EFFECTS OF HOT OIL TREATMENT ON PHYSICAL AND MECHANICAL PROPERTIES OF THREE SPECIES OF PHILIPPINE BAMBOO

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Received October 2007

MANALO RD & ACDA MN. 2009. Effects of hot oil treatment on physical and mechanical properties of three species of Philippine bamboo. The effects of hot oil treatment on physical and mechanical properties of three species of Philippine bamboo, *viz. Bambusa blumeana*, *B. vulgaris* and *Dendrocalamus asper* were investigated after exposure to virgin coconut oil at 160 to 200 °C for 30 to 120 min. The results showed improvement in water absorption and thickness swelling properties for all species tested. However, there was a reduction in strength properties as indicated by modulus of elasticity, modulus of rupture and toughness. The improvement in dimensional stability and reduction in strength properties were correlated with temperature but duration seemed to have little or no effect on physical or mechanical properties.

Keywords: *Bambusa blumeana, Bambusa vulgaris, Dendrocalamus asper,* dimensional stability, virgin coconut oil, thermal modification

MANALO RD & ACDA MN. 2009. Kesan rawatan minyak panas terhadap ciri-ciri fizikal dan mekanik tiga spesies buluh negara Filipina. Kesan rawatan minyak panas terhadap ciri-ciri fizikal dan mekanik tiga spesies buluh negara Filipina iaitu *Bambusa blumena, B. vulgaris* dan *Dendrocalamus asper* dikaji. Buluh dirawat dengan minyak kelapa dara pada suhu 160 °C hingga 200 °C selama 30 min hingga 120 min. Kajian menunjukkan perbaikan dari segi serapan air dan pembengkakan ketebalan dalam kesemua spesies yang dikaji. Namun, terdapat penurunan dalam ciri-ciri kekuatannya seperti yang ditunjukkan oleh nilai-nilai modulus kekenyalan, modulus kepecahan dan keliatan. Perbaikan dalam kestabilan dimensi dan penurunan dalam ciri-ciri kekuatannya berkorelasi dengan suhu tetapi tempoh rawatan nampaknya tiada atau hanya mempunyai sedikit kesan terhadap ciri-ciri fizikal dan mekanik.

INTRODUCTION

Bamboo is an important forest resource in Asia. It is used for various applications, such as light building materials, scaffolding, mats, fencing, handicrafts, toys and musical instruments (PCARRD 1991, Rivera 1997). However, the supply of bamboo is fast depleting due to increasing utilization brought about by dwindling timber resources (Ganapathy *et al.* 1996). Proper utilization and protection are, therefore, necessary to maximize the benefits we derive from this material. Unfortunately, bamboos are susceptible to attack by decay fungi and boring insects, and difficult to treat with preservatives (Liese 1998, Wang *et al.* 1998). In general, protection of bamboo from biodeterioration has received little attention in Asian countries (Wang *et al.* 1998). Some preventive and control measures using wood preservatives have been developed in China, India, Japan and the Philippines (Singh & Tewari 1979, 1981a, 1981b, Xu 1983, Kumar *et al.* 1985, Liu & Xu 1985, Zhou 1985, Thapa *et al.* 1992, Garcia *et al.* 1997, Acda 2007).

One method that has been studied recently to improve the properties and durability of bamboo is thermal modification through hot oil treatment (Leithoff & Peek 2001, Wahab *et al.* 2004, 2005). The technique involves immersion of bamboo in an oil bath at 180 to 220 °C for two to four hours (Rapp & Sailer 2001, Militz 2002). The oil facilitates fast and uniform heat transfer and provides limited oxygen in the heating vessel (Rapp & Sailer 2001, Militz 2002). Vegetable oils with high boiling point such as hemp and palm oil have been used in thermal modification of bamboo (Leithoff &

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Peek 2001, Wahab *et al.* 2004, 2005). However, the effectiveness of hot oil treatment seems to be affected by the type of oil used (Wang & Cooper 2005). Studies on heat treatment of bamboo reported reduction in mechanical properties but with marked improvement in dimensional stability and durability (Leithoff & Peek 2001, Wahab *et al.* 2004, 2005). This paper reports the effects of hot oil treatment on physical and mechanical properties of three species of bamboo commonly used in furniture and handicraft in the Philippines. It is part of a larger study to explore the feasibility of using thermal modification to improve the resistance of Philippine bamboo against decay fungi and wood boring insects.

