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Properties of Oil-Cured Cultivated *Bambusa vulgaris*

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Abstract: The suitability of using an eco-friendly oil curing process was investigated on cultivated *Bambusa vulgaris* bamboo in order to prolong their service life span. *B. vulgaris* was chosen as it is a type of bamboo species that is easy to cultivate and has good physical as well as mechanical properties. Matured bamboo culms of 4 year-old from internodes 5, 6 and 7 in green and air-dried conditions were heat treated. The heat treatment process used palm oil as the heating medium at temperatures of 140, 180 and 220°C for durations of 30, 60 and 90 min. The air-dried culms exhibited overall higher physical, strength and durability properties than the green and untreated culms. The Modulus of Elasticity (MOE) values of heat treated bamboo in bending was reduced by 13 to 42% in green and by 3 to 29% in air-dried conditions. The compression strength were reduced by 18 to 33% in green and by 14 to 27% in air-dried ones. The heat treated bamboo lost from 5 to 34% of their initial weight after undergoing 12 months of ground-contact tests for both green and air-dried conditions.

Key words: Cultivated, *Bambusa vulgaris*, oil-curing process, biodegradation, weight loss, durability

INTRODUCTION

Bamboo is considered as an alternative to future wood. Being a fast growing species, it possesses one of the highest strength properties among woody materials. However, bamboo is susceptible to fungal and insect attack (Liese, 1985; Razak, 1998; Anwar *et al*., 2004). The properties of bamboo will deteriorate rapidly if the material is not treated with preservatives (Liese, 1986; Razak, 1998). The used of preservative in bamboo has long been recognized as necessary and important if they are to be considered for utilization in furniture and construction industry (Razak, 1998; Anwar *et al*., 2004). The used of preservatives however is not always effective as bamboo being a monocot species is not easily treated (Liese, 1986).

An alternative method in treating bamboo by mean of oil-curing process has been studied by several researchers (Leithoff and Peek, 2001; Razak *et al*., 2004a, b, 2005). The initial findings indicated that this method is effective in enhancing the bamboo durability against insects and fungi biodegradation. However, the effectiveness of this process is largely depending on the system used and type of oil that is to be use as the heating medium. Oil with high boiling point is normally preferred.

Several earlier studies on the oil-curing process using diesel and palm oil as heating medium has been carried out by Razak *et al*. (2002 and 2005). The diesel heat-treated bamboo was found to be effective for an indoor usage. This study intends to determine the effect of heating process on some aspects of physical, strength and durability of cultivated bamboo culm.

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MATERIALS AND METHODS

Cultivated *Bamboo vulgaris* or locally known as Buluh Minyak was used in this study. The bamboo culms were harvested from a private plantation plot located near the Kawang Forest Reserve areas in Papar, Sabah, in Malaysia. Thirty-two culms of mature age of 4 year-old were harvested randomly from selected clumps. All culms used in this study possess diameters ranging from 8 to 10 cm. For practical and uniformity in sampling purposes only internodes 5, 6 and 7 were used for the study.

After harvesting, all the culms samples were taken immediately to a wood working workshop in UMS for further process. Two sets of samples were investigated. The first set consistin of bamboo samples in green condition with an average moisture content of 65% and the second samples in air-dried condition with moisture content average 14%.

The oil-curing processes were done using an ordinary stainless steel tank. Palm oil was used as the heating medium as it is organic in nature, readily available and possesses a high boiling point. The palm oil was pour into the tank and heated up using a stove to a temperature of 80°C. Then the bamboo samples were submerged in the heated oil by placing them in a metal cage. The bamboo samples were taken out by batches started with treatment of 140°C with interval of 30, 60 and 90 min of exposure duration. Later was followed by treatment of 180 and 220°C with same duration of time. The technique developed by Razak *et al*. (2002, 2004a and b) was adopted in this study with slight modification to suit for bamboo.

