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Effect of high temperature treatment on dimensional stability and bonding quality of bamboo strips

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Abstract: A study was undertaken to determine the effect of high temperature curing on dimensional stability and bonding quality of bamboo strips (*Gigantochloa scortechinii* and *G. brang*). Strips with epidermis removed were subjected to high temperature conditions using palm oil as heating medium. The temperatures applied were 140, 160 and 180°C for durations of 30, 60 and 120 min. The treatment improved the dimensional stability and reduced the moisture absorption by bamboos strips. Anti-swelling efficiency (ASE) values increased as the durations of treatment increased irrespective of the treatment temperature. The best treatment condition for *G. scortechinii* to achieve maximum ASE value (85.6%) was 180°C and 120 min while for *G. brang*, the maximum ASE value (91.7%) could be attained with treatment condition of 180°C and 60 min. In general, the high temperature treatment significantly reduced the shear strength of the bamboo laminates. Between the two bamboo species, the reduction in shear strength was more pronounced in *G. scortechinii* than in *G. brang*. The optimum oil treatment condition for *G. scortechinii* in order to meet the minimum standard requirement of glue bond quality for plywood was 160°C and 30 min, while for *G. brang* it was 180°C and 60 min.

Key words: Gigantochloa scortechinii, Gigantochloa brang, oil-treatment, anti-swelling efficiency, shear.

INTRODUCTION

Bamboo is well known for its versatile use and has been getting attention as a substitution material for wood. Like other lignocellulosic material, bamboo is susceptible to fungal and insect damage, dimensionally unstable and hygroscopic (Liese, 1985a; Anwar *et al.*, 2005a; Hamdan *et al.*, 2007). Bamboo deteriorates rapidly if the material is not treated with preservatives (Liese, 1985a). Low durability is the major limitation of bamboo as a building material and thus it is often considered only for temporary uses (Liese and Kumar, 2003). In this regard the use of preservative treatment has been recognized important for utilization of bamboo for furniture and

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construction purposes. Nevertheless, the use of preservatives is not always effective as bamboo is not easily treatable (Liese, 1985b).

One of the potential non-chemical treatment methods is oil curing at high temperature. This method has proved to be effective in protecting bamboo from insect and fungal degradation (Leithoff and Peek, 2001). The type of oil and boiling point of the heating medium determine the effectiveness of this treatment. Razak *et al.* (2004) found that tropical bamboo cured using palm oil attains high resistance against insects and fungi, but the strength properties are significantly reduced. The strength reduction is found to be very much dependent on the temperature and duration of the treatment. It is also worth investigating if any other properties such as dimensional stability and bonding quality of bamboo are also affected by this treatment.

The objective of this study was to evaluate the effect of oil curing treatment on dimensional stability and bonding quality of bamboo strips. Two common tropical bamboo species, namely *Gigantochloa scortechinii* and *G. brang*, were chosen for the study.

MATERIALS AND METHODS

Three-year-old culms of *G. scortechinii* (Buluh Semantan) and *G. brang* (Buluh Brang) were used in this study. Internodes with a minimum wall thickness of 7 mm were cut from the culms to ensure obtaining 4 mm thick strips after final dressing. The heating medium used was crude palm oil with boiling point more than 200 °C. Using a hand splitter, the bamboo culms were split into 20 mm wide, 150 mm long strips. The epidermis and inner layers of the strips were removed and the strips were dressed into 4 mm × 20 mm × 1500 mm. The strips were then air dried to approximately 40 per cent moisture content prior to cutting them into 150 mm long samples. These samples were then randomly assigned into seven groups (6 for treatments and one for untreated control). Each group consisted of 30 replicates. For dimensional stability evaluation, the samples were cut into two end-matched pieces with the first half as control and the other as treated sample.