MATERIALS AND METHODS

Bamboo

Two, three-year-old poles (80–100 mm diameter, 3 m length) of *Bambusa blumeana*, *B. vulgaris* and *Dendrocalamus asper* were collected from the bamboo plantation at the Ecosystem Research and Development Bureau (ERDB), Department of Environment and Natural Resources in Mt. Makiling, Los Banos, Laguna. These species are widely used in various applications, such as light building materials, furniture and handicrafts in the Philippines and other tropical countries. The samples were brought to the laboratory, nodes removed and split into 25 × 300 mm slats. Average culm thicknesses were 12.50, 9.62 and 14.27 mm for *B. blumeana*, *B. vulgaris* and *D. asper* respectively. All samples with average moisture content of 65% were randomly selected and used for heat treatment within three days of collection.

Hot oil treatment

Bamboo samples (25 × 300 mm) were immersed in hot oil using a fabricated oil curing apparatus. The apparatus consisted of stainless steel cylindrical vessel (300 mm diameter and 450 mm height) heated by electric plates (5000 watts) connected to a thermocouple and digital temperature controller. Virgin coconut oil (VCO, Grade B, specific gravity 0.92, viscosity 1.5 cps, pH 5.9, smoke point 212 °C) obtained from the National Institute of Molecular Biology and Biotechnology, University of the Philippines Los Banos was used in this study. VCO is naturally processed from fresh coconut meat (non-copra) or its derivative (coconut milk and milk residue) produced through enzyme catalyzed extraction (BIOTECH 2005). It is a clear liquid at ambient temperature and has a very high degree of saturated fatty acids (Dayrit 2003, Kabara 2003). The coconut oil was first heated to 60 °C. Bamboo samples were completely submerged in the heated oil. Oil temperature was raised to 160, 180 or 200 °C for 30, 60 or 120 min. Treatment time started when the oil bath reached the target temperature. Treated samples were then blotted using paper and allowed to cool for 24 hours. Untreated bamboo samples conditioned for eight weeks at 21 °C and 65% relative humidity were used as controls.

Physical properties

Bamboo samples were removed from the vessel and carefully inspected for any change in colour, odour, texture and sign of collapse or other defects. The effects of hot oil treatment on hygroscopicity and dimensional stability were measured using water absorption and thickness swelling. Water absorption and thickness swelling tests were determined by submerging specimens horizontally in water at room temperature for 24 hours using the test methods of the American Society for Testing Materials D 143-94 (ASTM 1995). After submersion, samples were drained of excess water and measured for change in thickness and amount of water absorbed. Thickness swelling (nearest 0.1) was measured at three marked points along the length of each sample with digital callipers. Water absorption and thickness swelling were expressed as percentage of the original weight or thickness respectively. Three replicates were used for each test and untreated bamboo samples described above served as controls. Data of water absorption and thickness swelling tests were subjected to an analyses of variance (ANOVA) fitted in 3 × 3 factorial in a completely randomized design and means separated using Tukey's highly significant difference test (HSD, $\alpha = 0.05$) (Statgraphics 1999).

Mechanical properties

The effects of exposure to hot oil on mechanical properties were evaluated using a three point bending test following ASTM D 143-94 (ASTM

1995). Prior to testing, all samples were conditioned to constant moisture content in a chamber maintained at 21 °C and 65% relative humidity. Samples without node were tested for static bending and modulus of elasticity (MOE). Modulus of rupture (MOR), maximum load and deflection were determined for each specimen. Loading was made at the centre of the specimen with rind in the compression side. The rate of loading was varied according to culm thickness on 254 mm span using a Shimadzu universal testing machine. Toughness was determined using a single blow impact test on 20 × 280 mm samples following ASTM D 143-94. Four replicates were used for each test and untreated bamboo samples described above served as controls. Data were subjected to analysis of variance and means separated as described above to determine if hot oil treatment resulted in significant reduction in strength properties.

RESULTS AND DISCUSSION

The colour of bamboo (ground tissue and rind) was affected by temperature and duration of hot oil treatment. The treatment changed the colour of the ground tissue from cream to light brown at 160 °C or dark brown at 200 °C. The colour of the rind also changed from light yellow to light brown or dark brown for temperatures from 160 to 200 °C. Although the treatment resulted in a generally darker appearance, the colour change was uniform throughout the samples indicating uniform treatment. No extractive precipitation or signs of treatment defects were evident. Bamboo samples exhibited a typical smoky smell which disappeared after a few weeks. Changes were also observed in the physical properties of the VCO. The treatment resulted in a change in colour, acidity (pH 3.8–5.4) and viscosity of the oil (cps 1.8). The oil changed in colour from clear to light brown at 180 °C to dark brown as temperature increased to 200 °C. Wang and Cooper (2005) suggested that oils used in thermal modification undergo chemical reactions with cellulose or hemicelluloses, altering its physical properties.