Physical Properties

The method used in this investigation was based on ISO 22157 (Anonymous, 2004). Samples were cut from culms at internodes 6 with dimensions 25×25 mm×culms wall thickness. Five replicates were used in this investigation. They were weighed and dried in an oven at 103±2°C for 48 h until a constant weight was attained. The samples were then cooled for half an hour in dessicators before re-weighing.

Determination of Basic Density

Samples of 10×30 mm×thickness of culms wall were obtained from the middle portion of internodes 6. Five replicates were used in the investigation. The samples were oven dried for 48 h at 103±2°C until a constant weight were attained. The basic density of bamboo was obtained using the values of the bamboo oven dry weight per the bamboo green volume.

Strength Properties

Shear strength, compression parallel to grain and static bending were conducted using a Universal Testing Machine on split bamboo. The preparation of the test samples blocks and methods were made according to ISO 22157 (Anonymous, 2004). All testing blocks were conditioned to 12% moisture content prior to testing. This was performed by placing the test blocks in a conditioning chamber under controlled relative humidity of 55% and temperature at 25°C for a week.

The samples were tested with various sizes depending on type of test; 1) Shear strength parallel to the grain: 40×20 mm×bamboo culms wall thickness. 2) Compression strength parallel to the grain: 40 mm (height)×20 mm (width)×bamboo culms wall thickness. 3) Static bending: 300 mm (length) ×20 mm (width)×bamboo culms wall thickness. Test samples were obtained from the middle portion of internodes 6.

Durability

Sample size of 100×10 mm×culms wall thickness and were chosen from internodes 5 and 7. Durability against biodeterioration on field tests were conducted based on EN 252 (Anonymous, 1989) with some modifications.

The test stakes were buried upright completely in the ground. They were installed 200 mm apart within and between rows and were distributed randomly based on randomized complete-block design. The tests were monitored for a period of 12 months. The stakes were installed during the dry season. The site is located in UMS Nursery with lowland area of 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 samples were based on the percentage of weight loss of each stake.

RESULTS AND DISCUSSION

In general, *Bamboo vulgaris* culms were able to be treated using palm oil at high temperature with no evident of defect. The color appearance of treated stakes varied considerably from light yellowish brown to dark brown.

Moisture content and basic density before and after treatments are represented in Table 1 and 2. The final moisture content for green and air dried samples ranged between 4 to 7%. Table 3 shows the ANOVA of moisture content and basic density. There is a significant different in the final moisture content between green, air-dried bamboo and durations of application during the oil-curing process. The

Table 1: Mean Moisture Contents (MC) heat treated bamboo at 140, 180 and 220°C of green and air dried bamboo

Temperature and duration	Green bamboo			Air-dried bamboo		
	Before (%)	After (%)	Percentage change	Before (%)	After (%)	Percentage change
Control	72.6	-	0.0	12.6	-	0.0
140°C, 30 min	75.3	6.1	91.9	12.5	7.2	42.4
140°C, 60 min	76.2	5.8	92.4	11.9	7.1	40.3
140°C, 90 min	71.2	5.7	92.0	12.4	6.7	50.0
180°C, 30 min	74.5	6.0	91.9	12.8	5.2	59.4
180°C, 60 min	75.4	5.4	92.8	12.6	5.1	59.5
180°C, 90 min	76.7	4.8	93.7	11.6	4.5	61.2
220°C, 30 min	75.5	5.2	93.1	12.6	5.0	60.3
220°C, 60 min	76.2	5.1	93.3	12.9	4.5	65.1
220°C, 90 min	74.3	4.1	94.5	11.3	3.9	65.5

No. of replicates = 5

Table 2: Mean Basic Density (BD) of heat treated bamboo of green and dried bamboo

Temperature and duration	Green bamboo			Air-dried bamboo		
	Before (%)	After (%)	Percentage change	Before (%)	After (%)	Percentage change
Control	660	-	0.0	682	-	0.00
140°C, 30 min	675	746	10.5	587	722	23.00
140°C, 60 min	646	750	16.1	658	745	13.20
140°C, 90 min	639	754	18.0	656	753	14.80
180°C, 30 min	670	669	0.1	583	662	13.60
180°C, 60 min	643	674	4.8	655	646	1.37
180°C, 90 min	638	685	7.4	661	678	2.60
220°C, 30 min	673	675	0.3	584	682	16.80
220°C, 60 min	643	678	5.4	654	694	6.10
220°C, 90 min	641	686	7.0	655	688	5.00

