (from 1.5% to 15.9%) according to the temperature increase. But, there was a reduction in the strength (from 22.6% to 35.0%) when the time was used as the main effect. Thus, this study revealed that thermal treatment's temperature and time duration factors were more influential than the portion factor towards treated *Acacia* hybrid's physical and mechanical properties.

Keywords - Palm Oil Curing Treatment, Planted *Acacia,* Strength, Durability, Temperature.

INTRODUCTION

The natural forest log become declining since high global timber demand, especially since the early 2000s [1] and the forest plantation has growth as an important idea to overcome the shortage of log supply [2, 3]. The Sarawak state in Malaysia with land area about to one million ha has earmarked for planted forests by the year 2020 [4] according to the plantation forestry are significantly shorter in term of growth rotation than in natural stands [5]. *Acacia* is one of plantation species based on its quick growth, easy adaptability to local soil condition and the high quality of wood it produced [6]. However, *Acacia* hybrid is classified under the slightly durable category, the wood requires preservative to prolong its use especially when used in exposed condition and in ground contact uses [7]. According to the Sunarti *et al*., 2013[8], *Acacia* hybrid is an out-crossed variety between *Acacia mangium* and *A. auriculiformis*, either naturally or artificially. Also, agreed by researcher the *Acacia* hybrid has some merits as compared to the pure parents, such as fast growth, straight main stem, light branches, soft bark, and resistance to pest and disease. It has wide growth rings that produce low-density wood which exhibited inferior mechanical properties. The durability of the wood becomes weak due to these problems resulting in the wood being attacked by bio-deteriorating agents [9].

Over the last few years, its productivity has decreased due to fungal attack which causes heart and root rots [10]. A few methods are used for the heat treatment process on the wood or non-wood, it is sometimes known as rectified or torrefied wood due to the mild pyrolysis causing chemical transformation on the wood chemical components [11]. However, the hot oil thermal modification process seems to be a suitable modification because of its competitive advantage as an environment friendly process, since it does not require the uses of chemicals preservative [6, 12]. Believed that the thermal treatment process can alter the treated wood's cell morphology, affecting the other properties of wood. Means, thermal treatment are explain the effectiveness on wood resistance toward the decaying and attack by fungi [11, 13].

MATERIALS AND METHODS

Sample preparation

The study was investigated of physical and mechanical properties of *Acacia* hybrid with diameter-breast-height (DBH) up to 40 cm. The randomly selected three (3) log of research were harvested from Bintulu plantation, Sarawak. Sample was cut into three portion which are bottom, middle, and top. The trees was harvested 50 cm from ground level and 50 cm below the first main branch. Total length of the A. hybrid logs were divide into 3 portion and 100 mm disc were taken to each portion for investigation purpose. The sample were maintain the condition and transported to the laboratory for treatment, physical, and mechanical properties determination. The sample collections were conducted according to the standards determined by the International

Organization for Standardization ISO 4471-1982: Wood – Sampling sample trees and logs for determination of physical and elasto-mechanical properties of wood in homogenous stands [14].

Moisture Content Determination

The determination of moisture content on *A. hybrid* was conducted follow the standards specified in the International Organization for Standardization, ISO 13061-15:2017 - Physical and mechanical properties of wood [15]. The green condition samples were cut into cross-sectional dimensions 20 mm x 20 mm for moisture content.

Density and Basic Density Determination

The test was conducted based on standards specified in the International Organization for Standardization, ISO 3131-1975E: Wood – Determination of density for physical and mechanical tests [16]. The principle is to find out sample mass with weighing machine and volume by measuring the dimensions. Density is the mass per unit volume of solid wood matters.