Hot oil treatment from 160 to 200 °C resulted in decreased water absorption for all species. *Bambusa blumeana*, *B. vulgaris* and *D. asper* showed reduction in water absorption of 31.7 to 65.3%, 14.5 to 46.0% and 11.5 to 44.7% respectively, with respect to untreated controls (Figure 1). Treatment temperatures from 160 to 200 °C had a highly significant effect on water absorption ($p < 0.001$) for all the species tested. However, effects of treatment duration from 60 to 120 min on water absorption were not significant ($p > 0.169$). Interactions between temperature and duration of treatment for all species tested were also not significant ($p > 0.95$). Improvement in dimensional stability, as indicated by reduction in thickness swelling, was evident for all three species (Figure 2). Samples of *B. blumeana*, *B. vulgaris* and *D. asper* showed reduction in thickness swelling of 43.8 to 97.0%, 42.4 to 77.7% and 25.7 to 80.1% respectively, with regard to untreated controls. Both temperature and time had significant effects on thickness swelling ($p < 0.001$). However, no significant and obvious interactions were evident in all three bamboo species tested. Similar improvements in dimensional stability were reported in hot oil treatment of wood (Rapp & Sailer 2001, Wang & Cooper 2005). The reduction in hygroscopicity or improvement in dimensional stability is believed to be due to chemical changes of cell wall components such as decomposition of hemicelluloses or demethoxylation of lignin during treatment resulting in reduction or modification of adsorption sites in the cell wall (Burmester 1973, Giebeler 1983, Tjeerdsma *et al.* 1998a, 1998b).

Mechanical tests showed that strength properties of treated bamboo were also affected by temperature and duration of hot oil treatment. MOE values for *B. blumeana*, *B. vulgaris* and *D. asper* showed a 16–22% reduction in stiffness with increasing treatment temperature compared with untreated controls (Figure 3). MOE at 200 °C significantly differed from that at 160 °C for *B. vulgaris* but statistically similar to that of *B. blumeana* and *D. asper*. Duration of treatment from 30 to 60 min and its interaction with temperature seemed to have little or no effects on MOE ($p > 0.20$). MOR showed a marked reduction of 31–60% with respect to untreated control at 200 °C (Figure 4). Increasing temperatures from 160 to 200 °C had a significant effect on MOR for all species tested ($p < 0.001$). Duration of treatment and interaction with temperature, however, had little or no effect on variation in MOR of *B. blumeana*, *B. vulgaris* and *D. asper* ($p > 0.076$). The reductions in MOE and MOR of treated bamboo species were comparable with those reported by Wahab *et al.* (2004, 2005) for *Gigantochloa scortechi* using palm oil but higher

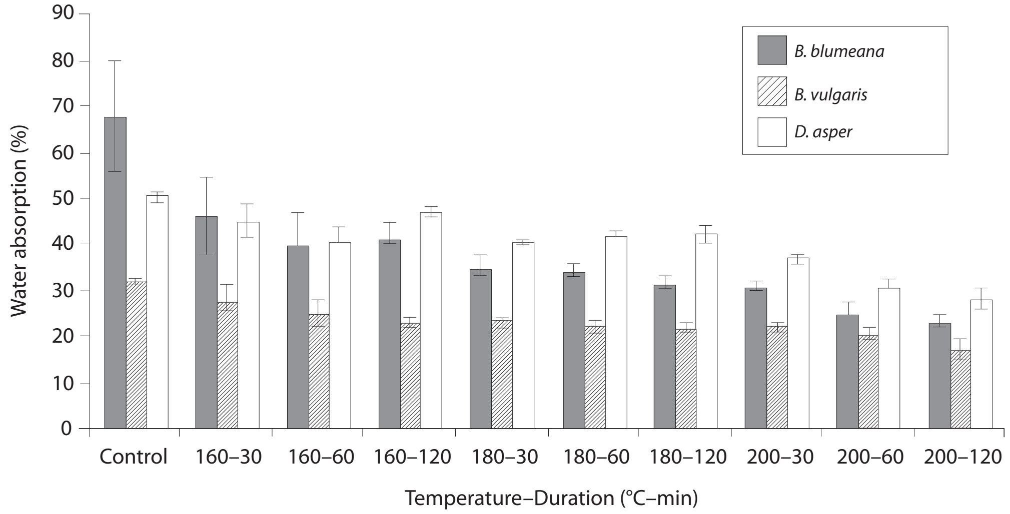

Figure 1 Water absorption of three species of Philippine bamboo as affected by temperature and duration of hot oil treatment. Lines on top of bars represent standard errors of the means.