Each sample group was submerged in the heated oil in a thermostat-controlled oil bath. Palm oil was used as the heating medium as it is organic in nature, easily available and has high boiling point. Samples were heated out at 140, 160 and 180 °C for 30, 60 and 120 min and were taken out.

Evaluation of dimensional stability

End-matched samples from treated and untreated strips were selected for dimensional stability test. They were cut into 4 mm × 20 mm × 20 mm specimens. The specimens were placed in a forced-circulation oven maintained at 35±2 °C for 3 days followed by oven drying at 102±3 °C until they attained constant weight. The oven-dry weight and dimensions were determined. Subsequently, the specimens were placed above water level in a dessiccator at room temperature (25±2 °C) until the weight of the specimens became constant. The humidity created in the dessiccator was 95±2 per cent. The weight and dimensions of the wet specimens were again determined. The dimension was measured at the same point where the first measurement was made. These values were used to calculate the moisture excluding efficiency (MEE) and anti-swelling efficiency (ASE) (Rowell and Youngs, 1981).

Evaluation of bonding quality of treated bamboo strips

Before the treated strips were evaluated for their bonding quality, both the buffering capacity and wettability of the treated materials were first determined. For buffering capacity evaluation, treated and untreated strips were ground to pass through a 53 μm mesh sieve. The aqueous bamboo extract was prepared by refluxing 10 g ground bamboo in 100 ml distilled water for 1 h. After refluxing, the mixture was filtered using filtering glass crucible with an aspirator vacuum. The distillate was diluted to 250 ml and cooled to room temperature before titration. The solution was then titrated against 0.01N hydrochloric acid until pH 3 was obtained. The titration was repeated using 0.01N sodium hydroxide till pH 11 was reached. The pH value was recorded at every 5 ml addition during titration. The experiment was done in triplicate to obtain values with less than 5 per cent deviation.

A microscope with an attached camera was used to observe the contact angle of treated and untreated strips which was first conditioned at 20±2 °C and 65±2 per cent RH for one week. One droplet of distilled water was dropped onto the surface of the strip. The angle made between the droplet and the bamboo surface, the contact angle, was measured after two seconds. This procedure was repeated using upper and lower surfaces of the strips.

Gluing of bamboo strips

Gluing study was carried out on 150 mm × 20 mm × 4 mm treated and untreated strips. The MC of the strips was maintained at 12 per cent. Phenol formaldehyde (PF) was used to laminate the bamboo strips. This adhesive was supplied by a local manufacturer and was formulated specifically for bonding bamboo.

Treated and untreated strips were glued separately parallel to each other to produce 3-ply laminates. The glue spread was 230 g/m^2 single glue line. Immediately after glue spreading, the laminate was left for assembling for 5 min and was placed between two metal plates and cold pressed at 10 kg/cm^2 for 15 min at room temperature. After pre-pressing, laminates were hot pressed for 7 min at 140 °C and 14 kg/cm^2. Laminated bamboo was conditioned at 20±2 °C and 65±2 per cent relative humidity in a conditioning room prior to testing (EMC = 12%).

