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Effect of heat treatment using palm oil on properties and durability of Semantan bamboo

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

Key words: Bamboo; Semantan bamboo (*Gigantochloa scortechinii*); heat treatment; physical properties; strength; durability.

INTRODUCTION

Bamboo, being a cheap material, having a fast growing rate and possessing high mechanical properties amongst woody materials, is currently being considered as an alternative to wood. However, bamboo is easily susceptible to fungal or insect attack [1–3]. The physical and mechanical properties of bamboo will deteriorate rapidly if the material is not treated with preservatives [2–4]. The use of preservatives in

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bamboo has been recognized as necessary and important if the bamboo is to be considered for utilization in furniture and construction [4]. However, the use of preservatives is not always effective, as bamboo is not easily treated [3].

An alternative technique of treating bamboo by means of a heat-treatment process has been studied by several researchers in Europe, Africa and Asia. In Europe the heat-treatment process has long been used for timber treatment and in Asia it has been used for rattan. Work by Leithoff and Peek [5] reported that the heat treatment is effective in enhancing the durability of bamboo against insects and fungi biodegradation. They use linseed oil as the heating medium. The effectiveness of this technique depends largely on the type of oil that is to be used. Oil with a high boiling point is normally preferred. Razak *et al*. [6, 7] have conducted a similar study on a tropical bamboo, using diesel. The results of these studies indicated that the heat-treated bamboo is effective for indoor usage. However, for exterior use the results were rather disappointing. This could be attributed to the boiling point of diesel (about 150°C).

The objective of this study is to investigate the use of palm oil as the heating medium because palm oil possess higher boiling point (ranging from 140°C to 220°C) and is considered more organic in nature. Comparative properties between natural and heat-treated bamboo, and their physical and strength values were investigated.

MATERIALS AND METHODS

All bamboo culms used in this study were taken from the forest research area in Nami, Kedah, Malaysia. Bamboo culms of known age were taken from randomly selected clumps. All culms used in this study possess diameters ranging from 8–10 cm and culm-wall thickness from 8 to 10 mm. They were harvested immediately after the rainy season. Investigations indicated that bamboo harvested during this period contained a very minimum amount of starch [2, 8]. All together about 100 four-year-old bamboo culms were harvested. For practical purposes only internodes 6, 7 and 8 were used for the study. These internodes have an average culm wall thickness of 10 mm.

Within a week after harvesting, all the culm samples were taken to the Forest Research Institute Malaysia for drying, heat treatment and for subsequent investigations. Two sets of samples were investigated. The first set consisted of bamboo samples in green condition with average moisture content of 65% and the second set consisted of air-dried samples with an average moisture content of 14%.

The heat treatment on the bamboo was done using an electrical heat-treatment machine which was made as a prototype model. Palm oil was used as the heating medium, as it is organic in nature, readily available and has a high boiling point. The palm oil was first heated up to a temperature of 80°C. Then the bamboo samples were submerged in the heated oil by placing them in a metal cage. Bamboo samples were taken out at 140°C, 180°C and 220°C after 30, 60 and 90 min of immersion.

A control panel was used in controlling the temperature and the duration of the process. A procedure developed by Leithoff and Peek [5] and Razak *et al*. [9] was adopted in this study with modification to make it suitable for bamboo.

Physical properties

Moisture content (MC). The method used in this investigation was based on ASTM D4442-92 [10]. Only fresh samples were used for this investigation. Samples were cut from culms at internodes 6 and 7 with dimensions 25 mm × 25 mm × culm wall thickness. Five replicates were used in the investigation. They were weighed and dried in an oven at 105 ± 2°C for 48 h to attain a constant weight. The blocks were then cooled for 30 min in a dessicator before re-weighing.

Determination of basic density. Samples of 10 mm × 30 mm × culm wall thickness were obtained 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 h at 105 ± 2°C to attain a constant weight.

To obtain the green volume, the samples were placed in water under vacuum of about 700 mmHg for 24 h until fully 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.

