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Termite resistance and physico-mechanical properties of particleboard using waste tobacco stalk and wood particles

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A B S T R A C T

The study investigated the termite resistance, physical and mechanical properties of particleboard made from waste tobacco (*Nicotiana tabacum* L.) stalk and *Paraserianthes falcataria* wood particles. Boards containing at least 25% tobacco stalk exhibited excellent termite resistance in laboratory no-choice feeding test against the Asian subterranean termite, *Coptotermes gestroi* Wasmann. Underground ground field exposure tests also showed that particleboard containing at least 50% tobacco stalk provided excellent protection against Philippine subterranean termites. Termite resistance of particleboard containing tobacco stalk is most likely due to the presence of residual nicotine in the samples. Addition of *P. falcataria* wood particles in all proportions used in this study resulted in boards with internal bond, stiffness and strength properties above the minimum set by the European standard EN 312-2 (1996) for general use particleboards. Boards containing 50–100% tobacco stalk showed high water absorption and thickness swelling after 24 h soaking in water. Results of the study showed that tobacco stalk can be used as an alternative material either alone or in combination with wood particles for the manufacture of particleboard with direct positive impact on disposal problem and efficient utilization of this waste biomass.

1. Introduction

Tobacco (*Nicotiana* spp.) is one of the most valuable agricultural products in the world. It is grown in over 125 countries on over 4 million hectares of land (Rodgman and Perfetti, 2008). Tobacco is an annual plant about 0.8–2.5 m in height and culturally managed for high grade quality leaf for cigarette manufacture (Agrupis and Maekawa, 1999). After the leaves are harvested, the stalks are incorporated in the soil or burned in the field. Waste tobacco stalk is a fibrous biomass consisting basically of cellulose, hemicellulose and lignin (Shakhes et al., 2011). Its basic chemical constituents are similar to those of broadleaf hardwood species but with lower density (Hepworth and Vincent, 1998). However, significant volume and presence of nicotine in waste tobacco stalks pose increasing solid waste disposal and pollution problems in many countries. Nicotine, 3-(1-methyl-2-pyrrolidinyl) pyridine, is one of the most highly toxic alkaloids from plants (Schmeltz, 1971). It is a non-persistent non-systemic, contact insecticide with some ovicidal properties (Thacker, 2002). It had been reported to be effective against aphids, capsids, leaf miners, thrips and saw flies (Thacker, 2002). Studies have been conducted to determine potential uses of waste tobacco stalks including adsorbents of heavy metals (Li et al., 2008), fertilizer (Wen et al., 2010), pesticide (Booker et al., 2010), fiber source for pulp and paper (Agrupis et al., 2000; Shakhes et al., 2011; Gao et al., 2012), animal feed (Gandi et al., 1997), industrial chemicals (Akpinar et al., 2010) and energy source (Putun et al., 2007; Martin et al., 2002, 2009; Pesevski et al., 2010). Waste tobacco stalks had also been used to produce particleboard (Castro et al., 1994, 1996). Particleboards are alternative building materials developed to replace plywood in such applications as paneling, table tops, cabinets, door skin, furniture components, etc. However, the potential insecticidal properties of particleboard containing tobacco stalks have not been investigated. Tobacco stalks have significant nicotine content that could potentially be toxic or repellent to wood boring insects such as termites and powder post beetles. The present paper reports on the preparation, termite resistance, physical and mechanical properties of particleboard from a mixture of waste tobacco stalk and wood particles.

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2. Materials and methods

2.1. Tobacco stalks

Tobacco stalks (1.5–2.0 cm in diameter and about 150–180 cm in length) of *Nicotiana tabacum* L. were obtained from tobacco farmers in La Union province, Philippines. The stalks were free of leaves, roots and soil with no sign of molds and fungal deterioration. The tobacco stalks with pith were then cut (30 cm), dried under the sun for several days then in an oven at 80 °C to bring the moisture content to 8%. Dried tobacco stalks were then hammermilled to pass through 4 mm screen.

2.2. Wood particles

Paraserianthes falcataria L. Nielsen (Moluccan sau) wood particles (density 420 kg m^{-3}) were used in this study. *P. falcataria* is a fast growing species intensively grown in industrial tree plantations in Southeast Asia. The wood of *P. falcataria* is commonly used as raw material for pulp and paper, furniture and various wood products. *P. falcataria* wood shavings were obtained from a furniture manufacturing plant in Manila then hammermilled to pass through 4 mm screen. Wood particles were then dried in an oven at 80 °C for several days to bring the moisture content to 8%.

