ISSN: 0976-3376

Available Online at http://www.journalajst.com

ASIAN JOURNAL OF SCIENCE AND TECHNOLOGY

Asian Journal of Science and Technology
Vol. 09, Issue, 05, pp.8227-8233, May, 2018

RESEARCH ARTICLE

CHANGES IN STRENGTH CHARACTERISTICS AND DURABILITY ON 4-YEAR-OLD TROPICAL BAMBOO *GIGANTOCHLOA SCORTECHINII* THROUGH HEAT TREATMENT

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ARTICLE INFO

Article History:
Received 19th February, 2018
Received in revised form
20th March, 2018
Accepted 16th April, 2018
Published online 30th May, 2018

Key words:

Gigantochloa scortechinii,
Heat treatment process
Physical properties,
Strength,
Durability.

ABSTRACT

The effect of heat treatment on tropical bamboo *Gigantochloa scortechinii* on the physical, strength and durability were studied. Matured bamboo culms of 4-year-old culms were harvested and subjected to high-temperature condition using palm oil as a heating media. Two group of samples; green and air-dried were used in the studies. The temperature applied were 140°C, 180°C and 220°C with an exposure duration of 30, 60 and 90 min respectively. The results show the heat treated bamboo retained most of their original physical and strength properties after undergoing the heat treatments process. Green or air-dried bamboo culms can be dried to an MC of 6-7% within 2 to 3 hours of treatment. The basic densities of bamboo were found to improve slightly by the heat application. The overall strength properties of the heat treated bamboo were found to decrease. The modulus of elasticity in bending strength was reduced between 2-33% in the green condition and between 6-9% in the air-dried condition. For the modulus of rupture in bending strength, the value was reduced between 1-23% in green condition and between 4-16% in air-dried condition. The compression strength was reduced in the range between 2-3% in green and 2-35% in air-dried conditions. The shear strength was reduced in the range between 16-24% in green and between 12 to 24% in air-dried conditions.

INTRODUCTION

Bamboo is a cheap material, having a fast growth rate and possess high mechanical properties among woody materials is currently being considered as an alternative to wood. However, bamboo is easily susceptible to fungal or insect attack (Liese, 1985 and 1986; Wahab, 1998). The physical and mechanical properties of bamboo will deteriorate rapidly if the material is not treated with preservatives (Wahab, 1998 and 2010; Salim *et al*., 2009 and 2010). The use of the chemical in bamboo has been recognized as necessary and essential if the bamboo is to be utilized for furniture and construction purposes (Wahab *et al*., 2013). However, the use of chemicals is not always practical as bamboo is not easily treated (Sultoni, 1983; Wahab *et al*., 2015a). An alternative technique of treating bamboo by mean of heat treatment process has been studied by several researchers in Europe, Africa, and Asia. Their initial finding indicates that this technique is useful in enhancing the bamboo durability against insects and fungi biodegradation. However, the effectiveness of this technique depends mainly on the type of oil that is to be used as the heating medium. Oil with a high boiling point is usually preferred. Razak *et al.* (2013 and 2016a) conducted a study on the heat treatment process using diesel as a heating medium. The heat treated bamboo was found to be useful for indoor usage. However, for exterior use, the results were somewhat disappointing. This condition could be attributed to the low boiling point of diesel (about 150°C). Heat treatment study using linseed oil on temperate bamboo reported that the treated bamboo possess good resistance against insects and fungi attacks (Liese, 1986; Wahab *et al*. 2012). This study is to study and compare properties between natural and heat treated bamboo were made on their physical and strength values. Palm oil (an organic in nature) with high boiling temperature was used as the heating medium in the study.

