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Properties of Altered Matured *Bambusa vulgaris* via Heat Treatment Process.

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ABSTRACT

Cultivated *Bambusa vulgaris* culms of 4-year-old were used in this study. The culms were harvested from FRIM's bamboo research plot located in Selangor, Malaysia. Bamboo samples consisting of internodes 6, 7 and 8 were cross-cut and taken to FRIM laboratory for the heat treatment process, testing and analysis. A stainless tank measuring 0.6 x 0.6 x 1.2 m was used as the heating pot and an organic in nature palm oil was used as the medium of heat transfer. This process used temperature and the duration of immersion as their 2 main parameters. The temperature of 140ºC, 180ºC and 220ºC, and the immersion periods of 30, 60 and 90 min. were applied to the bamboo. The physical and strength properties of the heat treated bamboo were assessed and evaluated. The results of the treatment show that the process enhanced on the physical properties of the bamboo. The process however lowered the strength of the bamboo.

Keywords: Cultivated *Bambusa vulgaris*, heat treatment process, palm oil, physical properties, strength properties.

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INTRODUCTION

Bamboo being a fast-growing species and possessing high strength properties among bio-natural materials is considered as an alternative to future wood. It will deteriorate rapidly if the material is not treated with preservatives [1-3]. Bamboo is easily susceptible to fungal or insect attack [2-4]. They need to be treated either through traditional or modern process. The used of preservative in bamboo has been recognized as necessary and important if they are to be considered for utilization in furniture and construction application [2, 5, 6]. The used of preservatives, however, is not always effective as bamboo being a monocot species is not easily treated [1, 2]. An alternative method in treating bamboo by mean of heat treatment process has been studied by researchers in the world. The initial finding indicates that this method is effective in enhancing the bamboo durability against insects and fungi biodegradation. However, the effectiveness of this method largely depends on the type of oil that is to be used as the heating medium and also the treatment durations [2, 7]. Oil with a high boiling point is normally preferred. A study on the heat treatment process using diesel as a heating medium was conducted by Wahab *et al*. [8]. The heat treated bamboo was found to be effective for indoor usage. However, for exterior use, the results were rather disappointing. This could be attributed to the low boiling point of diesel (about 150°C). Wahab *et al.* [9] in their heat treatment study on *Gigantochloa scortechinii* reported that the treated bamboo possess good resistance against insects and fungi attacks if treated at 180ºC at 60 min. The present study focused on properties between natural and heat treated *Bambusa vulgaris.* Palm oil (an organic in nature) with high boiling temperature was used as the heating medium in the study. Only cultivated *Bambusa vulgaris* were used in the study.

MATERIAL AND METHODS

Thirty-two (32) culms of *Bambusa vulgaris* of known 4-year-old were randomly selected from various bamboo clumps from the Bamboo Plot located in Forest Research Institute Malaysia (FRIM) in Kepong. All culms used in this study possess diameters ranging from 8 to 10 cm. For practical purposes, only internodes 6 and 7 were used for the study. Within a week after harvesting, the culms samples were air-dried and underwent the respective heat treatment process in natural round forms. Two sets of samples were investigated. The first set consists bamboo samples in green condition with an average moisture content of above the fiber saturation point (≤30%), and the second set consists of samples air-dried to equilibrium moisture content conditions. The heat treatment processes conducted using an ordinary stainless steel tank. Oil palm oil was used as the heating medium as it is organic, easily available and has a high boiling point. The palm oil was first heated up using a stove to a temperature of 80ºC. Then the bamboo samples were placed into the heated oil in a stainless steel container. Bamboo samples were taken out at 140ºC, 180ºC and 220ºC interval after 30, 60 and 90 min of exposure respectively. A procedure developed by Wahab *et al.* [8, 9] was adopted in this study with modification to suit for bamboo.

Physical Properties

Moisture content

Procedures based on ISO 22157 [10] were applied and green or fresh bamboo were used in the studies. The bamboo were cross-cut from culms at internodes 7 and 8 with dimensions 25 mm (length) x 25 mm (width) x culm wall thickness. They were weighed and dried in an oven at 105±2°C for 48 hrs. until a constant weight attained. The blocks were then cooled for 30 min. in a desiccator before re-weighing. Five (5) replicates were used in the investigations.

Determination of basic density

Bambo of 30 mm (length) x 10 mm (width) x thickness of culm wall were obtained from the middle portion of internode 6 of every bamboo culm. Five (5) replicates were used in the investigation. The samples were oven dried for 48 hours at 105±2°C until a constant weight were attained. 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 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 values of the bamboo oven dry weight per the bamboo green volume. Procedure by ASTM D 1758-74 [11] and Sulaiman et al. [12] was

followed.