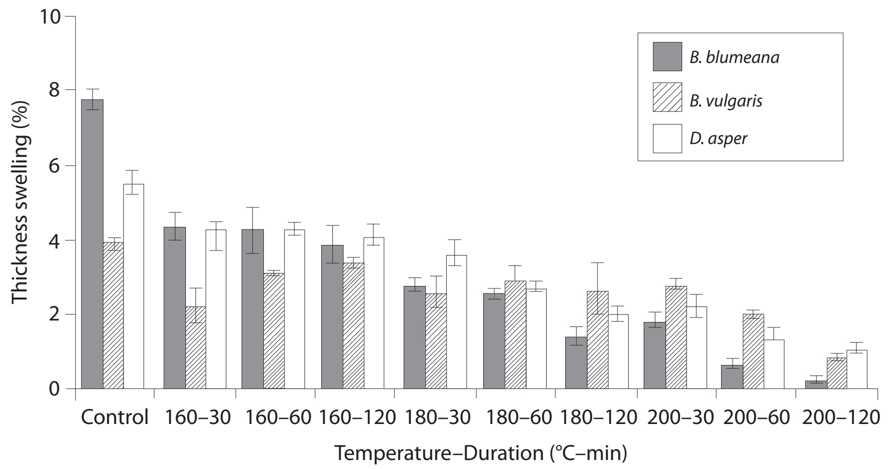

Figure 2 Thickness swelling of three species of Philippine bamboo as affected by temperature and duration of hot oil treatment. Lines on top of bars represent standard errors of the means.

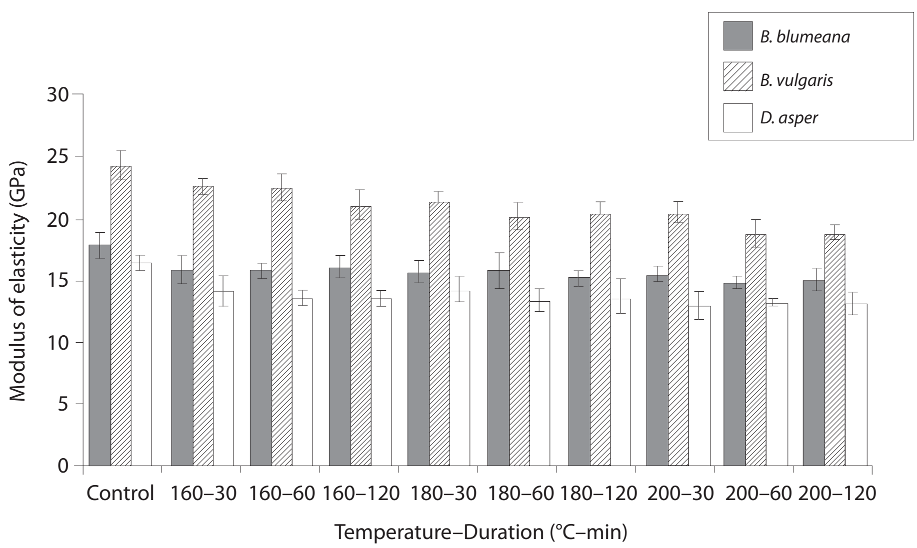

Figure 3 Modulus of elasticity of three species of Philippine bamboo as affected by temperature and duration of hot oil treatment. Lines on top of bars represent standard errors of the means.

than those reported by Leithoff and Peek (2001) for *Phyllostachys pubescens* using hemp seed oil.

Toughness of bamboo samples also showed reduction of 5.7 to 61.6% in shock resistance using virgin coconut oil at 160 to 200 °C (Figure 5). Both treatment temperature and time had highly significant effects on toughness of *B. blumeana*, *B. vulgaris* and *D. asper* ($p < 0.001$). Interactions between temperature and time had little to no effects on shock resistance ($p > 0.90$) of the three bamboo species. The range of toughness values reported in the present study was slightly higher compared with that reported by Leithoff and Peek (2001). Similar reduction in strength properties were also reported in thermal modification of wood at elevated temperature (Boonstra *et al.* 1998, Tjeerdsma *et al.* 1998b). Studies in the past attributed this to the degradation of cell wall carbohydrates (Burmester 1973, Giebeler 1983, Tjeerdsma *et al.* 1998a, b).