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MATERIALS AND METHODS

G. scortechinii has been identified as one of the most important and extensively used species in the bamboo industry and is the most widely distributed in Peninsular Malaysia. *G. scortechinii* grows in closely and densely tufted clumps. The culms are stiffly erect with branches growing from the mid-culm node upwards. Branching consists of small and sub-equal branches. The culm is 15–20 m tall and 8–12 cm in diameter. The internode is 40–50 cm long with a wall thickness of 4–12 mm (Abdul Razak *et al.* (1995). All bamboo culms used in this study were taken from the Forest Research Area in Nami, Kedah in Malaysia. There is about 500 ha of natural bamboo stands in Nami, and about 20 ha has been developed by FRIM,

Forest Department Malaysia, and the International Development Research Centre, Canada (IDRC) under the "Management of Natural Bamboo Stands Project" since 1988. Almost all of the bamboos found in this area are of *G. scortechinii.* Bamboo culms of known age were taken randomly from selected clumps. All culms used in this study possess diameters ranging from 8 to 10 cm. They were harvested immediately after the rainy season. Investigations indicated that bamboo collected during this period contained a very minimum amount of starch (Sulthoni, 1983; Liese, 1985; Mohamed *et al*., 1997; Wahab *et al*. 2012 and 2013). Altogether about 100 bamboo culms of four-year-old were harvested. For practical purposes, only internodes 6, 7 and eight were used for the study. These internodes have an average culm wall thickness of 10 mm. Within a week after harvesting, all the culms samples were taken to FRIM for drying, heat treatment and subsequent investigations. Two sets of samples were investigated. The first set consists bamboo samples in green condition with an average moisture content of 65% and the second set consists samples in air-dried condition with moisture content average 14%.

Oil-curing process

The oil-curing process of the bamboo was done using an electrical oil-curing machine. Palm oil was used as the heating medium as it is organic, readily available and has a high boiling point. The palm oil was first heated up to a temperature of 60ºC. Then the bamboo samples were submerged in the heated oil by placing them in a metallic cage. Bamboo samples were taken out at 140ºC, 180ºC and 220ºC interval after 30, 60 and 90 minutes of exposure. A control panel was used in controlling the temperature and the duration of the process. A procedure developed by Razak et al. (2010a), Kamal et al. (2012) and Mustafa et al. (2017) was adopted in this study with modification to suit for bamboo.

Physical properties

Moisture content (MC): The method used in this investigation was based on ISO/TR 22157 (2004) and Ashaari *et al*. (2004). Only fresh samples were used for this investigation. Samples were cut from culms at internodes 6 and 7 with dimensions 25 mm x 25 mm x culm wall thickness. Five replicates were used in the investigation. They were weighed and dried in an oven at 105±2°C for 48 hours to attain a constant weight. The blocks were then cooled for half an hour in a desiccator before re-weighing.

Determination of basic density: Samples of size 10 mm x 30 mm x thickness of culm wall were taken from the middle portion of internode 6 of every bamboo culm. Five replicates were used in the investigation. The samples were oven dried for 48 hours at 105±2°C to attain a constant weight. The samples were then weighed to give the oven dried weight. To obtain the green volume, the samples were placed in water under a vacuum of about 700 mm Hg for 24 hours until thoroughly saturated. The volume of the fully saturated samples was then obtained using the water displacement method. The weight displaced is converted to volume of the sample as a green volume.

Strength Characteristics: Eighty *G. scortechinii* culms samples consisting of green and kiln-dried bamboo and 5 replicate were used in the study. Strength tests of shear, compression parallel to grain and static bending were conducted using the Shimadzu Computer Controlled Universal Testing Machine on split bamboo. These tests were conducted in the Structural and Mechanical Laboratory in Forest Research Institute Malaysia (FRIM). The preparation of the test blocks and methods were made according to the ASTM D 143-52 (Anon., 1974) with modification. There is no universal standard method of tests for evaluating the mechanical properties of bamboo. All testing blocks were conditioned to 12% moisture content before testing. This method was done by placing the test blocks in a conditioning chamber and controlling the relative humidity, temperature and air-circulation for 2 weeks until the required equilibrium moisture contents were obtained. The blocks were tested in the split form and the sizes used were; (1) Shear strength parallel to the grain: 40 mm x 20 mm x bamboo culm wall thickness; (2) Compression strength parallel to the grain: 60 mm x 20 mm x bamboo culm wall thickness; and (3) Static bending: 300 mm x bamboo culm wall thickness