Strength properties

Green and air-dried *B. vulgaris* culms were used for this studies. Strength tests of shear, compression parallel to grain and static bending were conducted using a Universal Testing Machine on split bamboo. These tests were conducted in FRIM testing laboratory. The preparation of the test blocks and methods were made according to ISO 22157 [10] on determination on physical and strength properties of bamboo. All testing blocks were conditioned to 12% moisture content before testing. This was done by placing the test blocks in a conditioning chamber under controlled of the 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 (length) x 20 mm (width) x bamboo culm wall thickness, (2) Compression strength parallel to the grain: 40 mm (length) x 20 mm (width) x bamboo culm wall thickness, (3) Static bending: 300 mm (length) x 20 mm (width) x bamboo culm wall thickness.

Biological & 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 [13] with some modification. The test stakes were buried upright completely in the ground. They have installed 200 mm apart within and between rows and were distributed randomly based on randomized complete-block design [14, 15, 16]. The test stakes were exposed to the decay hazard as well as termites. The tests were monitored for 6 months. The stakes were installed during the dry season. The testing site for the field/grave-yard study was located in FRIM grave-yard tests site. The site is located in a lowland area. The site is having hot and humid climate throughout the year with an average daily temperature vary from 21° to 32°C and an 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 tabulated in Table 1 and Table 3. Comparisons were made between green and air-dried samples.

Table 1: Moisture contents of heat treated bamboo at in green and air-dried conditions.

	Treatment duration (min.)	Green bamboo		Air-dried bamboo	
		Before Treatment	After Treatment	Before Treatment	After Treatment
Temperature 140°C	0	72.6	72.6	12.6	12.6
	30	75.3	6.1	12.5	7.2
	60	76.2	5.8	11.9	7.1
	90	71.2	5.7	12.4	6.7
Temperature 180°C	0	72.6	72.6	12.6	12.6
	30	74.5	6.0	12.8	5.2
	60	75.4	5.4	12.6	5.1
	90	76.7	4.8	11.6	4.5
Temperature 220°C	0	72.6	72.6	12.6	12.6
	30	75.5	5.2	12.6	5.0
	60	76.2	5.1	12.9	4.5
	90	74.3	4.1	11.3	3.9

Mean values taken from 5 replicates;
Treatment duration of 0 min. represent the control samples.

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

Main effect MC	Sum of squares	F-Ratio	P-values
Treatment duration	9059.1	17.2	*
Bamboo condition	1799.2	10.3	*

The results obtained in the physical studies show that the heat treatment process can be used to dry bamboo culms [17]. Furthermore, the process took less than 3 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 of bamboo obtained from the heat treatment process is less than 10%. There is no much different 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 [6, 18]. Table 2 shows the ANOVA of MC.

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

	Treatment duration (min.)	BD of green bamboo (kg/m^3)		BD of air-dried bamboo (kg/m^3)	
		Before Treatment	After Treatment	Before Treatment	After Treatment
Temperature	0	660	660	682	682
140°C	30	675	746	587	722
	60	646	750	658	745
	90	639	754	656	753
Temperature	0	660	660	682	682
180°C	30	670	669	583	662
	60	643	674	655	646
	90	638	685	661	678
Temperature	0	662	662	682	682
220°C	30	673	675	584	682
	60	643	678	654	694
	90	641	686	655	688

Mean values taken from 5 replicates; Treatment duration of 0 min. represent the control samples.

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

The main effect in BD	Sum of squares	F-Ratio	P-values
Treatment duration	103590	60.1	*
Bamboo condition	13.2	0.1	ns

There is an increase in the basic density values of samples treated by the heat treatment process [19]. An average increased of 15% in values were obtained for the samples after treatments. The heat applied has somehow managed to alter slightly the bamboo structure or cells [20, 21]. Significant different was observed in the basic density values when various treatment duration was applied [19, 22]. No significant different were noted in the used of green or air-dried bamboo. Table 4 shows the ANOVA of basic density.

Strength Properties

Tables 5, 6 and 7 shows the results of the strength studies conducted on the *B. vulgaris* before and after undergoing the heat treatments process. Comparisons were made between the green and air-dried bamboo.

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Table 5: Bending strength on heat treated bamboo

	Treatment duration (min.)	Density (g/cm²)		MoE (MPa)		MoR (MPa)	
		Green	Air-dried	Green	Air-dried	Green	Air-dried
Temperature	0	990	746	16989	18582	158	174
140°C	30	959	687	16694	17403	136	167
	60	943	676	12944	17084	133	164
	90	925	663	11452	16973	121	145
Temperature	0	990	746	16989	18582	158	174
180°C	30	935	716	14735	16844	135	159
	60	950	687	13451	11746	143	169
	90	956	625	11332	16851	133	152
Temperature	0	909	746	16989	18582	158	174
220°C	30	951	672	15297	16832	130	152
	60	956	683	13424	16748	126	147
	90	935	619	14335	16533	106	132

Mean values taken from 5 replicates; Treatment duration of 0 min. represent the control samples.

The results of the study and statistical analysis conducted on the treated bamboo samples show that the strength within them reduced from their original value [5, 23]. The amounts of the strength reduced are dependent on the amount of heat and duration of the treatment applied [5]. Generally, the higher the temperature and duration applied, the higher will be the strength reduced from the bamboo [24]. There are significant differences in the used 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.