The basic density of bamboo was obtained using the following formula:

$$\text{Basic density (kg/m}^3) = \frac{\text{Ovendry weight (kg)}}{\text{Green volume (m}^3)}.$$

Mechanical properties

Eighty *G. scortechinii* culms samples consisting of green and kiln-dried bamboo and 5 replicates 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). There was no universal standard method available to test mechanical properties of bamboo. However, the test was conducted as close as possible in accordance to ASTM D 143-52 [11] with some modification. All testing blocks were conditioned to 12% moisture content prior to testing. This was done by placing the test blocks in a conditioning chamber with controlled relative humidity, temperature and air-circulation for a week until the required equilibrium moisture contents were obtained.

The blocks were tested in the split form and the sizes used were as follows: (1) Shear strength parallel to the grain: 40 mm × 20 mm × bamboo culm wall thickness. (2) Compression strength parallel to the grain: 40 mm (height) × 20 mm (width) × bamboo culm wall thickness. (3) Static bending: 300 mm (length) × 20 mm (width) × bamboo culm wall thickness.

Biological and durability aspects

The bamboo samples for this test were taken from the treated bamboo described earlier. These blocks were converted into 100 mm × 10 mm × culm wall thickness and were chosen from internode 6 of each culm. This test was conducted based on EN 252: 1989 (BS 7282: 1990) [12] and procedure developed by Jackson [13] with some modification.

The test stakes were buried upright with 80% 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 were monitored for a period of 6 months. The stakes were installed during the dry season. The testing site for the field/graveyard study was located in Jasin District, Melaka, Malaysia. The site is located in a lowland area. The site is 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.

Assessment on the bamboo stakes was based on the percentage of weight loss experienced by each stake. The stakes were conditioned to 12% moisture content before and after ground contact tests.

RESULTS AND DISCUSSION

Physical properties

The results on the physical properties tests, namely the moisture content (MC) and basic density (BD) between bamboo samples before and after treatments, are

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

Temperature (°C)	Treatment duration (min)	Green bamboo		Dried bamboo	
		Before treatment	After treatment	Before treatment	After treatment
140	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	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	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 parentheses are standard deviations. Treatment duration 0 min represents the control samples.

tabulated in Tables 1–4. Comparisons were made between green and air-dried samples.

The results in Table 1 show that the heat-treatment process can be used to dry bamboo culms. Furthermore, the process took less than 2 h to be completed. The use of kiln dryer or air drying process will take about 7 and 45 days, respectively, for the bamboo to reach a stable MC from green condition. The final MC of bamboo obtained from the heat-treatment process is less than 10%. There is not 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 use of green and air-dried bamboo and the various durations applied during the heat treatment process. Table 2 shows the ANOVA on MC.

Table 3 shows an increase in the BD values of samples treated by the heat treatment process. An increase of 15% in BD value was obtained for the samples before and after treatments. The heat applied has somehow managed to alter slightly the bamboo structure or cells. Significant differences were observed in the BD values when various treatment durations were applied. However, no significant differences were observed in the use of green or air-dried bamboo. Table 4 shows the ANOVA of BD.

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	$<0.05^{*}$
Bamboo condition	1799.22	10.25	$<0.05^{*}$

* Significant.

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

Temperature (°C)	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
140	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	0	662 (32.16)	662 (32.16)	683 (41.17)	683 (41.17)
	30	670 (28.21)	669 (27.05)	583 (29.92)	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	0	662 (32.16)	662 (32.16)	683 (41.17)	683 (41.17)
	30	673 (28.21)	675 (38.23)	584 (29.92)	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 parentheses are standard deviations. Treatment duration 0 min represents the control samples.

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

Main effect SG	Sum of squares	*F* ratio	*P* values
Treatment duration	103590	60.01	$\leqslant 0.05^{*}$
Bamboo condition	13.225	0.02	$>0.05^{ns}$

* Significant; ns, not significant.