2.3. Termites

Secondary nests of three active colonies of *Coptotermes gestroi* Wasmann (Isoptera: *Rhinotermitidae*) were collected from infested buildings in the University of the Philippines Los Banos campus and placed in black garbage bags. The nests were immediately transported to the laboratory and placed inside 100 L plastic containers with lids and kept in a room at 25 °C for three days. Distilled water was sprayed on the sides of the container to keep the relative humidity above 80%. Mature worker (pseudergates beyond the third instar as determined by size) and soldier termites were separated from nest debris by breaking apart and sharply tapping materials into plastic trays containing moist paper towels. Termites were then sorted using a soft bird feather and used for bioassay within 1 h of extraction and segregation.

2.4. Board formation

A series of single layer particleboards measuring 10 mm × 300 mm × 300 mm were fabricated at target density of 650 kg m^{-3} using various ratios of tobacco stalks to wood particles (100:0, 75:25, 50:50, 25:75, 0:100). Tobacco stalks and wood particles were uniformly mixed and sprayed with a commercial urea formaldehyde (UF) resin (Ures®, 65% resin solids, pH 7, viscosity, free formaldehyde) from RI Chemical Corporation, Pasig, Philippines. The amount of UF resin used was 8% based on the dry weight of the stalks and wood particles and catalyzed by 3% ammonium hydroxide. No wax was added to the mix in this study. Board consolidation was performed by pressing the particle mat between two metal plates using an electrically heated hydraulic press (Wabash) under 130 kg cm^{-2} pressure at temperature of 150 °C for 3 min. After pressing the boards were trimmed then conditioned for six weeks at 25 °C and 65% relative humidity prior to mechanical testing. Five replicate boards were made for each treatment combination.

2.5. Termite resistance test

The termite resistance of particleboard containing various proportions of tobacco stalk was evaluated in a laboratory no choice feeding test following the Japanese Wood Preserving Association (JWPA) Standard 11-1 (1981). Each sample (10 × 10 × 20 mm; edge sealed with epoxy resin) cut from the middle of each board was placed in the center of a plaster-bottomed cylinder (80 mm diameter and 60 mm height) set on damp cotton pads to keep the sample moist. *C. gestroi* (150 workers and 15 soldiers) were introduced and the experimental units placed in an unlit incubator at 27 °C and 85% RH for four weeks. Five replications were used for each treatment. At the end of the incubation period, termite mortality and percentage weight losses of the test samples were determined and compared with those of the untreated controls. Mass loss was obtained by getting the initial and final weight of samples before and after termite exposure by placing samples in a room maintained at 25 °C and 65% relative humidity for 2 weeks. Samples from each experimental board were also chipped, ground in a Wiley mill (1.0 mm) and analyzed for nicotine following the AOAC Official Method 960.8 (1997).

Particleboard that showed high termite resistance in the laboratory feeding test was further evaluated in underground field exposure test. One sample (10 × 25 × 100 mm) was placed on top of a small concrete block (100 × 100 mm) and installed inside underground termite bait station located in three high termite hazard locations within the University of the Philippines Los Banos campus. Each field location is at least 1 km apart. Underground bait stations (100 mm diameter) were similar to that used for commercial termite baiting products. Four replications were used in each test location. Test sites are known to have active field colonies of *Macrotermes*, *Nasutitermes*, *Microcerotermes* and *Coptotermes*. All samples were exposed for a total of 24 weeks. Weight losses of specimens were calculated from the difference between the weights of test specimens before and after termite exposure as described above.

2.6. Board testing

Water absorption (WA) and thickness swelling (TS) of the boards were measured following procedures of the American Society for Testing Material D 1037 (1995) with minor modifications in specimen size. Three specimens (76 mm × 76 mm) were cut from each experimental board and edge sealed with epoxy adhesive. A total of fifteen specimens were prepared for TS and WA measurements. Water absorption and thickness swelling tests were determined by submerging specimens horizontally in water at room temperature for 2 and 24 h. After each submersion period, samples were drained of excess water and measured for change in thickness and amount of water absorbed. The water was changed after the 2 h submersion. Thickness swelling was measured from three marked points along the length of each specimen. WA and TS were expressed as a percentage of the original weight and thickness, respectively.

Static bending tests to measure board stiffness (modulus of elasticity, MOE), strength (modulus of rupture, MOR) and internal bond (IB) were performed following ASTM D 1037. Two static bending specimens (76 mm × 300 mm) and three IB specimens (50 mm × 50 mm) were cut from the center of each replicate board. A total of 10 bending and 15 internal bond specimens were prepared for each treatment combination. MOE, MOR, maximum load and deflection were determined for each specimen by applying the load using a universal testing machine at crosshead speed of 5 mm min^{-1}. Load and deflection were continuously recorded using data acquisition software running in a personal computer. Internal bond tests were performed by gluing specimens to aluminum blocks using a hot melt adhesive. Uniform load at the rate of 1 mm min^{-1} was applied perpendicular to the surface until failure using a universal testing machine. The maximum load necessary to