Table 6: Compression strength on heat treated bamboo

	Treatment duration (min.)	Maximum compression (MPa)	
		Green bamboo	Air-dried bamboo
Temperature 140°C	0	53.4	61.9
	30	52.3	60.5
	60	51.9	49.1
	90	51.8	40.3
Temperature 180°C	0	53.4	61.9
	30	51.8	60.3
	60	51.5	46.4
	90	52.6	39.6
Temperature 220°C	0	53.4	61.9
	30	52.8	58.3
	60	51.1	44.8
	90	52.3	38.7

Table 7. Shear strengths on heat treated bamboo

	Treatment duration (min.)	Maximum compression (MPa)	
		Green bamboo	Air-dried bamboo
Temperature 140°C	0	8.9	8.5
	30	7.5	7.4
	60	7.8	6.8
	90	6.7	6.4
Temperature 180°C	0	8.9	8.5
	30	7.5	7.4
	60	7.6	6.7
	90	6.8	6.4
Temperature 220°C	0	8.9	8.5
	30	7.6	7.5
	60	6.7	6.5
	90	7.8	6.3

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

Main effect MOE	Sum of squares	F-Ratio	P-values
Treatment duration	1.2 E8	6.2	*
Bamboo condition	4.2 E7	6.5	*

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

Main effect MOR	Sum of squares	F-Ratio	P-values
Treatment duration	3746.1	29.7	*
Bamboo condition	4730.6	112.4	*

Mean values taken from 5 replicates; Treatment duration of 0 min. represent the control samples.

Durability

The results of the grave-yard test conducted on heat treated bamboo samples placed in ground contact for 12 months are tabulated in Table 10 and Table 11.

Table 10: Loss in the weight of bamboo after 12 months of ground contact tests

	Temperature (ºC) per treatment duration (min.)								
	140/30	140/60	140/90	180/30	180/60	180/90	220/30	220/60	220/90
Initial wt. (g)	6.5	6.6	6.8	6.6	7.2	7.3	5.9	6.1	6.5
Final wt. (g)	4.4	4.8	5.4	4.7	5.6	6.5	5.0	5.5	6.2
Wt. loss (%)	33.6	26.8	19.6	27.9	22.7	10.8	16.2	10.2	4.8

Table 11. Loss in weight of untreated or control after 12 months of grave-yard tests.

	Bamboo	Rubberwood (act as control)
Initial weight (g)	9.1	10.4
Final weight (g)	4.8	6.3
Loss weight (%)	47.8	39.4

Mean values taken from 5 replicates.

In natural forms bamboo has a very low durability against fungi and insects attacked. They deteriorate rapidly by the action of a mixed population of soil microorganisms and insects/termites when placed in contact with soil, especially the young bamboo culms or those that has been insufficiently treated with preservatives [2, 16]. Sufficiently preservatives treated bamboo may still be attacked by fungi and insects 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 [15]. Control samples that are composed of untreated bamboo and rubberwood experienced weight lost of about 48% and 40% respectively for the 6 months ground contact durability tests. The weight lost in the green and air-dried bamboo were reduced once they are treated by the heating process. The lost in weight were reduced from 48% for the untreated bamboo to between 5-34 % depending on the temperature and duration of heat applied. Similar results were obtained by Razak *et al.* [9, 24] in their study on durability of heat treated *Gigantochloa scortechinii* and *Acacia mangium* respectively.

CONCLUSIONS

The heat treatment process can be applied as a mean to accelerate the drying of matured (4-year-old culms and older) bamboo before utilization. Green and air-dried bamboo culms can be dried to an MC of 6-8% within 60 to 180 min. of treatment depending on sizes of the bamboos. Culms of younger age are not recommended for this type of treatment. The basic density of bamboo is improved by the heat treatment application from 630-665 kg/m^3 of the green condition to 740-755 kg/m^3 and 650-682 kg/m^3 of air-dried bamboo to 725-750 kg/m^3 .

The MoE value in the bending strength is reduced between 2 to 35% 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 25% from 158 MPa to 121-136 MPa in green condition and between 4 to 18% from 174 MPa in air-dried condition to 145-167 MPa. The compression strength is reduced in the range between 2 to 32% from 53.4 MPa in green condition to 51.8 - 52.6 MPa and 61.5 MPa air-dried to 40.2 - 60.5 MPa. The shear strength is reduced in the range between 16 to 24% from 8.9 MPa in green condition to 6.8 - 7.4 MPa and between 12 to 26% 8.48 from MPa in air-dried condition to 6.5 - 7.5 MPa.

The heat treatment process greatly enhanced the durability of bamboo. The loss in the weight of bamboo is reduced from 46% for the untreated bamboo to between 5-32 % depending on the temperature and duration of heat applied. Treatment duration of 90 min. was found to produce the most durable bamboo against fungi and insect attacked. This is followed by 60 and 30 min. treatment duration, respectively. 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 strength properties do change much from its original properties

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