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The Effects of Crude Oil Boiling Treatment on Physical Properties of *Bambusa vulgaris var. Striata* (Buluh Gading)

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ABSTRACT

Bamboo is a material formed from organic components such as cellulose, hemicellulose and lignin. It is often attacked by biodegradation agents due to the presence of the organic components which affect the physical properties and durability of the bamboo, hence limiting its utilization as an input for production of value-added products. Preservation treatment for lignocellulosic material is not an exception. Boiling treatment was found to be one of the eco-friendly methods to preserve the material. A research was undertaken to study the effects of crude oil boiling treatment on the physical properties and durability of *Bambusa vulgaris var. Striata* (Buluh Gading) against biodegradation agents. Bamboo strips were boil treated in palm oil at 160-200^{0}C for 10 minutes. The untreated and treated strips were tested using physical tests such as relative density, moisture content, swelling and shrinkage. The durability of the strips was also tested using weathering test, where they were exposed to the surrounding for 3 months. The results showed that the boiling treatments improved the dimensional stability of the bamboo and its durability against fungi and boring insects. Meanwhile, the treatments at different temperatures significantly affected the relative density, moisture content, durability, swelling and shrinkage of the bamboo. The moisture content, swelling and shrinkage dropped with regards to the increase in the treatment temperature. The reductions were 18.6% – 2.38%, 16.28% - 7.51%, and 20.72% - 10.94, respectively. The relative density increased to 0.89% when the treatment temperature increased to 160^{0}C, but it decreased from 0.89 to 0.74% as the temperature was increased to 200^{0}C. The durability was assessed in term of percentage of weight loss (%). A smaller

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percentage of the weight loss indicates a better durability. Thus, the treatments were effective to reduce the percentage of weight loss for the above-ground and in-ground graveyard tests. The reductions were found to range from 28.14% - 9.92% and 28.14 – 3.39%, respectively. This study has indicated that bamboo becomes less hygroscopic and more durable when it is exposed to higher temperatures.

Keywords: Bamboo treatment, physical properties, moisture content, swelling and shrinkage, graveyard tests

INTRODUCTION

Bamboo is a type of grass which is commonly grown in Asia. It has a hard, woody and hollow stem. Bamboo is a fast-growing grass even in dense conditions, and matures early (Zhang *et al.,* 2002); thus, the plant is considered as one of the best renewal resources in the world (Anon, 2001). Nowadays, the world is facing decrement of forest resources due to its greater demand compared to its supply; hence, development and exploitation of bamboo are important as well. The properties of bamboo are different that those of timber and for this reason, the readily available processing methods for timber cannot be applied for bamboo. This is why it is essential to create treatment and processing methods that are exclusively for bamboos (Zhang *et al.,* 2002).

Bamboo is a lignocellulosic material. It is susceptible to attacks by decay fungi and boring insects (see Fig.1). In order to reduce the attacks of the biodegradation agents, preservation of bamboo should be conducted. Preservation of bamboo refers to the removal of starch and lignin the plant, as well as to degrade hemicellulose which is the favourite component of fungi and insects to survive (Zhao *et al*., 2010). Even though preservation of bamboos using conventional treatment has been extensively studied, the results are rather discouraging due to the impermeability of the materials (Liese, 1998; Zaidon *et al*., 2007). Therefore, oil treatment was introduced as one of the effective ways to preserve bamboo (Rafidah *et al*., 2010; Razak *et al*., 2004).

Oil treatment can be done using vegetable oils with high boiling point, such as palm oil and hemp oil (Razak *et al*., 2004) because oil can facilitates fast and uniform heat transfer, and hence provide a uniform preservation (Manalo & Acda, 2009). The technique involves immersion of bamboo in an oil bath at different temperatures and durations (Rafidah *et al*., 2010; Razak *et al*., 2004; Manado & Acda, 2009; Zhao *et al*., 2010; Razak *et al*., 2005). Therefore, this paper reports the efficacy of hot oil treatment on physical properties and durability of *Bambusa vulgaris var Striata* when exposed to weathering for 3 months.