Biological and Durability: The bamboo samples for this test were taken from the treated bamboo described earlier. These blocks were converted into 100 mm x 10 mm x culm wall thickness and were chosen from internode 6 of each culm. This test was conducted based on EN 252: 1989 (BS 7282: 1990) with some modification. The test stakes were buried upright with four-fifths of their length in the ground. They were installed 200 mm apart within and between rows and were distributed randomly based on randomized complete-block design. The test stakes were exposed to the decay hazard as well as termites. The tests monitored for six months. The bamboo stakes installed during the dry season. The testing site for the field/grave-yard study located in Jasin District, Melaka, Malaysia. The site is located in a lowland area. The site was an ex-agriculture land, having hot and humid climate throughout the year with an average daily temperature vary from 21° to 32°C and average rainfall of about 2540 mm. The stakes were inspected at the end of the 12 months period. The criteria for testing were based on the weight loss experienced by the stakes. The stakes were conditioned to 12% MC before and after the ground contact tests.

RESULTS AND DISCUSSION

Physical properties

The results of the physical properties tests namely the moisture content (MC) and basic density (BD) between bamboo samples before and after treatments are tabulated in Table 1 and Table 2. Comparisons were made between green and air-dried samples. The results obtained in the physical studies show that the heat treatment process can be used to dry bamboo culms. Furthermore, the process took less than 2 hours to be completed. The use of kiln dryer or air drying process will take about 7 and 45 days respectively for the bamboo to reached stable MC from the green condition. The final MC ranged from 4.14 to 6.07 and 3.96 to 7.16 for green bamboo condition and air dried bamboo condition, respectively. In another word, there was a change range between 91.9% to 94.4% in MC in green bamboo condition and 42.5% to 65.0% in the air-dried bamboo condition (Table 1). According to Wahab *et al*., (2012) the final MC of bamboo obtained from the heat treatment process is less than 10%.

Table 1. Moisture contents of heat treated bamboo at 140°C, 180°C and 220°C of green & air-dried bamboo

140°C at treatment duration (min.)	Green bamboo		Dried bamboo	
	Before Treatment	After Treatment	Before Treatment	After Treatment
0	72.62 (3.52)	72.62 (3.52)	12.61 (1.22)	12.61 (1.22)
30	75.25 (4.46)	6.07 (0.62)	12.45 (0.83)	7.16 (0.68)
60	76.23 (3.29)	5.82 (0.55)	11.91 (0.54	7.05 (0.63)
90	71.15 (3.05)	5.71 (0.49)	12.35 (0.62)	6.74 (0.56)

180°C at treatment duration (min.)	Green bamboo		Dried bamboo	
	Before Treatment	After Treatment	Before Treatment	After Treatment
0	72.62 (3.52)	72.62 (3.52)	12.61 (1.22)	12.61 (1.22)
30	74.53 (3.91)	5.95 (0.57)	12.81 (0.62)	5.16 (0.61)
60	75.36 (5.35)	5.42 (0.52)	12.58 (0.71)	5.05 (0.72)
90	76.65 (4.16)	4.82 (0.46)	11.64 (0.58)	4.45 (0.59)

220°C at treatment duration (min.)	Green bamboo		Dried bamboo	
	Before Treatment	After Treatment	Before Treatment	After Treatment
0	72.62 (3.52)	72.62 (3.52)	12.61 (1.22)	12.61 (1.22)
30	75.47 (4.21)	5.22 (0.64)	12.56 (1.14)	5.03 (1.06)
60	76.23 (3.08)	5.12 (0.45)	12.85 (0.87)	4.52 (0.82)
90	74.31 (4.07)	4.14 (0.81)	11.32 (0.76)	3.96 (0.72)

Mean values taken from 5 replicates, Values in brackets are standard deviations,
Treatment duration 0 min represent the control samples.