Table 5.
Mean of bending strength on heat treated bamboo

Temperature (°C)	Treatment duration (min)	Density (g/cm^2)		MOE (MPa)		MOR (MPa)	
		Green	Dried	Green	Dried	Green	Dried
140	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	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	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 parentheses are standard deviations. Treatment duration 0 min represents the control samples.

Strength properties

The results on the strength properties tests of bamboo samples before and after treatments are tabulated in Tables 5–7 and the ANOVA results in Tables 8 and 9. Comparisons were made between green and kiln-dried samples.

The results of the study and the statistical analysis conducted on the treated bamboo samples show that the strength within them decreased from their original value. The amount of strength decrease depends on the amount of heat and duration

Table 6.
Mean of compression on heat treated bamboo

Temperature (°C)	Treatment duration (min)	Maximum compression (MPa)	
		Green bamboo	Dried bamboo
140	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	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	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 parentheses are standard deviations. Treatment duration 0 min represents the control samples.

Table 7.
Mean of shear strengths on heat treated bamboo

Temperature (°C)	Treatment duration (min)	Maximum compression (MPa)	
		Green bamboo	Dried bamboo
140	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	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	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 parentheses are standard deviations. Treatment duration 0 min represents the control samples.

of the treatment applied. Generally, the higher the temperature and duration applied the higher will be the strength reduction of the bamboo.

There are significant differences in the use of the heat treatment duration as well as the green and dried bamboo. These are clearly stated in Tables 8 and 9 of the ANOVA for MOE and MOR of heat-treated bamboo at 140°C for 30, 60 and 90 min.

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* value
Treatment duration	1.21252E8	6.24	$\leqslant 0.05^{*}$
Bamboo condition	4.22405E7	6.52	$\leqslant 0.05^{*}$

* Significant.

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* value
Treatment duration	3746.07	29.66	$\leqslant 0.05^{*}$
Bamboo condition	4730.63	112.38	$\leqslant 0.05^{*}$

* Significant.

Table 10.
Mean loss in weight of bamboo after 6 months of graveyard tests

	Temperature applied and duration of exposure								
	140/30	140/60	140/90	180/30	180/60	180/90	220/30	220/60	220/90
Initial weight (g)	6.54 (1.74)	6.57 (0.96)	6.76 (2.15)	6.55 (1.56)	7.20 (2.04)	7.33 (1.48)	5.93 (0.99)	6.06 (1.45)	6.50 (1.06)
Final weight (g)	4.35 (1.22)	4.82 (1.31)	5.44 (0.91)	4.69 (1.13)	5.57 (1.38)	6.54 (2.07)	5.04 (1.49)	5.45 (1.93)	6.19 (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 parentheses are standard deviations. 140/30 = 140°C at 30 min immersion, 140/60 = 140°C at 60 min immersion, etc.

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 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.

The results of the graveyard test conducted on heat-treated bamboo samples placed in ground contact for the 6-month period are tabulated in Tables 10 and 11.

Control samples of untreated bamboo and rubberwood experienced weight loss of about 48 and 40%, respectively, for the 6 months ground contact durability tests. The weight losses in bamboo are reduced once they are treated by the heating process. The weight losses were reduced from 48% for the untreated bamboo to between 5 and 34%, depending on the temperature and duration of heat applied.

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

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

Mean values taken from 5 replicates. Values in parentheses are standard deviations.

CONCLUSIONS AND RECOMMENDATIONS

Physical properties

Moisture content. Heat treatment process can be applied as a mean to speedify the drying of matured (4-year-old culms and older) bamboo prior to utilization. Green or air-dried bamboo culms can be dried to an MC of 6–7% within 2–3 h of treatment. Culms of younger age are not recommended for this type of treatment as their cells has not fully developed and can easily crack during the heating process.

Basic density. The basic density of bamboo is improved by the heat-treatment application from 630–660 kg/m^3 in the green condition to 740–750 kg/m^3, and in air-dried bamboo from 650–680 kg/m^3 to 720–750 kg/m^3.