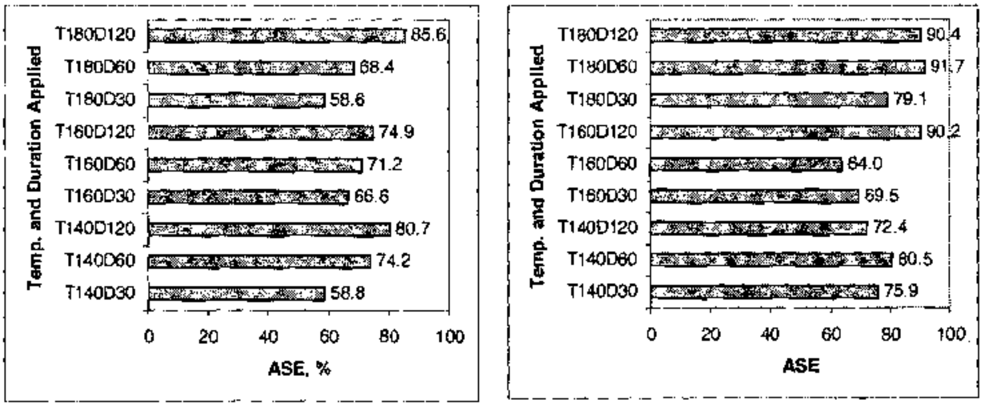
A plywood shear test was conducted on 25 mm × 25 mm × 100 mm sheared area in accordance with British Standard BS 6566 (BS, 1986). Six specimens from each treatment group were tested using Universal Testing Machine (INSTRON 50 KW) with a crosshead speed at 2.5 mm/min. Upon completion of the test, the specimens were examined for the estimated percentage of bamboo failure along the glue line. The failure of individual specimens was recorded to an accuracy of 10 per cent and the average shear strength and wood failure were compared with the standard requirement.

RESULTS AND DISCUSSION

Effect of oil treatment on dimensional stability

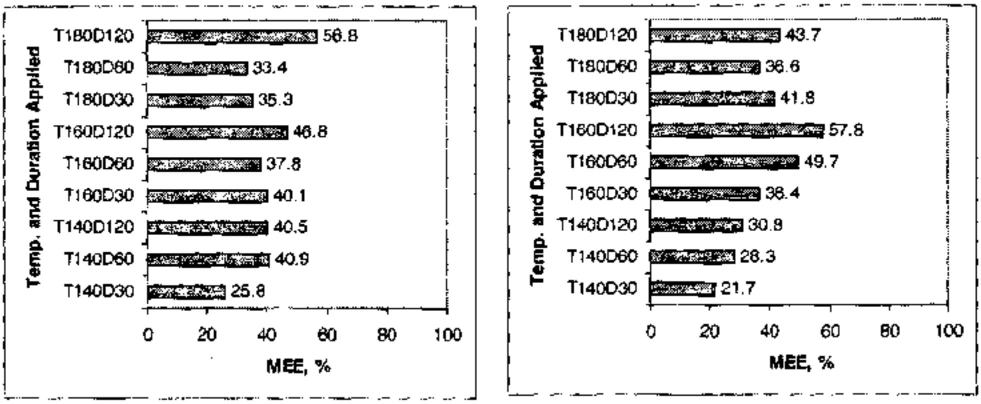
Results of anti-swelling efficiency (ASE) and moisture excluding efficiency (MEE) are shown in Figures 1 and 2. Oil curing treatment improved the dimensional stability and reduced the moisture absorption of bamboo strips. The ASE values ranged from 58.6 to 85.6 per cent for *G. scortechinii* and 64.0 to 90.4 per cent for *G. brang*. The reduction in water absorption was in the range of 25.8 to 56.8 per cent and 21.7 to 57.8 per cent for *G. scortechinii* and *G. brang*, respectively. The ASE and MEE values indicate that the high temperature used in the treatment had successfully reduced the amount of hydroxyl groups in the cellulose chains leading to a lower moisture uptake; consequently the swelling reduced. The treatment also played an important role in imparting dimensional stability. For *G. scortechinii*, (Fig. 1), the duration of treatment was more important than temperature in imparting dimensional stability. At a specific temperature, the ASE values increased as the duration of the treatment increased. The best curing condition for this bamboo was T180D120 (180 °C and 120 min) where an average ASE value of 85.6 per cent was achieved. However, for *G. brang*, there was no specific trend in ASE with treatment duration when the bamboo was heated below 160 °C. At 180 °C, the longer the duration of treatment, the higher was the ASE value. The maximum ASE values of more than 90 per cent were attained at treatment conditions of T160D120, T180D60 and T180D120. The ASE value found in the treated bamboo was very much higher compared to wood treated at high temperatures. Rowell and Youngs (1981) found that heating of wood at 350 °C in the absence of oxygen for a short time resulted in 40 per cent reduction in swelling. Lower temperatures for longer periods of time also produced similar results. The difference was probably due to the dual effects caused by the oil heating treatment on bamboo. Firstly, the high temperature used in the treatment would have reduced the number of hydroxyl groups, thus reducing the number of sites for water adsorption, and secondly, the oil medium would coat the cell lumen, thus preventing the remnant cell wall hydroxyl groups from adsorbing water. These treatments may be effective for dimensional stabilization of bamboo, but it has been reported that mechanical properties are reduced from the treatment (Razak *et al.*, 2004). Nevertheless, the resistance of the heat-treated bamboo to white rot fungus and termites increases as a result of the treatment (Razak *et al.*, 2004; Leithoff and Peek, 2001).