Table 2. ANOVA for MC of heat treated bamboo at 140°C for 30, 60 and 90 min

Main effect MC	Sum of squares	F-Ratio	P-values
Treatment duration	9059.12	17.21	*
Bamboo condition	1799.22	10.25	*

* = significant at $P \leq 0.05$

Table 3. Basic density (BD) of heat treated bamboo at 140°C of green and dried bamboo

140°C at treatment duration (min.)	BD of green bamboo (kg/m^3)		BD of dried bamboo (kg/m^3)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
0	662 (37.04)	662 (37.04)	683 (41.17)	683 (41.17)
30	675 (28.21)	746 (40.32)	587 (29.92)	722 (36.41)
60	646 (42.52)	750 (36.38)	658 (45.26)	745 (43.41)
90	639 (32.16)	754 (44.19)	656 (34.11)	753 (31.32)

180°C at treatment duration (min.)	BD of green bamboo (kg/m^3)		BD of dried bamboo (kg/m^3)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
0	662 (32.16)	662 (32.16)	683 (41.17)	683 (41.17)
30	670 (28.21)	669 (27.05)	583 929.92)	662 (36.28)
60	643 (42.53)	674 (42.26)	655 (45.26)	646 (34.04)
90	638 (32.16)	685 (37.24)	661 (34.11)	678 (27.62)

220°C at treatment duration (min.)	BD of green bamboo (kg/m^3)		BD of dried bamboo (kg/m^3)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
0	662 (32.16)	662 (32.16)	683 (41.17)	683 (41.17)
30	673 (28.21)	675 (38.23)	584 929.92)	682 (41.62)
60	643 (42.53)	678 (42.44)	654 (45.26)	694 (37.42)
90	641 (32.16)	686 (62.21)	655 (34.11)	688 (51.24)

Mean values taken from 5 replicates, Values in brackets are standard deviations,
Treatment duration 0 min represent the control samples.

There is no much difference in the final MC obtained in term of the duration of the heat treatment process. There is a significant difference in the final MC obtained in the used of green, air-dried bamboo and the various durations applied during the heat treatment process. Also, there is an increase in the BD values of samples treated by the heat treatment process with ranged 4.8% to 18.0 % for the green bamboo condition, and 2.6% to 16.8% for air-dried bamboo condition (Table 3). According to Wahab *et al*., (2010b) an average increase of 15% in BD value was obtained for the samples before and after treatments. The heat applied has somehow managed to alter the bamboo structure or cells slightly.

Significant differences were observed in the BD values when different treatment duration was applied. However, no significant differences observed in the used of green or air-dried bamboo. Table 4 shows the ANOVA of BD.

Strength properties

The results on the strength properties tests of bamboo samples before and after treatments are tabulated in Figures 5 to 7. Figures 1 and 3 show the MOE of the bending strength on oil-cured green bamboo at 140°C, 180°C and 220°C at 30, 60 and 60 minutes duration of treatments. Figures 5, 6, and 7 shows the MOE, MOR of the bending strength.

Table 4. ANOVA for BD of heat treated bamboo at 140°C for 30, 60 and 90 min

Main effect BD	Sum of squares	F-Ratio	P-values
Treatment duration	103590	60.01	*
Bamboo condition	13.225	0.02	ns

* = significant at P≤0.05; ns = not significant

Table 5. Bending strength on heat treated bamboo

140°C at treatment duration (min)	Density (g/cm^2)		MOE (MPa)		MOR (MPa)	
	Green	Dried	Green	Dried	Green	Dried
0	989 (86.21)	744 (58.16)	16989 (1128)	18582 (1952)	158 (13.95)	174 (16.25)
30	959 (93.47)	687 (69.98)	16694 (1525)	17403 (1246)	136 (10.21)	167 (20.34)
60	943 (68.94)	676 (52.49)	12944 (1593)	17084 (2287)	133 (16.76)	164 (17.86)
90	925 (81.26)	663 (77.66)	11452 (1398)	16973 (1892)	121 (15.28)	145 (19.98)