MATERIAL AND METHODS

At the age of 3 to 4 years old, *Bambusa vulgaris var Striata* were harvested randomly from their natural stands at the riverside near Kingfisher Residential Area, Kota Kinabalu, Sabah. At this age, bamboo culms were selected for the experiment because they started to mature (Razak *et*

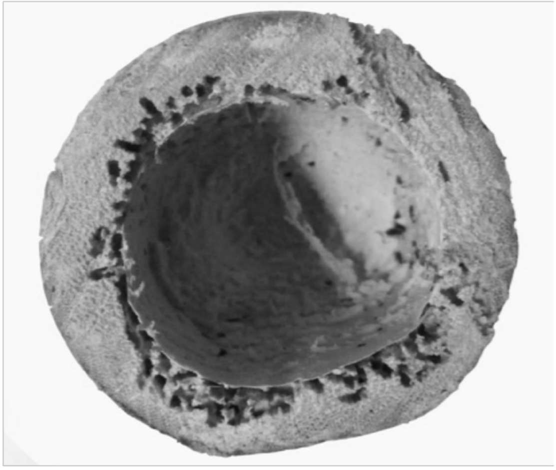

Fig.1: Entrance holes by *Dinoderus minutus* at the cut end of felled culms

al., 2005). A total of 10 culms (from 4th and 6th internodes) were utilised from the fell bamboos. The average moisture content of the green culms was 60%. Meanwhile, crude palm oil was used as treatment media.

Heat Boiling Treatment Processing Using Crude Oil

The treatment temperatures used in this study were 160ºC, 180ºC and 200ºC. The treatments were conducted separately based on the treatment temperature. The fresh bamboo culms were cut into 40 strips with a size of 20 cm long x 5 cm wide (l x w). The strips were divided into 4 groups (30 samples for the treatments and 10 samples as the untreated), as shown in Fig.2. The initial weight of each strip was recorded prior to the treatments. The treatment media were heated in a tank to a temperature of 80ºC. The bamboo strips were then submerged in the heated oil for 10 minutes. It is crucial to make sure that the oil temperature is 80ºC before immersing the bamboo strips to prevent the oil from excessively penetrating into the strips and affecting the evaluations of the physical properties (Razak *et al*., 2005).

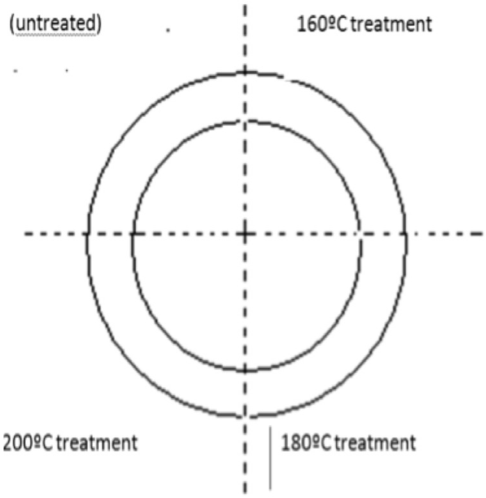

Fig.2: Bamboo culms were divided into four parts (1 part as the untreated, 3 parts for the treatments)

The bamboo strips were further heated until the crude oil temperature achieved the target temperatures (160ºC, 180ºC, or

200ºC). Once the assigned temperatures had attained, the bamboo strips were removed from the heating media, while the surfaces of the strips were blotted using a piece of cloth. Then, the treated strips were dried in an oven which was set with (103) ±2 ºC until a constant weight was attained.

Graveyard Tests

The effects were assessed by weight loss of the bamboo strips in accordance with ISO EN252 (Anon, 1990). The initial weight (W_i) of each strip (untreated or treated) was measured before the tests were conducted. The tests were carried out at a nursery in Universiti Malaysia Sabah. The treated strips were cut into smaller size (1cm x 10 cm) before they were oven-dried. Sixty samples of the same size were reserved for the graveyard tests. The above-ground graveyard test was performed by arranging the treated and untreated strips on the soil at the nursery. As for the in-ground graveyard test, half of the samples length was buried in the soil. Gaps of three centimetre wide should be established between each strip. Thirty strips were utilized for each of the graveyard tests. The bamboo strips were left at the site for 75 days. After 75 days, they were taken to the laboratory, cleaned and subsequently oven dried at 105 ± 2°C until a constant weight was reached before the final weight (W_f) was recorded. The observations of colour change, white rot, brown rot, as well as insect attacks on the samples were also conducted.