There was no specific trend in MEE for *G. scortechinii* except for the highest value



G. scortechinii *G. brang*

Figure 1. Mean anti-swelling efficiency (ASE) of oil-treated *G. scoretchinii* and *G. brang*



G. scortechinii *G. brang*

Figure 2. Mean moisture excluding efficiency (MEE) of oil-treated *G. scoretchinii* and *G. brang*

(56.8%) attained by treatment T180D120. On the contrary, for *G. brang*, the values increased with temperatures and duration of treatments below 160 °C. Beyond this temperature, the MEE values reduced.

Effect of oil treatment on bonding quality

Buffering capacity

The buffering capacity of a substrate is important in gluing especially if the adhesive is pH sensitive. This property is governed by the pH of the material and an extreme value of wood pH had been reported to be troublesome for achieving good adhesive bonds (William and Khan, 1980). Substrate pH has no direct effect on gluing strength and wood failure but has some effect on the adhesive curing process (Sakuno and Moredo, 1993). The buffering capacity of *G. scortechinii* and *G. brang* was found to be more sensitive towards alkaline than towards acidic range. Table 1 shows the amount

Table 1. Buffering capacity and contact angle (°) of *G. scortechinii* and *G. brang*

	G. scortechinii			*G. brang*		
Treatment conditions	Volume of HCl (0.01N) required to reach pH 3 (ml)	Volume of NaOH (0.01N) required to reach pH 11 (ml)	Contact angle (°)	Volume of HCl (0.01N) required to reach pH 3 (ml)	Volume of NaOH (0.01N) required to reach pH 11 (ml)	Contact angle (°)
Control	6.44	1.12	Outer[1] 7 Inner[2] 16	8.51	1.02	Outer 1 Inner 9
T140D30	7.73	1.26		8.47	1.38	
T140D60	7.76	1.11		8.37	1.09	
T140D120	8.06	1.04		8.58	1.05	
Mean	7.84	1.14	Outer 13 Inner 23	8.47	1.17	Outer 13 Inner 46
T160D30	8.21	1.11		8.52	1.05	
T160D60	8.41	1.09		8.61	1.02	
T160D120	8.48	1.04		8.81	1.01	
Mean	8.36	1.08	Outer 18 Inner 34	8.65	1.03	Outer 30 Inner 51
T180D30	8.07	1.16		7.63	0.97	
T180D60	8.33	1.07		8.53	0.96	
T180D120	8.18	1.05		8.60	0.98	
Mean	8.19	1.09	Outer 14 Inner 24	8.25	0.97	Outer 36 Inner 53

[1]Outer, surface of strips at peripheral layer of bamboo culm, [2]Inner, suface of strips at inner layer of bamboo culm

of 0.01 N NaOH and 0.01 N HCl required to change the pH value of untreated and treated bamboo to 11 and 3, respectively. Untreated *G. scortechinii* required 1.12 ml NaOH to change the pH to 11 and 6.44 ml HCl to change the pH to 3; untreated *G. brang* required 1.02 ml NaOH and 8.51 ml HCl, respectively. For oil-cured *G. scortechinii,* a slightly higher amount of HCl (7.84-8.36 ml) was required to change the pH to acidic than untreated bamboo, but comparable amount of NaOH (1.08-1.14 ml) to untreated bamboo to change the pH to alkaline. For *G. brang*, the amount of HCl and NaOH required to change the pH of treated and untreated material were comparable. It was 8.25-8.65 ml of HCl and 0.97-1.17 ml for NaOH.