180°C at treatment duration (min)	Density (g/cm^2)		MOE (MPa)		MOR (MPa)	
	Green	Dried	Green	Dried	Green	Dried
0	989 (86.21)	744 (58.16)	16989 (1128)	18582 (1952)	158 (13.95)	174 (16.25)
30	53.35 (6.75)	61.90 (6.48)	53.35 (6.75)	16844 (1246)	135 (10.21)	159 (20.34)
60	950 (72.45)	687 (42.49)	13451 (1593)	11746 (2287)	143 (15.65)	169 (18.65)
90	956 (74.63)	625 (68.76)	11332 (1286)	16851 (1481)	133 (12.44)	152 (17.83)

220°C at treatment duration (min)	Density (g/cm^2)		MOE (MPa)		MOR (MPa)	
	Green	Dried	Green	Dried	Green	Dried
0	989 (86.21)	744 (58.16)	16989 (1128)	18582 (1952)	158 (13.95)	174 (16.25)
30	951 (81.54)	672 (60.82)	15297 (1353)	16832 (1405)	130 (9.84)	152 (16.38)
60	956 (68.94)	683 (43.94)	13424 (1234)	16748 (1473)	126 (15.63)	147 (12.73)
90	53.35 (6.75)	61.90 (6.48)	14335 (1675)	16533 (1456)	106 (12.56)	132 (13.83)

Mean values taken from 5 replicates, Values in brackets are standard deviations,
Treatment duration 0 min represent the control samples.

The shear strength between the two conditions of the bamboo is shown in Figure 7. Comparisons were made between the green and air-dried bamboo samples. Reduction in the strength properties of the oil-cured bamboo occurred in the range from 2% to 58%. The bending strength for MOE value indicated reduced from 1.7% to 33.3% for the green bamboo condition while for air-dried bamboo condition ranged from 6.3% to 36.8%. The value of MOR highlighted reduced from 9.5% to 32.9% and 2.9% to 24.1% for green bamboo and air dried bamboo condition, respectively (Table 5). Its means, air-dried bamboo exhibited a small loss in MOR but indicated a higher loss in MOE. Then, green bamboo highlight a small loss in MOE while show a higher loss in MOR when subjected to higher and longer duration of the treatment. These reductions are however dependent on the condition of the bamboo used, amount of heat and duration applied to them (Sulaiman *et al*., 2006; Wahab *et al*., 2015b). These reduction in strength are still acceptable as they are within the range of strength reduction of those bamboo or other woody materials that were chemically treated with preservatives. The heat treatment process has reduced the value of compression strength in ranged 1.05% to 4.5% and 2.3% to 37.5% for green bamboo and air dried bamboo condition (Table 6), respectively. While Table 7 was highlighted the shear strength reduced from 12.2% to 24.7% for green bamboo condition and 12.0% to 25.1% for the air-dried bamboo condition. The results of the study and statistical analysis shown in Tables 8 and 9 (summary of the analysis of variance) conducted on the treated bamboo samples shows that the strength within them was reduced from their original value. The amount of the strength reduced is dependent on the amount of heat and duration of the treatment applied. Generally, the higher the temperature and duration applied the higher will be the strength reduced from the bamboo. There are significant differences in bending, compression and shear strengths between green and air-dried bamboo, the oil-curing process duration and the various temperatures applied.

Durability

Bamboos are considered to have a very low natural durability. When placed in contact with soil, in particular, young bamboo culms or that has been insufficiently treated with preservatives, they usually deteriorate rapidly by the action of a mixed population of soil microorganisms and termites. Even those regarded as adequately treated with the chemical may still be colonized by fungi and termites although decay and the attack rates may be slower, and patterns of fungal colonization of such bamboo may differ from untreated or less adequately treated bamboo.

Table 6. Compression of heat treated bamboo

140°C at treatment duration (min)	Maximum compression (MPa)	
	Green bamboo	Dried bamboo
0	53.35 (6.75)	61.90 (6.48)
30	52.26 (6.98)	60.47 (5.53)
60	51.93 (4.82)	49.11 (3.92)
90	51.88 (5.71)	40.33 (5.41)

180°C at treatment duration (min)	Maximum compression (MPa)	
	Green bamboo	Dried bamboo
0	53.35 (6.75)	61.90 (6.48)
30	51.76 (4.54)	60.32 (4.36)
60	51.54 (5.58)	46.42 (3.25)
90	52.64 (6.21)	39.56 (5.34)

220°C at treatment duration (min)	Maximum compression (MPa)	
	Green bamboo	Dried bamboo
0	53.35 (6.75)	61.90 (6.48)
30	52.79 (4.32)	58.25 (3.67)
60	51.06 (4.15)	44.81 (4.72)
90	52.27 (6.21)	38.68 (5.34)

Mean values taken from 5 replicates, Values in brackets are standard deviations, Treatment duration 0 min represent the control samples.