Determination of Static Bending on A. hybrid

The static bending from tangent surface of *A. hybrid* was carried out as follow the ISO 3349 standards Wood – Determination of modulus of elasticity in static bending [17]. The samples was cut into specific size (20 x 20 x 320 mm) and conducted using Universal Testing Machine (UTM). The Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) were recorded to measure the performance of *A. hybrid.*

Determination of A. hybrid Compressive Performance

The compression test on parallel to grain of *A. hybrid* was carried out as follow the ISO 3787 standards: Wood – Determination of ultimate stress in compression parallel to grain [18]. The specimens was cut into specific size (20 x 20 x 60 mm) and conducted using Universal Testing Machine (UTM) with conditioning at 20 ± 2^{O}C of temperature and 65± 3% of relative humidity.

Thermal Treatment Process on A. hybrid for Durability of Physical and Mechanical Properties

The thermal treatment on *A. hybrid* samples were conducted using an electric oil-curing machine and a palm oil as a heat medium at different temperatures (160°C and 200°C) and durations (1, 2, and 3 hours). Palm oil as organic in nature medium are easily available and has high boiling point [38]. The specimens for thermal treatment were cut to the specific size (70 mm x 70mm x 700mm) according to the ISO 3129:1975 standard [19] and the treatment was began when the oil bath reached the specified temperature [39]. A data acquisition system with connecting thermocouples wires were used in monitoring the temperature of the heating mediums and the wood samples.

RESULTS AND DISCUSSIONS

Untreated physical properties of A. hybrid as a control purpose

Figure 1 represented the mean value of untreated *Acacia hybrid* moisture content at different portions of the samples. The highest value indicated at the middle portion with 71.0%, followed by the middle portion with 68.0% and top portion at 65.2%. The statistical analysis of ANOVA, highlighted there are no significant difference between the means of moisture content at different portions of the *Acacia hybrid* tree with p-value was 0.319 ($p > 0.05$). The basic density of *Acacia hybrid* indicated that the highest value at middle portion and followed by top and bottom with 71.7 kg/m^3, 69.4 kg/m^3, and 66.8 kg/m^3, respectively. The statistical analysis highlighted that there are no significant difference in the mean basic density at different portions of the *Acacia hybrid* tree with p-value 0.458 ($p > 0.05$). Nonetheless, the density of untreated *Acacia hybrid* represented the highest value at middle portion and followed by top and bottom with mean value at 75.9 kg/m^3, 74.2 kg/m^3, and 73.0 kg/m^3, respectively. The ANOVA value was show no significant difference between the portions of the *Acacia hybrid* tree with 0.772 ($p > 0.05$).

The *Acacia hybrid* at green conditions (untreated) indicated that the middle portion showed the highest mean reading of moisture content than followed by the bottom and top portion even though the results were not significant between the tree portions.

The results were consistent with the theory of Bowyer *et al.* [20] where within a single tree there is a typically considerable variation in moisture content. These can be explained by assuming that variations of moisture content are influenced by many factors. Firstly, inherent properties of the species such as age, porosity, pits, density, permeability of pit membranes, deposits, grain and extractives; and secondly, the environmental factors for instances, relative humidity, temperature and air circulation [21] . Bowyer *et al.* also stated that within any species there is considerable variation depending upon the location, age, season of harvest and tree size [20].