Since bamboo is sensitive to alkali-based adhesives such as phenol formaldehyde, a buffer is required in the adhesive formulation to ensure sufficient curing of the resin (William and Khan, 1980). Anwar *et al.* (2005b) stated that when an alkaline resin like phenol formaldehyde is spread on the bamboo surface, the adhesive at the boundary layers would change its pH to slightly lower than normal, enough to slow down the setting of phenol formaldehyde resin, which normally occurs between pH 11 and 12. This would not happen if the binder is an acid curing resin like urea formaldehyde, since bamboos are stable in acid. In this study, however, a longer press time was employed to bond the PF-based boards. The pressing time was increased to 7 min, instead of 6 min, as specified by the resin manufacturer's specification for plywood (MAC, 1999).

Contact angle

The contact angle formed between a surface and a liquid provides useful indication of how well the adhesive wets, spreads and penetrates while gluing. Wettability of bamboo is one of the indicators of how well the substrate reacts with liquid. When the contact angle is zero, a complete wetting occurs. On the contrary, if the contact angle is more than 90 °, there is lack of wetting. The contact angle for untreated *G. scortechinii* was between 7 ° and 16 ° and for untreated *G. brang* it was between 1 ° and 9 ° (Table 1). It is interesting to note that the inner surface of the bamboos had smaller contact angle suggesting that the surface was easier to be wetted than the outer surface. The faster absorption of water on the inner surface is attributed to the presence of large sized vessels (Anwar *et al.*, 2005b). When treated with palm oil at high temperatures, the contact angle of both bamboos markedly increased. In a preliminary analysis, the wettability of treated bamboos was not affected by the duration of treatment at a specific heating temperature. The reduction of wettability of the treated bamboos may be due to the filling of void spaces and cell lumens by the oil, thus preventing the water penetration.

In bonding process, higher wettability (lower contact angle) suggests shorter assembly time needed in the manufacture of laminates. The mean contact angles found for bamboos in this study were lower than the average contact angle for wood. Paridah *et al.* (2001) found that the average contact angles for rubber wood *(Hevea brasiliensis)* and sentang *(Azadirachta excelsa)* immediately after placing the droplet were 65 ° and 57 °, respectively. The results suggest that the adhesive used for wood cannot be used for bamboo without modifying the formulation. The adhesive formulations were slightly modified to have acceptably high viscosity to control the penetration of adhesive into the strips.

Glue bond quality

Shear strength and failure percentage values of a laminate indicate the glue bond integrity of the bonded product. Theoretically, when both the shear strength and wood failure percentage are high, a good bonding is achieved. If one of them is high and the other is low, it indicates that either the bamboo strips are of low strength or the adhesive bond is poor.

The shear strength and wood failure percentage of both untreated and treated bamboo laminates are given in Table 2. In general, the oil treatment process significantly reduced the shear strength of the bamboo laminates. At a particular heating temperature, the shear strength of *G. scortechinii* was not affected by the duration of treatment but for *G. brang*, a significant reduction in shear strength was recorded when the duration of heating was longer (120 min). The untreated *G. scortechinii* and *G. brang* had average shear strength values of 4.18 and 4.16 N mm^{-2}, respectively. Boiling of *G. scortechinii,* at temperatures between 140 and 160 °C reduced the shear strength of