No. of replicates = 5

Table 3: ANOVA for moisture content and basic density of heat treated bamboo

Source of variation	F-value and statistical significance	
	Treatment duration	Bamboo condition
Moisture content	17.2*	10.3*
Basic density	60.1*	0.1^{ns}

ns: Not significant; *Significant at p<0.05; **Highly significant at p<0.01; Bamboo condition is referred to bamboo at green or air-dried condition; Treatment duration is referred to exposure period of 30, 60 or 90 min with temperature at 140, 180 or 220°C green samples loss about 91.9 to 94.5% moisture content. These may probably due to ease of moisture flow out from the fresh bamboo. Air-dried bamboos loss between 42.4 to 65.5% for the whole oil-curing duration applied. Air-dried bamboo culms have undergone drying process of which may cause low moisture gradient and more energy need to be absorbed.

There were an increased in the basic densities between 0.1 to 23% of the bamboo after undergoing the oil-curing. The additional increase in density might be due to some of the oil that able to penetrate in the cell wall and influence the total weight of the sample. Significant different were observed in the basic density values when various treatment temperatures and durations were applied.

The strength properties of bamboo before and after treatments are shown in Table 4 and 5. The MOE value in the bending strength changed from 6.3 to 33.3% for green condition and 4.7 to 15.3% for air-dried. Whilst the MOR value was reduced between 9.5 to 32.9% for, green condition and 4.0 to 24.1% for air-dried condition.

Statistical analysis conducted on the treated bamboo samples shows that the strength for both MOR and MOE was significantly (at $p<0.05$) affected by treatment duration and bamboo condition. Air-dried bamboo exhibits small loss in MOE and MOR while green culms shows higher loss of MOE and MOR when subjected to higher and longer duration in heating process (Table 6).

Table 4: Mean MOE bending strength on heat treated bamboo

		Density (g cm^{-2})		MOE (MPa)			
Temperature (°C)	Duration (min)	Green bamboo	Air-dried bamboo	Green bamboo	Percentage change	Air-dried bamboo	Percentage change
Control	-	990	746	16989	-	18582	-
140	30	959	687	16694	4.7	17403	6.3
140	60	943	676	12944	9.9	17084	8.1
140	90	925	663	11452	13.3	16973	8.7
180	30	935	716	14735	15.6	16844	9.3
180	60	950	687	13451	20.8	11746	9.4
180	90	956	625	11332	20.9	16851	9.4
220	30	951	672	15297	23.8	16832	9.9
220	60	956	683	13424	32.6	16748	11.0
220	90	935	619	14335	33.3	16533	15.3

No. of replicates = 5

Table 5: Mean MOR bending strength on heat treated bamboo

		Density (g cm^{-2})		MOR (MPa)			
Temperature (°C)	Duration (min)	Green bamboo	Air-dried bamboo	Green bamboo	Percentage change	Air-dried bamboo	Percentage change
Control		990	158	174	-	746	-
140	30	959	136	167	9.5	687	4.0
140	60	943	133	164	13.9	676	5.8
140	90	925	121	145	14.6	663	6.9
180	30	935	135	159	15.8	716	8.1
180	60	950	143	169	15.8	687	8.6
180	90	956	133	152	17.7	625	12.6
220	30	951	130	152	20.3	672	15.5
220	60	956	126	147	23.4	683	16.7
220	90	935	106	132	32.9	619	24.1

No. of replicates = 5

Table 6: ANOVA for MOR and MOE heat treated bamboo at 140, 180 and 220°C for 30, 60 and 90 min

	F-value and statistical significance	
Source of variation	Treatment duration	Bamboo condition
MOR	29.7*	112.4*
MOE	6.2*	6.5*

ns: Not significant; *Significant at $p<0.05$; **Highly significant at $p<0.01$; Bamboo condition is referred to bamboo at green or air-dried condition; Treatment duration is referred to exposure period of 30, 60 or 90 min with temperature at 140, 180 or 220°C