Table 7. Shear strengths of heat treated bamboo

140°C at treatment duration (min)	Maximum compression (MPa)	
	Green bamboo	Dried bamboo
0	8.93 (0.97)	8.48 (1.84)
30	7.54 (1.28)	7.43 (1.26)
60	7.84 (2.03)	6.77 (0.85)
90	6.76 (1.48)	6.45 (0.71)

180°C at treatment duration (min)	Maximum compression (MPa)	
	Green bamboo	Dried bamboo
0	8.93 (0.97)	8.48 (1.84)
30	7.47 (1.28)	7.39 (1.26)
60	7.64 (2.03)	6.72 (0.85)
90	6.87 (1.48)	6.41 (0.71)

220°C at treatment duration (min)	Maximum compression (MPa)	
	Green bamboo	Dried bamboo
0	8.93 (0.97)	8.48 (1.84)
30	7.62 (1.23)	7.46 (1.44)
60	6.72 (1.49)	6.58 (0.97)
90	7.84 (1.13)	6.35 (0.76)

Mean values taken from 5 replicates, Values in brackets are standard deviations, Treatment duration 0 min represent the control samples.

Table 8. ANOVA for MOE of heat treated bamboo at 140°C for 30, 60 and 90 min.

Main effect MOE	Sum of squares	F-Ratio	P-values
Treatment duration	1.21252E8	6.24	*
Bamboo condition	4.22405E7	6.52	*

* = significant at P≤0.05

Table 9. ANOVA for MOR of heat treated bamboo at 140°C for 30, 60 and 90 min.

Main effect MOR	Sum of squares	F-Ratio	P-values
Treatment duration	3746.07	29.66	*
Bamboo condition	4730.63	112.38	*

* = significant at P≤0.05

The results of the grave-yard test conducted on heat treated bamboo samples placed in ground contact for six months period tabulated in Tables 10 and 11. Control samples that are composed of untreated bamboo and rubberwood experienced weight loss of about 48% and 40% respectively for the six months ground contact durability tests (Wahab *et al*., 2010a and 2016b).

The weight loss in bamboo reduced once the heating process treats them. The weight loss was reduced from 48% for the untreated bamboo to be tween 5 - 34 % depend on temperature and duration of heat applied. Bamboos are considered to have a very low natural durability. When placed in contact with soil, in particular, young bamboo culms or that has been insufficiently treated with preservatives, they will deteriorate

Table 10. Mean loss in weight of bamboo after 6 months of grave-yard tests

Mass (gm)	140/30	140/60	140/90	180/30	180/60	180/90	220/30	220/60	220/90
Initial weight	6.54	6.57	6.76	6.55	7.20	7.33	5.93	6.06	6.50
	(1.74)	(0.96)	(2.15)	(1.56)	(2.04)	(1.48)	(0.99)	(1.45)	(1.06)
Final weight	4.35	4.82	5.44	4.69	5.57	6.54	5.04	5.45	6.19
	(1.22)	(1.31)	(0.91)	(1.13)	(1.38)	(2.07)	(1.49)	(1.93)	(0.79)
% loss in weight	33.62	26.83	19.62	27.98	22.66	10.77	16.20	10.20	4.81

Mean values taken from 5 replicates, Values in brackets are standard deviations
140/30 = 140ºC at 30 min immersion, 140/60=140 ºC at 60 min immersion, 140/90=140 ºC at 90 min immersion, 180/30 = 180ºC at 30 min immersion, 180/60=180 ºC at 60 min immersion, 180/90=180 ºC at 90 min immersion, 220/30 = 220ºC at 30 min immersion, 220/60=220 ºC at 60 min immersion, 220/90=220 ºC at 90 min immersion,