Table 2. Shear strength and wood failure of untreated and oil-cured bamboos

Treatment conditions	*Gigantochloa scortechinii*		*Gigantochloa brang*	
	Shear (τ)[1] N mm^{-2}	Bamboo Failure, %	Shear (τ) N mm^{-2}	Bamboo Failure, %
Control	4.18^{A}[2] (0.362)	85-100	4.16^{A} (0.690)	88-100
T140D30	1.90^{B} (0.520)	42-55	2.81^{B} (0.440)	55-60
T140D60	1.94^{B} (0.428)	45-60	2.46^{B} (0.399)	50-55
T140D120	2.12^{B} (0.455)	40-45	2.34^{BC} (0.529)	50-55
T160D30	1.77^{B} (0.528)	40-50	2.88^{B} (0.579)	55-60
T160D60	2.07^{B} (0.645)	38-48	2.97^{B} (0.394)	50-60
T160D120	1.69^{BC} (0.432)	40-45	2.40^{BC} (0.432)	50-55
T180D30	1.57^{C} (0.557)	32-45	2.38^{C} (0.600)	45-55
T180D60	1.15^{C} (0.216)	25-32	2.04^{C} (0.159)	30-45
T180D120	1.53^{C} (0.251)	20-30	1.49^{C} (0.264)	20-40
British Standard	$0.35 < \tau < 0.7$		Average wood failure >75%	
	$0.7 < \tau < 1.7$		Average wood failure > 50%	
	$1.7 < \tau < 2.5$		Average wood failure > 25%	
	$2.5 < \tau$		Average wood failure > 15%	

[1]Mean of 6 specimens
[2]Means within a column followed by same alphabet are not significantly different at P<0.05
Values in parentheses are standard deviations

the material to 1.69–2.12 N mm^{-2}. Statistical analysis shows that these values were not significantly different. However, when heated at 180 °C, the average shear values of this bamboo significantly reduced to 1.15-1.53 N mm^{-2}. On the other hand, boiling of *G. brang* at temperatures between 140 and 160 °C reduced the shear strength to 2.34-2.97 N mm^{-2} whilst at higher boiling temperature (180 °C), the shear strength markedly reduced to 1.49–2.08 N mm^{-2}.

Wood failure is commonly used to detect the strength of glue joints. Table 2 shows the average bamboo failure of the laminates. Apparently, untreated bamboo produced high percentage of bamboo failure, 85-100 per cent for *G. scortechinii* and 88-100 per cent for *G. brang*. On the contrary, oil treatment increased the glue failure which reflects weak cohesive bonding at the glue line. It is possible that the oil penetrated into the strips and filled the void spaces and cell lumens forming a layer surrounding the cell wall, making the cellulose chain more hydrophobic. This prevented an adequate cohesive bonding with the adhesive. On the other hand, a significant bamboo failure (20-60%) found in the treated bamboo laminates indicates that the hot oil treatment might have resulted in disintegration of the cell walls, thus making them more brittle. In general, oil treatment of bamboos at 160 °C or milder, can still achieve the minimum standard requirement of glue bond quality for plywood.

CONCLUSIONS

Hot oil treatment was found to improve the dimensional stability and reduction of the moisture absorption bamboo. The duration of treatment was more dominant in imparting the dimensional stability of *G. scortechinii* than the temperature. The best curing condition for this bamboo to achieve maximum ASE value was 180 °C for 120 min. For *G. brang*, there was no specific trend for ASE when the bamboo was heated below 160 °C. However, at higher temperature, the longer duration of treatment, gave higher ASE value. The optimum curing condition for this bamboo was 180 °C for 60 min. In general, the oil treatment significantly reduced the shear strength of the bamboo laminates. Between the two bamboos, the reduction in shear strength was more prominent in *G. scortechinii* than in *G. brang*. The optimum curing condition for *G. scortechinii* in order to meet the minimum standard requirement of glue bond quality for plywood was 160 °C or milder, while for *G. brang* it was 180 °C but with a shorter treatment duration.

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