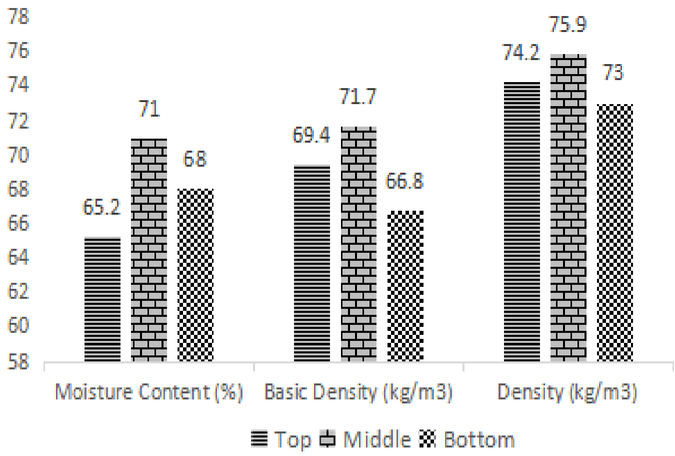

FIGURE 1

CONTROL SAMPLES OF *A. HYBRID* ON PHYSICAL PROPERTIES

According to the Ratnasingam *et al.* [22] stated that wood density is believably the most critical factor which reflects the inherent contents of the material. Researcher also believed that the higher of density proportionally greater in the mass per unit volume, which provides for a much stronger wood. Bowyer *et al.* [20] also stated that the basic density of wood are the most important physical property. Most mechanical and physical properties of wood are closely correlated to basic density and density.

According to the Anon[a] [23], the *Acacia hybrid* samples classified between light to medium hardwood. The results seem to be higher compared to the previous study by Juing [24] and Shukari Midon *et al.* [25] on the same species. The density assessment also highlighted the higher values compared than the density of *Acacia mangium* as stated by Wong , 2002 [26].

These results were in line with the theory of Bowyer *et al.* [20] which provide evidence that wood density varies greatly within any species at any tree due to a number of factors such location in a tree, location within the range of the species, site condition (soil, water and slope), and genetic source. The physico-mechanical properties of wood also influenced by three factors which are the porosity or proportion of void volume which can be estimated by measuring the density. Second, the organization of the cell structure, which includes the microstructure of the cell walls and the variety and proportion of cell types. The third are indicated the density decreases as moisture content decreases, but below the fiber saturation point (FSP), the basic density increases as the moisture content decreases. The increase occurred because of the dry weight remains constant while the volume decreases during drying. The greater the volumetric shrinkage, the greater the difference between the green and the oven-dry basic density.

The Physical Properties on A. hybrid under Thermal Treatment – Moisture Content

Figure 2 represented the mean on modification of physical properties via thermal treatment process at three different parameter (portion, temperature, and time) of *Acacia hybrid* tree. The highest mean moisture content was 19.1%, followed by 18.8% and 18.7% at the bottom, middle and top portions, respectively. The ANOVA results highlighted that there are no significant difference between the mean moisture content at three portions of *Acacia hybrid* tree after thermal treatment process with p-value 0.109 ($p > 0.05$). At different temperature, mean values appear to be fairly equal at the three different temperatures with the range 18.8 to 18.9%. The p-value on ANOVA was 0.664 ($p > 0.05$) which represented that there was no significant difference between the mean moisture content at three temperatures. While at different time duration for thermal treatment indicated that the highest moisture content at 3 hours and followed by 2 hours and 1 hour. The ANOVA results showed the p-value was 0.001 ($p < 0.01$) which showed that there was a highly significant difference between the mean moisture content at four time durations of thermal treatment process.

Based on the previous research, believed that the mechanical properties are affected by changes in the moisture content below the fiber saturation point [27]. According to Bowyer *et al.* [20], the strength of wood will decrease greatly over time when subjected to the deleterious effects of microorganisms, high temperature, drastic moisture fluctuation, strong chemicals or some other external detractor. Temperature has an effect on the wood-water relationships and high temperatures have a permanent effect on the wood itself. Wood that has been subjected to temperatures in excess of $100^{O}C$ for long periods becomes less hygroscopic; that is, it equalizes at lower moisture content than normal wood. Desch and Dinwoodie (1996) also explained that moisture content has an influence on the stiffness and almost all the strength properties of wood [28]. Thus, at high moisture content, toughness decreases with decreasing temperature, while at low moisture content (for example 12%) toughness will increase with decreasing temperatures.