Assessments of the Physical Properties

The physical and mechanical properties assessments were done in accordance with ISO 22157-1:2004 (Anon, 2004). The parameters for the physical properties assessed were moisture content, basic density, percentage of swelling after the treatment and percentage of shrinkage at the oven temperature. Ten samples were utilized for each test. The relative density (RD) is the weight of the sample after conditioning at room conditions (Wo) divided by the weight of an equal volume of water (Wwd), as determined using water immersion method in accordance with ASTM D2395-93:1997 (Anon, 1997) (Equation 1):

$$\text{RD (gcm}^{-3}) = \frac{Wo}{Wwd} \qquad \text{Equation 1}$$

The moisture content (MC) test was conducted in accordance with ASTM D4442-07 (Anon, 2007). The samples were conditioned in a conditioning chamber at a temperature of 25±2 ºC and a relative humidity of 65 ± 2% before their initial weights (W_1), as well as dimensions were assessed. Then, all the samples were oven dried for 24 hours at 103 ± 2ºC. After oven drying, the samples were cooled in desiccators and their final weights (W_2) were measured. The data were used to calculate the moisture content using the following formula (Equation 2):

$$\text{MC} = ((W1 - W2) / W2) \times 100\% \qquad \text{Equation 2}$$

Shrinkage and Swelling

The swelling test was performed to study the degree of swelling experienced by the samples after the treatment. The percentage of swelling (S) was calculated using Equation 3, as follows:

$$\text{Sw } (\%) = V_1 - V_2 \ / V_2 \times 100\,\%$$

Equation 3

Where, V_1 is the volume of the samples before the treatment and V_2 is the volume of the samples after the treatment. As for shrinkage (Sh), the test was performed to assess the percentage of the samples' shrinkage after being oven-dried. The formula is as follows:

$$\text{Sh } (\%) = Vol_1 - Vol_2 \ / Vol_1 \times 100\,\%$$

Equation 4

Where, Vol_1 is the volume of samples before oven dried and Vol_2 is the volume of samples after oven dried at 103 ºC±2 ºC for 24 h. The statistical analysis was carried out using the analysis of variance (ANOVA) to determine the differences in the properties between the treatment levels. The untreated samples were used for comparison purposes.

RESULTS AND DISCUSSIONS

Table 1 showed that moisture content (MC), relative density (RD), swelling (Sw), shrinkage (Sh), in-ground graveyard (IGGY) and above-ground graveyard (AGGY) tests were significantly affected by treatment temperatures. In particular, the colour of the bamboo was affected by the temperature of the treatment. The treatments changed the colour of the bamboo from light yellow to dark brown with the increase of the treatment temperature from 160°C to 180°C. The bamboo experienced slight burnt when the treatment temperature was increased to 200°C.

Graveyard Tests

The percentages of the weight loss for the samples tested with above and in-ground graveyard tests are summarized in Fig.3. For the above-ground graveyard test, the results revealed that with the increase in the treatment temperature, the weight loss of the samples decreased. Meanwhile, the mean weight loss for the untreated samples, 160°C, 180°C and 200°C-treated samples was 28.14%, 11.03%, 10.29% and 9.92%, respectively. A similar pattern of the results was recorded from the samples of the in-ground graveyard test. The mean weight

TABLE 1
The ANOVA of the heat-treated strips for the effects of different temperatures on the properties of *Bambusa vulgaris var. Striata*

Property	MC	RD	Sw	Sh	IGGY	AGGY
	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)	Temp. (°C)
F-value	80.07	16.31	7.03	6.77	20.25	26.77
P-value	0.0	0.0	0.0008	0.001	0.0	0.0
Significant level	*	*	*	*	*	*

*=significant at p≤0.05; Temp=temperature; MC=moisture content, D=density, Sw=swelling test; Sh=shrinkage test; IGGY=In-ground graveyard test; AGGY=Above-ground graveyard test

loss for the untreated samples was 28.14%, whereas those treated at the temperatures of 60°C, 180°C and 200°C were 10.21%, 7.55% and 3.39%, respectively. Damages by weathering in bamboo were the peeling off of the outermost layer and the vertical checks on the surface.

