PARTICLEBOARD AND MDF PANELS MADE FROM A MIXTURE OF WOOD AND PINECONES: RESISTANCE TO DECAY FUNGI AND TERMITES UNDER LABORATORY CONDITIONS

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Particleboard and medium density fiberboard (MDF) panels were produced using stone pine (*Pinus pinea*) cones, which were mixed with either wood particles or fibers from pine and beech wood at various ratios. Specimens from the panels were subjected to AWPA E10-06 soil-block tests using two brown-rot fungi, *Gloeophyllum trabeum* and *Postia placenta* and two white rot fungi, *Trametes versicolor* and *Pleurotus ostreatus* for 12 weeks. Specimens were also subjected to subterranean termites, *Coptotermes formosanus,* according to the JIS K 1571 standard test method for 3 weeks. Pinecone material in the furnish had no considerable effect on the decay resistance of particleboard and MDF specimens subjected to the brown-rot fungi; however, mass losses in the specimens exposed to the white-rot fungi were gradually decreased as the pinecone ratio in the furnish increased. No increased resistance was observed in the specimens exposed to the termites. In some cases, the specimens containing pinecone furnish had greater mass losses compared to the control specimens.

Keywords: Particleboard; MDF; Pinecone; Decay resistance; Termite resistance

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INTRODUCTION

Lignocellulosic materials can provide the forest products industry with the opportunity to develop high performance materials and composites. High performance lignocellulosic composites can be produced using fiber modification, fiber technology, and high performance adhesives (Rowell 1992). In recent years the growing demands for raw materials in wood panel industry have led to research into the use of alternative lignocellulosic resources such as naturally durable wood fibers, preservative treated waste wood, agricultural fibers, waste tea leaves, tree bark, pine needles, pine cones, corn peels, peanut hull, hazelnut shell and husk, coconut shell, and soybean and wheat straw (Schmidt et al. 1994; Felton and DeGroot 1996; Kamdem and Munson 1996; Vick et al. 1996; Souza et al. 1997; Munson and Kamdem 1998; Yalinkilic et al. 1998; Wolfe and Gjinolli 1999; Huang and Cooper 2000; Kartal and Clausen 2001; Almeida et al. 2002; Kartal and Green 2003; Yang et al. 2003; Nemli et al. 2006, 2008; Ye et al. 2007; Çöpür et al. 2008; Güler et al. 2008; Lertsutthiwong et al. 2008; Wang et al. 2008, Terzi et al.

2009). Previous studies evaluated the mechanical and physical properties of, and formaldehyde emissions from, particleboard and medium density fiberboard (MDF) panels made with pinecones (Buyuksari et al. 2010; Ayrilmis et al. 2009). The results showed that with the increasing amounts of the pinecones (up to 50% wt) in the particleboard panels, the thickness swelling and water absorption values decreased from 19.2% to 13.9% and 70.4% to 36.4%, respectively. In MDF specimens, with the exception of addition of 10% cone flour, further additions significantly decreased water resistance of the MDF panels. The addition of pinecones into particleboard or MDF significantly decreased formaldehyde emission values.

Stone pine (*Pinus pinea* L.) is grown in different regions in the world, and according to Forestry Statistics of Turkish General Directorate of Forestry stone pine forests of Turkey cover approximately 43,000 ha (Anonymous 2010) and almost 6200 tons of cones were harvested in 2006 (Anonymous 2009). Pinecones contain large quantities of glucose, and smaller quantities of mannose, galactose, and xylose, significant amounts of lignin and phenolic extractives, phenol, and condensed tannins (Petterson 1984; Micales et al. 1994). Gonultaş (2008) reported that stone pine cone contains lower holocelluloses and higher extractives than its wood. The amount of holocelluloses and lignin in the stone pinecone measured 67.6% and 37.2% respectively, based on the weight of extracted pinecone. The diethyl ether extracts of pinecones inhibited the growth of representative mold, sap-stain, and wood-decay fungi (Micales et al. 1994). Therefore, pinecone appears a promising alternative to naturally durable composites.

Numerous previous studies have evaluated fungi and termite resistance of various lignocellulosics in composites, however, there is no information on the resistance of composites made from pinecones. The objective of this study, therefore, was to investigate the decay and termite resistance of particleboard and MDF panels produced with both wood and pinecone furnish.

EXPERIMENTAL

Preparation of Pinecones

Fresh cones were collected from stone pine (*Pinus pinea*) trees in the Fatih Forest District in the Belgrade Forest in Istanbul, Turkey. The cones were spread on a plastic sheet in the sun for drying. Nuts in the cones were then taken out and the pine cones without nuts were soaked in hot water for 4 h at 90°C. This treatment is believed to partially remove gum off the surface of the cones and improve grinding process and bonding properties of the cone flour (Ayrilmis et al. 2009). The wet cones were then dried in an oven at 60°C for 10 h to reduce the moisture content to 20-30%.