Table 7: Mean of compression and shear strength on heat treated bamboo

	Maximum compression (MPa)							
	Compression/to grain				Shear/to grain			
Temperature and duration	Green	Percentage change	Air-dried	Percentage change	Green	Percentage change	Air-dried	Percentage change
Control	53.4	0.0	61.9	0.0	8.5	0.0	8.9	0.0
140°C, 30 min	52.8	1.1	60.5	2.3	7.8	12.4	7.5	11.8
140°C, 60 min	52.6	1.5	60.3	2.6	7.8	12.4	7.4	12.9
140°C, 90 min	52.3	2.1	58.3	5.8	7.6	14.6	7.4	12.9
180°C, 30 min	52.3	2.1	49.1	20.7	7.6	14.6	6.8	20.0
180°C, 60 min	51.9	2.8	46.4	25.0	7.5	15.7	6.7	21.2
180°C, 90 min	51.8	2.8	44.8	27.6	7.5	15.7	6.5	23.5
220°C, 30 min	51.8	3.0	40.3	34.9	6.8	23.6	6.4	24.7
220°C, 60 min	51.5	3.6	39.6	36.0	6.7	24.7	6.4	24.7
220°C, 90 min	51.1	4.3	38.7	37.5	6.7	24.7	6.3	25.9

No. of replicates = 5

Table 8: Mean weight loss of bamboo after a 12 months of ground contact tests

Temperature (°C)	Duration (min)	Initial wt. (g)	Final wt. (g)	Weight loss (%)
Rubber wood	-	10.4	6.3	39.4
Control bamboo	-	9.1	4.8	47.8
140	30	6.5	4.4	33.6
140	60	6.6	4.7	27.9
140	90	6.6	4.8	26.8
180	30	7.2	5.6	22.7
180	60	6.8	5.4	19.6
180	90	5.9	5.0	16.2
220	30	7.3	6.5	10.8
220	60	6.1	5.5	10.2
220	90	6.5	6.2	4.8

No. of replicates = 5

The compression strength is reduced in the ranged between 1.1 to 4.3% in a green condition while for air dry between 2.3 to 37.5% (Table 7). The shear strength is reduced in the ranged between 12.4 to 24.7% for green and between 11.8 to 25.9% for air-dried. Both, condition show almost same percentage loss. These reductions in strength after undergoing the oil-curing process were slightly better that those bamboo that were treated with preservatives (Razak, 1998). Razak (1998) found that bamboo *Gigantochloa scortechinii* experienced the strength reduction between 12 to 42% after undergoing preservatives treatment.

Bamboos in natural forms are considered to be of low durability. When placed in contact with the soils they usually deteriorate rapidly by the action of a mixed population of soil microorganisms. Bamboos treated with a preservative may still be colonized by fungi and termites although decay and the attack rates may be slower.

The results of the ground contact test conducted on heat treated bamboo samples for a 12 months period are shown in Table 8. Untreated bamboo and rubber wood (control) experienced weight loss of about 48 and 40%, respectively for the 12 months ground contact durability tests. The average weight losses of heat treated bamboo were found to vary from 5 to 34%. Similar results were obtained by Razak *et al*. (2004a and b) in their study on durability of heat treated *Gigantochloa scortechinii*.

Treatment duration of 90 min at 220°C shows the most durable bamboo against fungi and termites attacked. This is probably because at this temperature and duration the bamboo physical and strength properties changed much from its original properties. These were follows by 220°C at 60 min and 180°C at 90 min.

CONCLUSION

- Air-dried bamboos possess better properties compared to green bamboo when subjected to an oil-curing process.
- Temperatures, duration of the oil-curing process and the initial condition of the bamboo influences their properties after treatment.
- An oil-curing process greatly enhanced durability of the bamboo.
- The reduction in strength of the bamboo after undergoing oil-curing process is acceptable and comparably to bamboo treated with preservatives.

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