The decrease of weight loss indicates that the treatment temperature has improved the durability of the samples. This is expected due to the removal of starch, since fungus or pest depends on starch as their food to survive (Rafidah *et al*., 2010). Starch is an important factor for borer infestation and will infest as soon as the culm is felled, which is related to the presence of starch in the parenchyma (Liese, 1998). In addition, the treatment has helped to reduce white rot attack by removal of lignin. White rot consumes cellulose and permits lignin to live. The attack caused the colour of the samples to appear lighter than the original colour (i.e. the colour before they were tested with the in-and above-ground graveyard tests) due to the degradation of lignin by lignin-degrading enzymes produced by white rot (Vaithanomsat *et al*., 2010; Zaidon *et al*.,2000).

Moisture Content

The results for moisture content after treatment are given in Fig.4. The moisture content dropped sharply (more than 100%) when the treatment was applied. The mean moisture content values for the untreated and the samples treated at the temperatures of 160°C to 200°C were 18.6%, 3.55%, 3.43% and 2.38%, respectively.

The results showed that the treatment was effective in eliminating moisture from bamboo. Water elimination is essential to improve durability as decay-causing fungi are generally attracted to lignocellulosic materials that have high moisture content. Decay fungi work best when there are moisture (water), oxygen, and food (lignin, starch and cellulose) to survive (Acaron *et al*., 2010). The attack has been found to be more severe if the moisture content is between 27% to 30%, the condition which allows the spores of the fungi to germinate and develop, and hence causing rotting

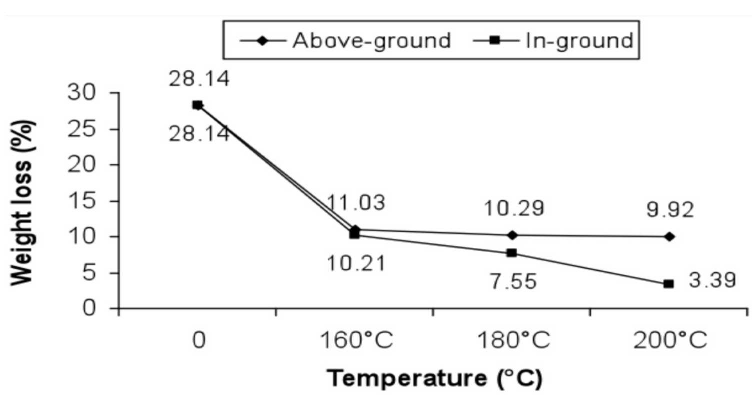

Fig.3: The Graveyard test on the relationship between weight loss and treatment temperature

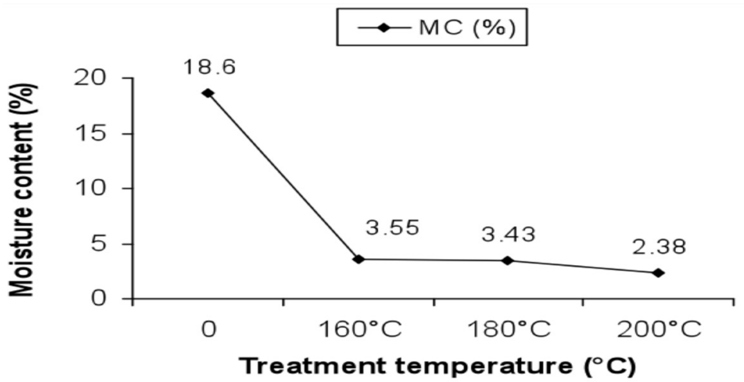

Fig.4: The Graveyard test between treatment temperature and percentage of moisture content

effect (Acaron *et al*., 2010). A high moisture content also attracts insects such as termites (Cowley, 2010; Smith, 2010) and beetles (Koehler & Oi, 2004) which can cause worse destructive effects.

Relative Density

The effects of the treatment temperature on the relative density of *Bambusa vulgaris var. Striata* are shown in Fig.5. It is shown that the relative density values are rather inconsistent between the different treatment temperatures. The control samples exhibited lower relative density value as compared to the ones that were treated at 160°C and 180°C. The samples treated at 200°C presented the lowest mean relative density value. The mean relative density value for the control samples was 0.823gcm^{-3}. Meanwhile, the mean relative density values for the treated samples tested at 160°C, 180°C and 200°C were 0.89 gcm^{-3}, 0.842 gcm^{-3} and 0.74 gcm^{-3}, respectively. The reductions of relative density values are usually related to the degradation of celluloses and hemicelluloses (Rafidah *et al*., 2010). The results showed that the degradation happened when the temperature was increased to 180°C. A further degradation was observed when the temperature was 200°C.