Table 11. Loss in weight of untreated or control after 6 months of exposure in the grave-yard tests

Mass (gm)	Bamboo	Rubberwood
Initial weight	9.07 (2.36)	10.41 (3.41)
Final weight	4.78 (1.45)	6.29 (2.24)
Loss weight (%)	47.86%	39.39%

Mean values taken from 5 replicates, Values in brackets are standard deviations

rapidly by the action of a mixed population of soil microorganisms and termites. Even those regarded as adequately treated with preservative may still be colonized by fungi and termites although decay and the attack rates may be slower, and patterns of fungal colonization of such bamboo may differ from untreated or less adequately treated bamboo. There is an overall decrease in weight loss of oil-cured samples before and after six months tests. Green condition sample recorded a decreased in weight loss between 4% to 33% and 4% to 33% in air-dried samples. Oil-cured bamboo performed much better compared to those of untreated in the ground contact tests. The weight loss in term of percentage after 12 months tests varies from 4% to 34% with samples oil-cured at a higher temperature and longer duration losing less weight. Control samples that are composed of untreated bamboo and rubberwood experienced weight loss of about 48% and 40% respectively for the 12 months ground contact durability tests. The weight loss in bamboo is reduced once the oil-curing process treats them. There are no significant differences in the condition of bamboo used in the study. Significant differences were observed in the treatment duration and at different temperature applied to the oil-cured bamboo. This analysis data can be seen in the summary of the analysis of variance in Table 1 below. Bamboo that was oil-cured at 180ºC and exposed for 60 minutes experienced an average weight loss of less than 12%. This temperature can be taken as an optimum temperature for effective treatment of bamboo through the oil-curing process using palm oil as the heating medium. Bamboo oil-cured at lower temperature experienced higher weight loss and are therefore not sufficient to withstand fungi or insect attack. Bamboo oil-cured at a temperature below 180ºC can be considered for utilization but an indoor usage. Further study will have to be undertaken in determining the optimum temperature and duration of treatment before this bamboo can be recommended for effective indoor usage.

Conclusion

Heat treatment process can be applied as a mean to speedify the drying of matured (4-year-old culms and older) bamboo before utilization. Green or air-dried bamboo culms can be dried to an MC of 6 - 7% within 30 to 90 minutes of treatment. Culms of a younger age are not recommended for this type of treatment. The heat treatment application from 630 improves the basic density of bamboo - 660 kg/m^3 of the green condition to 740 - 750 kg/m^3 and 650 - 680 kg/m^3 of air-dried bamboo to 720 - 750 kg/m^3. The MOE value is reduced between 2 to 33% from 16989 MPa to 11452 - 16694 MPa in green condition and between 6 to 9% from 18582 MPa in air-dried condition to 16973 - 17403 MPa. For the MOR, the value is reduced between 1 to 23% from 158 MPa to 121 - 136 MPa in green condition and between 4 to 16% from 174 MPa in air-dried condition to 145 - 167 MPa. The compression strength is reduced in the ranged between 2 to 35% from 53.35 MPa in green condition to 51.88 - 52.26 MPa and 61.90 MPa air-dried to 40.33 - 60.47 MPa. The shear strength is reduced in the ranged between 16 to 24% from 8.93 MPa in green condition to 6.76 - 7.54 MPa and between 12 to 24% 8.48 from MPa in air-dried condition to 6.45 - 7.43 MPa. The heat treatment process significantly enhanced the durability of bamboo. The loss in weight of bamboo is reduced from 48% for the untreated bamboo to between 5 - 34 % depending on the temperature and duration of heat applied. Treatment duration of 90 minutes was found to produce the most durable bamboo against fungi and insect attack. This treatment is followed by the 60 and 30 minutes treatment duration respectively. Treatment temperature at 180°C at 90 minutes is recommended for the bamboo treatment. This is due to the temperature and duration of the bamboo physical and mechanical properties are changed from its original properties

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