Strength properties

Bending strength. MOE value is reduced between 2 and 33% from 16 989 MPa to 11 452–16 694 MPa in green condition, and between 6 and 9% from 18 582 MPa in air-dried condition to 16 973–17 403 MPa. For the MOR, the value is reduced between 1 and 23% from 158 MPa to 121–136 MPa in green condition, and between 4 and 16% in air-dried condition from 174 MPa to 145–167 MPa.

Compression strength. The compression strength is reduced in the range between 2 and 35% from 53.35 MPa in green condition to 51.88–52.26 MPa, and air-dried from 61.90 MPa to 40.33–60.47 MPa.

Shear strength. The shear strength is reduced in the range between 16 and 24% from 8.93 MPa in green condition to 6.76–7.54 MPa, and between 12 and 24% in air-dried condition from 8.48 MPa to 6.45–7.43 MPa.

Durability

The heat-treatment process greatly enhanced the durability of bamboo. The loss in weight of bamboo is reduced from 48% for the untreated bamboo to 5–34%, depending on the temperature and duration of heat applied.

A treatment duration of 90 min was found to produce the most durable bamboo against fungi and insect attack. This is followed by the 60 and 30 min treatment durations, respectively.

A treatment temperature at 180°C at 90 min is recommended for the bamboo treatment. This is because at this temperature and duration the bamboo physical and mechanical properties are changed from its original properties

REFERENCES

1. O. A. Razak, M. A. Latif, W. Liese and H. Norini, *Planting and Utilization of Bamboo in Peninsular Malaysia, FRIM Research Pamplet no. 118*. FRIM, Kepong (1995).
2. W. Liese, *Bamboos: Biology, Silvics, Properties, Utilization, Schriftenreihe der GTZ, no. 180*. GTZ, Eschborn (1985).
3. W. Liese, Characterization and utilization of bamboo, in: *Bamboo Production and Utilization. Proceedings of the Congress Group 5.04, Production and Utilization of Bamboo and Related Species, XVIII IUFRO World Congress*, Ljubljana, Yugoslavia, T. Higuchi (Ed.), pp. 11–16. Kyoto University, Kyoto, Japan (1986).
4. W. Razak, Effect of selected preservatives on the durability of Gigantochloa scortechinii, PhD dissertation, University of London (1998).
5. H. Leithoff and R. D. Peek, Heat treatment of bamboo, Paper presented at the *International Research Group on Wood Preservation (IRG)*, Nara, Japan (2001).
6. W. Razak, W. S. Hashim, S. Othman and H. Rokiah, Effect of heating process on strength and durability of bamboo Gigantochloa scortechinii, Paper-poster presented at the *Conference on Forestry and Forest Product Research (CFFR)*, Kuala Lumpur, Malaysia (2003).
7. W. Razak, W. S. Hashim, M. Tarzimi, S. Othman and M. Azmy, Heat treatment process in enhancing the bamboo durability (Malay), Paper presented at the *Workshop on R&D and Bamboo Products Processing*, held at the Centre of Craf Development Kuala Pilah, Negeri Sembilan (2002).
8. A. Sulthoni, *Traditional Preservation of Bamboo by Soaking (Malay)*. International Development Research Center, Ottawa (1983).
9. W. Razak, M. Tarzimi and O. Arshad, Rattan oil curing, bleaching and preservation, *Transfer of Technology Model Series*. INBAR, Beijing (2001). Available from www.inbar.int/totem/
10. *Annual book of American Standards for Testing Materials D4442-92*. ASTM, West Conoshocken, PA (1997).
11. *Annual book of American Standards for Testing Materials D 143-52*. ASTM, West Conoshocken, PA (1974).
12. EN 252: BS 7282, Field test method for determining the relative protective effectiveness of a wood preservative in ground contact (1989).
13. W. F. Jackson, Durability of Malayan timbers, *Malayan Forester* **20**, 38–46 (1957).