Production of Particleboard Panels

Particleboard panels with target density of 0.65 g/cm^3 were designed to consist of 35% wood chips at the face layers and 65% at the core layer. The particles that remained between 3 and 1.5 mm and between 1.5 and 0.8 mm sieve openings were utilized in the core and middle layers of the panels, respectively. The boards were pressed at 2.6 N/mm^2

pressure and 150 °C for 7 min. Wood particles (a 50:50 blend) consisting of pine (*Pinus nigra*) and beech (*Fagus orientalis*) species were obtained from a commercial MDF plant in Turkey. The experimental design is shown in Table 1. The other process options, such as particle properties, resin type (UF), percentage of UF resin, and press parameters, were unchanged in all experimental panels. The pinecones were coarsely chipped and classified using a horizontal screen shaker. The particles used in particleboard production were dried at 110 °C in an oven to reach a target moisture content of 3%. Two experimental particleboard panels (550 mm by 550 mm by 10 mm) were produced for each design, and the panels were conditioned at 20±2°C and 65±5% relative humidity (RH) to a moisture content of about 12%. Edges of the boards were then trimmed to the final dimension of 500 mm by 500 mm by 10 mm. Urea-formaldehyde (UF) resin (10%) was used for the core and outer layers based on oven-dry weight. One-percent ammonium chloride (NH_4Cl) was added to the resin as a hardener. The chips were placed in a drum blender and sprayed with UF resin and NH_4Cl for 5 min to obtain a homogenized mixture. This study did not include the addition of any external wax or water-repellent chemicals to the wood and cone particles.

Table 1. Experimental Design of the Composition of Particleboard and MDF Panels

Panel Type	Particleboard		MDF	
	Pine Cone (%)*	Wood (%)	Pine Cone (%)	Wood Fiber (%)
I (Control)	0	100	0	100
II	10	90	10	90
III	20	80	20	80
IV	30	70	30	70
V	40	60	40	60
VI	50	50	50	50

* By weight.

Production of MDF Panels

MDF panels were manufactured at the laboratory using procedures simulating industrial production. Following drying, the cones were processed by a rotary grinder without adding water. The cone flour passing through a U.S. 35-mesh screen and retained by a U.S. 80-mesh screen were dried in a laboratory oven at 85 °C for 15 h to MC of 2 to 3%. Wood fibers (a 50:50 blend) consisting of pine (*Pinus nigra*) and beech (*Fagus orientalis*) species were obtained from a commercial MDF plant in Turkey. Wood fibers were produced using a thermo-mechanical refining process without any chemical and resin addition. After mixing wood fibers and cone flour and placing the mixture into a rotary drum blender, liquid UF resin (10%) was applied to the mixture, with an air-atomized nozzle system in a rotating blender. The mixture was weighed and then formed into a mat on an aluminum caul plate, using a 600 mm by 600 mm forming box. To reduce the mat height and densify the mat, the mat was cold-pressed. This procedure allowed easy insertion of the mats into the hot-press. Fiber mats at 10% MC were subjected to hot pressing, using a manually controlled electrically-heated press. The maximum press pressure, pressing temperature, and total press cycle were 3.5 MPa, 180 °C, and 8 min, respectively. MDF panels containing cone flour at 10%, 20%, 30%, 40%, or 50% based on the oven dry weight of fiber were then trimmed to a final size of 500 mm by 500 mm by 10 mm after cooling. The resulting panels were sanded with a sequence of 80- and 120-grit sand papers. A total of 12 experimental panels, two for each type of panel, were manufactured. Other process parameters such as percentage of UF resin, press parameters, were unchanged in all experimental panels. The density values of the MDF panels produced were 0.73-0.76 g/cm^3.

Decay Resistance Tests

A decay resistance test was carried out by exposing the specimens (19 mm by 19 mm by panel thickness) to four wood degrading fungi, *Gloeophyllum trabeum* (Pers.:Fr.) Murrill MAD 617-R, *Postia placenta* (Fr.) M.J. Larsen & Lombard MAD 698-R, *Trametes versicolor* (L.:Fr.) Pilát COV 1030 (*Coriolus versicolor* (L.:Fr.) Quél.), and *Pleurotus ostreatus* (Jacq.:Fr.) P. Kumm. PLO 9669, in a soil-block test according to the AWPA E10-06 standard method (AWPA, 2007). *G. trabeum* and *P. placenta* cultures were obtained from the USDA Forest Service Forest Products Laboratory, Madison, WI, USA, while *T. versicolor* and *P. ostreatus* cultures were received from the Research Institute for Sustainable Humanosphere (RISH), Kyoto University, Japan. After 12 weeks of incubation at 27 °C and 70% RH, the surface fungus mycelium on the specimens was removed, the specimens were dried at 60 °C, and mass losses were determined as percentages of total specimen mass. Nine specimens were tested for each fungus and group.