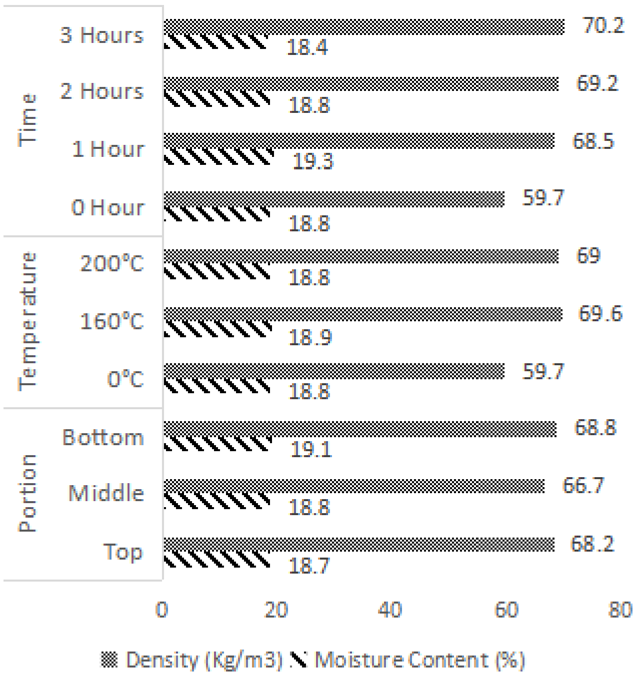

FIGURE 2

MODIFICATION OF PHYSICAL PROPERTIES ON A. HYBRID

The Physical Properties on A. hybrid under Thermal Treatment – Density

Figure 2 indicated that the highest mean density of treated samples was at the bottom and followed by top and middle portion with 68.8 kg/m^3, 68.2 kg/m^3, and 66.7 kg/m^3, respectively. Statistical analysis highlighted that there are no significant difference between the mean density at three portions of *Acacia hybrid* with p-value at 0.573 ($p > 0.05$). At different temperatures parameter, 160°C are represented the highest density value and followed to the temperature at 200 and 0 degree Celsius with 69.6 kg/m^3, 69.0 kg/m^3 and 59.7 kg/m^3, respectively. Then the ANOVA analysis highlighted there are high significant difference between the mean densities at three different temperatures with p-value 0.000 ($p < 0.01$). Nevertheless, the parameter for time duration shows the density value highest at 3 hours duration and the value decreased accordingly short duration with 70.2 kg/m^3, 69.2 kg/m^3, 68.5 kg/m^3, and 59.7 kg/m^3, respectively. ANOVA represented there are high significant difference between the mean density at four different time durations with p-value 0.001 ($p < 0.01$).

Based on observations and analysis of the study, the presence of oil in the cells may cause higher values in the mean density of heat treated samples as compared to the control samples. The statement was proved by Sulaiman *et al.* where the presence of oil could be seen as the weight of samples increasing after treatment indicating a gain in weight after heat treatment [29]. Researcher also believed that the weight gained could be attributed to the presence of oil in the cells because they found traces of oil seen in the lumen and in between the cell walls. The longer the time exposure may lead to a higher absorption of oil into the cells that may cause a higher gain in the weight of the samples. This could explain the reason for the trend in the increase of mean density of the treated samples with the increase in time duration of heat treatment. The results also correspond with a previous study on bamboo species by Wahab *et al.* where the densities improved slightly by the heat treatment using palm oil [30].

The Mechanical Properties on A. hybrid under Thermal Treatment – Static Bending

The study focused on static bending investigation for mechanical properties on treated *Acacia* hybrid. Two main indicator was represented the strength under static bending analysis which are Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). Figure 3 highlighted that the highest MOE with 9749.93 N/mm^2 at the bottom portion, followed by 9401.70 N/mm^2 for the top portion and 9083.29 N/mm^2 for the middle portion. Furthermore, the highest MOR (Figure 4) was indicated at the bottom and followed to the top and middle portion with 123.83 N/mm^2, 121.95 N/mm^2 and 109.62 N/mm^2, respectively. The statistical analysis shows there no significant difference between the mean of MOE (p-value = 0.426) and significant difference between the means of MOR (p-value = 0.053) at three different portions of *Acacia hybrid*. At different temperature, the highest MOE and MOR recorded at 0 ^{O}C (control sample) and followed to the temperature at 200 and 160 ^{O}C with 10711.90 N/mm^2, 9345.70