In general, hot oil treatment using virgin coconut oil on three species of bamboo commonly used in the Philippine, *viz. B. blumeana*, *B. vulgaris* and *D. asper*, showed significant improvements in dimensional stability as indicated by reduced water absorption and thickness swelling properties. However, there was a reduction in strength properties in all three bamboo species as shown by decreased modulus of elasticity, modulus of rupture and toughness values. Treatment duration and its interactions with temperature seemed to have little or no effect on

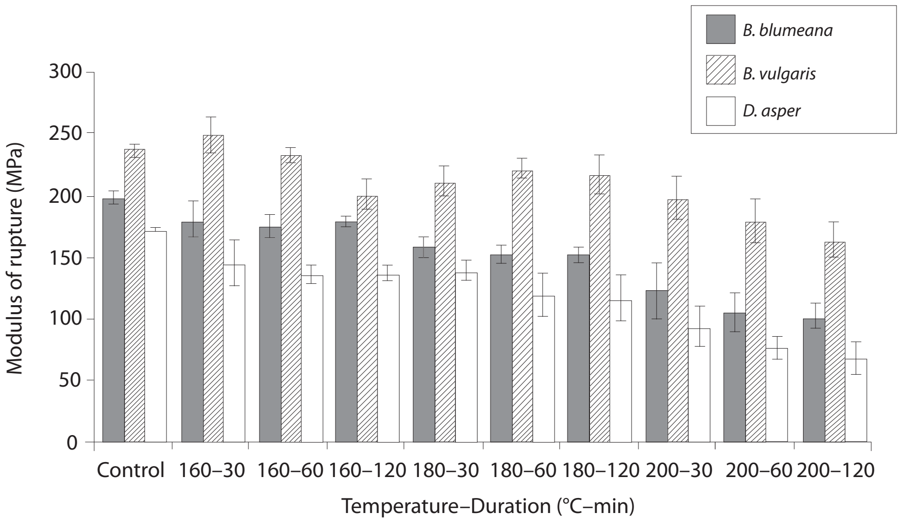

Figure 4 Modulus of rupture of three species of Philippine bamboo as affected by temperature and duration of hot oil treatment. Lines on top of bars represent standard errors of the means.

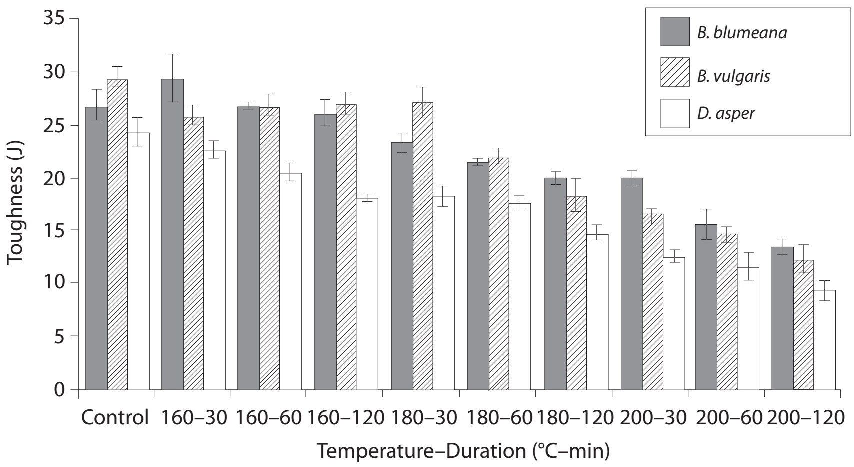

Figure 5 Toughness of three species of Philippine bamboo as affected by temperature and duration of hot oil treatment. Lines on top of bars represent standard errors of the means.

dimensional stability and mechanical properties of *B. blumeana, B. vulgaris* and *D. asper*. Hot oil treatment can be used to improve properties of Philippine bamboo.

ACKNOWLEDGEMENTS

The authors wish to thank M Alipon and the staff at the Materials and Evaluation Properties Division, Forest Products Research and Development Institute for use of the universal testing machine, to FZ Tambalo of BIOTECH for providing virgin coconut oil and to AB Exconde of ERDB for providing bamboo samples for this study.

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