Swelling and Shrinkage

Fig.6 shows the swelling and shrinkage behaviours on the treated and untreated samples. The mean percentage of swelling for the untreated and the samples treated at 160°C 180°C 200°C was 16.28%, 6.29%, 7.64%, and 7.51%, respectively. Higher percentages of shrinkage [after oven dried] were documented, and these were 20.72%, 19.97%, 14.62% and 10.94%, respectively. Greater percentage of shrinkage compared to the percentage of swelling represents the effectiveness of the treatment on moisture elimination.

The results are similar the findings obtained for the moisture content which have revealed higher treatment temperature contributes to lower moisture content. The lower percentage of swelling also indicates that the boiling treatment degrades

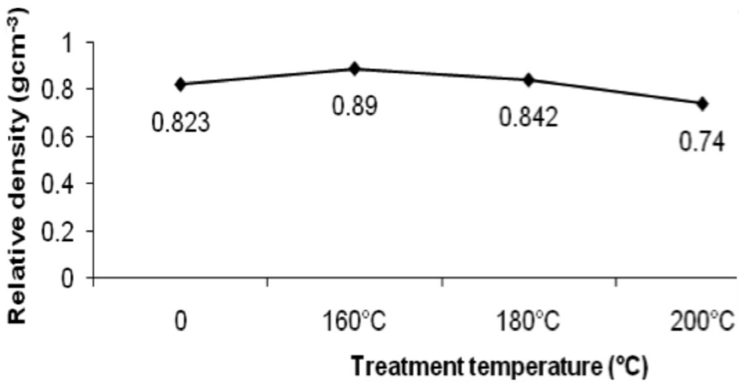

Fig.5: The Graveyard test between treatment temperatures and relative density

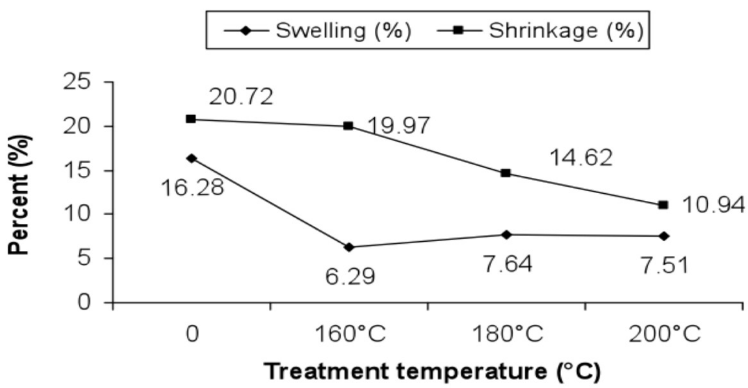

Fig.6: The Graveyard test on the percentages of swelling and shrinkage in relation to treatment temperature

hemicelluloses and modifies cellulose groups, and hence reduces the ability of the bamboo to absorb water (Zhao *et al*., 2010; Rafidah *et al*., 2010; Razak *et al*., 2004) after the treatment. The penetration of oil into the bamboo was also expected to have assisted in minimizing the absorption of water. Razak *et al.* (2005) have proven that palm oil penetration into bamboo cells happened during boiling treatment. It was proven by looking at the presence of palm oil between bamboo cells which was revealed through scanning electron microscopic images obtained from the project (Razak *et al.,* 2005).

CONCLUSIONS

Boiling treatment using crude palm oil was found to be effective in enhancing durability of bamboo against agents of bio-degradation such as insects and fungi. Similarly, treatment temperature has been shown to give significant effects to the increase of dimensional stability of the bamboo by removing moisture and minimizing hygroscopicity. The treatment media is biodegradable and eco-friendly. The treatment can be used for bamboo and solid wood. Apparently, the advantages that the treatment has can give benefits to managers of wood-based industries who are searching for good preservation treatment. The treatment media is readily available at lower or more affordable price and requires minimum energy contribution, which can be very profitable for the managers. However, continual improvements on the treatment can be made to suit with the production processes which are normally practised in the industry. On-site observations or consultations still need to be done to achieve this.

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