N/mm^2, and 9044.15 N/mm^2, for MOE then 152.59 N/mm^2, 118.72 N/mm^2, and 106.84 N/mm^2 for MOR respectively. The statistical analysis highlighted there was significant difference between the mean of MOE and MOR at three different temperatures with p-values 0.029 ($0.05 > p > 0.01$) for MOE and 0.000 ($p < 0.01$) for MOR. The MOE and MOR values at different time duration of thermal treatment was recorded the highest at control time (0°C) then follow to the 1, 3 and 2 hours with 10711.90 N/mm^2, 9298.12 N/mm^2, 9241.21 N/mm^2, and 9045.45 N/mm^2, respectively. But for MOR represented the value decreasing started from control, 3, 2, and 1 hour of duration (152.59 N/mm^2, 117.74 N/mm^2, 114.56 N/mm^2, and 106.04 N/mm^2). There are no significant different at MOE (p-value = 0.078) but highlighted the highly significant different for MOR value (p-value = 0.000) between the mean of MOR at four different time durations.

According to the Desch and Dinwoodie [28], the wood mechanical properties defined as the strength of wood refers to its ability to resist applied forces that could lead to its failure, while its elasticity determines the amount of deformation that would occur under the same applied forces. In this study, the *Acacia* hybrid tree categorized under Strength Group Number 4; referred to the strength group table by Gan and Lim [31]. The species at the same categorized under group 4 are indicated such as kapur, keruntum, meranti, merawan, and mempening. The research results also represented higher readings in terms of MOE and MOR compared to the previous study by Shukari Midon *et al.* [25] on the 4 year old *Acacia* hybrid. Concluded that the mature tree of *Acacia* hybrid had very high strength values compared to young age. However, when compared to the findings by Ramlee [32] on *Acacia* hybrid from the same locality, the MOE results were lower but the MOR results were higher. According to Bowyer *et al*. (2003), strength varies within and among species[20]. They also state that within any species, considerable variation exists in clear wood strength which corresponds to the variation in density and to the density-strength relationship for that property. Desch and Dinwoodie [28] reported that the strength and elasticity of wood can be influenced by several factors such as density, angle of grain, presence of knots, other anatomical features, moisture content, temperature, time and defects.

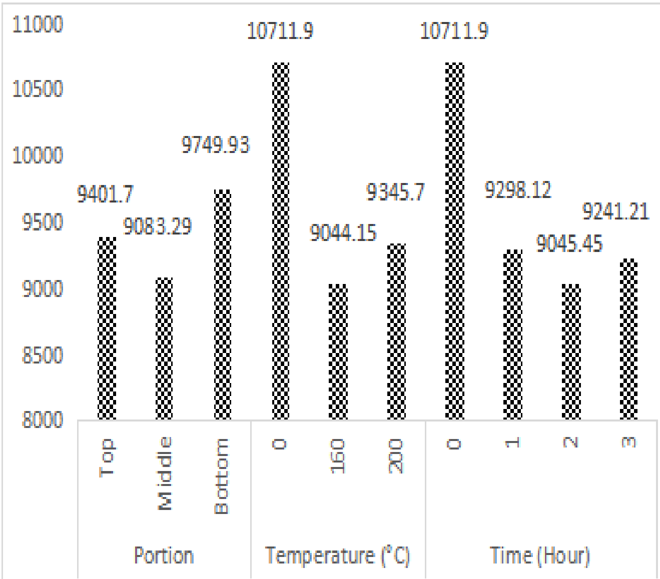

FIGURE 3

MOE VALUE ON STATIC BENDING TESTING OF *A. HYBRID*

Desch and Dinwoodie [28] also agreed that the where prolonged exposure of wood to elevated temperature will result in thermal degradation resulting in extreme cases in total embrittlement, that is zero toughness. Even exposure to cyclic changes in temperature over a long period will result in an appreciable loss in toughness. Long-term exposure to elevated temperatures results in a marked reduction in strength, stiffness and also toughness, the effect being greater with hardwoods than softwoods. Loss in toughness is usually associated with a very short brittle fracture and the terms 'brittle behaviour', or 'brashness' are frequently used as more descriptive expressions of loss in toughness.

They also can be described by Bowyer *et al.* [20] stating that the effect of high temperature has on wood tends to be cumulative; that is, the sum of short exposure times at a high temperature can often be as great as a single exposure of equal duration. One factor, however, may result in short exposures being less severe; namely, the interior of the wood may not have adequate time to heat to the equilibrium temperature. In that case, strength loss occurs only at the surface. It is also supported by Anon[b] (1999) [27] who stated that for extended noncyclic exposures to high temperature, it can be assumed that the entire piece reaches the temperature of the heating medium and will therefore be subject to permanent strength losses throughout the volume of the piece, regardless of size and mode of stress application. A previous study by Kotilainen *et al*. also recorded that the decrease in strength properties can be explained by the rate of thermal degradation and losses of substance after heat treatments [33]. The decrease in strength is mainly due to the depolymerization reactions of wood polymers. Hillis [34] also stated the primary reason for the strength loss is the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin.

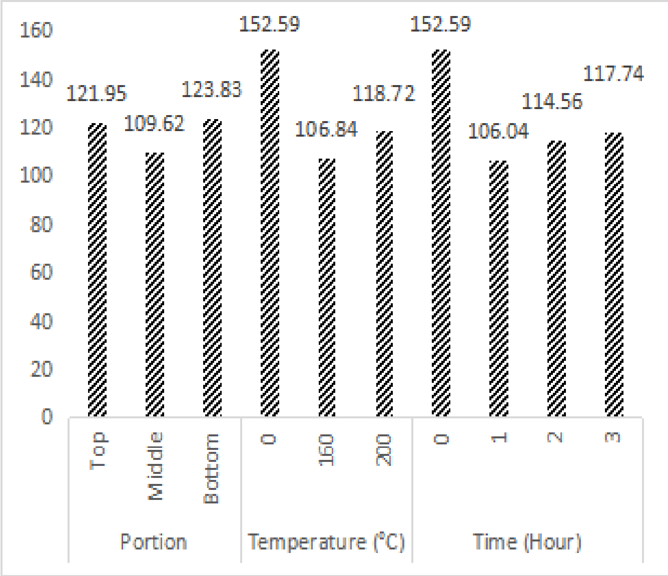

FIGURE 4

MOR VALUE ON STATIC BENDING OF *A. HYBRID*

The Mechanical Properties on A. hybrid under Thermal Treatment – Compression on parallel to the Grain

The highest compression force was at the bottom portion with 57.77 N/mm^2, followed by the middle portion with 50.59 N/mm^2 and 49.84 N/mm^2 at the top portion. The statistical analysis, highlighted that there are significant difference between the mean of compression force at three different portions with p-value 0.025 ($0.05 > p > 0.01$). At different temperature, the highest value shows at the control sample and decreased as followed temperature at 200 and 160°C with 71.26 N/mm^2, 44.56 N/mm^2 and 44.56 N/mm^2, respectively. There are highly significant difference between the mean of compression force at three different temperatures with p-value was 0.000 ($p < 0.01$). Nonetheless, the highest compression value recorded at control sample and decreased according the time from 3 to 1 hour which are 71.26 N/mm^2, 55.17 N/mm^2, 47.49 N/mm^2 and 46.49 N/mm^2. There are also represented highly significant difference between the mean of compression force at three different temperatures with p-value was 0.000 ($p < 0.01$). The situation concluded that all parameter investigated in study are highly influence the compression force readings of treated *Acacia hybrid* samples after going through the thermal treatment.

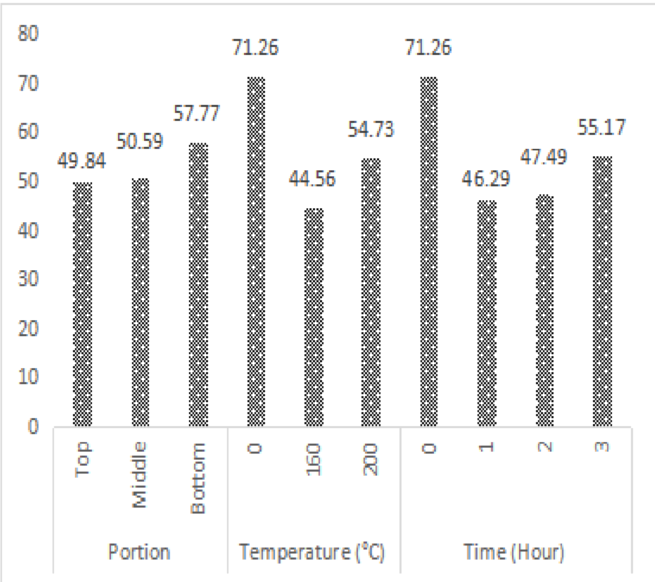

FIGURE 5

COMPRESSION VALUE FOR THERMAL TREATMENT PROCESS

According to the Desch and Denwoodie, (1996) the strength of a piece of wood in compression is closely related to its density though influenced by its moisture content. The above results can be explained by the their theory that is when a block of wood falls in longitudinal compression, a gross shear band occurs across the grain frequently almost horizontally on the radial surface and inclined at about 60^{O} to the vertical axis on the tangential face. This shear band comprises a zone of buckling of the cells and the occurrence within the cell wall of kinks (slip-planes) representing localized deformation of the microfibrillar structure. Since wood is non-homogenous, the properties of wood are not the same although the same samples are taken from the same species or the same tree or the same trunk or taken at the same height. The researcher also believe that the failure of compression wood is usually brittle. The statement was supported by their study that the longitudinal compressive strength of oven-dry timber was over three times that of timber at the fibre saturation point. However, the change in strength with changing moisture contents is non-linear. Other supportive results was conducted by Vital *et al.* [35], the study of compression parallel to grain in *Eucalyptus saligna* wood samples were heated to 100-155°C for 10-160 hours. Then the results found that the compression strength values generally deteriorated with increase in temperature or exposure time. Nevertheless, according to the Sweet and Winandy [36], the reductions on the strength by heat treated samples can be explained with the progressive degradation of hemicelluloses between microfibrills. Also state that during compression, large vessels caused smaller surrounding cells to be deformed more than in regions without vessels, increasing the energy absorbed. However, vessels that are too close together initiate kink banding at low loads and less energy is absorbed [37].

CONCLUSION

The study investigated the effects of thermal treatment with palm oil as a heating medium towards some of the physical and mechanical properties were recognized, such as moisture content, density, static bending at the tangential surface, and compression parallel to the grain. Found that the thermal treatment did not achieve a desirable outcome, such as getting a positive effect on the mechanical strength of the treated *Acacia hybrid*. However, the thermal treatment had better effects on the physical properties in terms of the faster wood drying time and higher density than the control samples. These were proven by the analyzed results from several pieces as described in the results and discussion. In addition, almost all strength assessment values with different temperatures and time durations showed lower figures than the untreated samples. Thus, the temperature and duration of heat treatments were more influential towards the physical and mechanical properties of treated *Acacia hybrid* than the portion factor.

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