Termite Resistance Tests

Particleboard and MDF specimens (20 mm by 20 mm by panel thickness) were exposed to the subterranean termite *Coptotermes formosanus*, according to the JIS K 1571 standard method (JIS 2004). An acrylic cylinder (80 mm in diameter, 60 mm in height) whose lower end was sealed with a 5-mm-thick hard plaster (GCNew Plastone, Dental Stone, G-C Dental Industrial Corp., Tokyo, Japan) was used as a container. A test specimen was placed at the centre of the plaster bottom of the test container. A total of 150 worker termites collected from a laboratory colony of RISH, Kyoto University, Japan were introduced into each test container together with 15 termite soldiers. Three specimens per panel group were assayed against the termites. The assembled containers were set on damp cotton pads to supply water to the specimens and kept at 28 °C and >85% RH in darkness for three weeks. The mass losses of the specimens due to termite attack were calculated based on the differences in the initial and final oven-dry (60 °C, 3 days) weights of the specimens after the debris from the termite attack was cleaned off.

Data Analysis

For statistical analysis, Duncan's Multiple Range Test ($p \leq 0.05$) was used to evaluate the differences among mass losses in the decay and termite resistance tests.

RESULTS AND DISCUSSION

Mass losses in the MDF and particleboard specimens exposed to test fungi *Gloeophyllum trabeum*, *Postia placenta*, *Trametes versicolor*, and *Pleurotus ostreatus* for 12 weeks are given in Tables 2 and 3. There was no significant effect of pinecone in the furnish on the susceptibility of the MDF specimens against the brown rot fungi, but mass losses for all samples were less than 10%. MDF specimens made from pinecone and mixed furnish were more resistant to brown-rot fungi attack than white-rot fungi. Mass losses in the MDF specimens exposed to *T. versicolor* ranged from 32% to 48%.

Table 2. Mass Losses (%) in the MDF Specimens in the Decay Resistance Tests[a]

Panel Type	Cone Amount (%)[b]	Fungi							
		P. placenta		*G. trabeum*		*P. ostreatus*		*T. versicolor*	
I	Control	2.13B	(0.76)	3.48C	(1.97)	19.38A	(6.20)	48.11A	(6.75)
II	10	3.62A	(0.78)	9.55A	(4.54)	16.90B	(2.22)	41.74AB	(5.68)
III	20	2.60AB	(0.90)	6.22B	(2.02)	16.91B	(0.61)	41.01AB	(7.22)
IV	30	2.18B	(0.83)	4.35C	(1.84)	16.59B	(2.09)	41.47AB	(4.18)
V	40	2.07B	(0.77	4.03C	(2.15)	15.82B	(3.01)	33.97B	(9.66)
VI	50	2.55AB	(0.75)	2.46D	(1.20)	15.90B	(3.85)	32.67B	(13.67)

[a] Each figure is average of nine replicate specimens. Figures in parentheses are standard deviations. The same letters in each column indicate that there is no statistical difference between the specimens according to Duncan's multiply range test ($p<0.05$).
[b] By weight.

Table 3. Mass Losses (%) in the Particleboard Specimens in the Decay Resistance Tests[a]

Panel Type	Cone Amount (%)[b]	Fungi							
		P. placenta		*G. trabeum*		*P. ostreatus*		*T. versicolor*	
I	Control	1.86AB	(0.61)	10.90A	(1.97)	25.22A	(3.22)	42.86A	(3.94)
II	10	2.51A	(1.26)	10.74A	(2.54)	21.53AB	(2.29)	41.13A	(9.01)
III	20	2.04AB	(1.05)	5.75B	(3.20)	19.88AB	(2.64)	37.09AB	(3.68)
IV	30	0.34C	(0.32)	4.86BC	(2.45)	20.71AB	(1.86)	36.75AB	(6.69)
V	40	0.33C	(0.24)	4.50BC	(3.32)	19.30AB	(4.80)	30.77B	(4.89)
VI	50	1.75AB	(0.67)	11.84A	(3.32)	18.41AB	(2.25)	30.24B	(4.32)

[a] Each figure is average of nine replicate specimens. Figures in parentheses are standard deviations. The same letters in each column indicate that there is no statistical difference between the specimens according to Duncan's multiply range test ($p<0.05$).
[b] By weight.

Similar results were obtained in the particleboard specimens. There was no significant effect of pinecone in the furnish on the susceptibility of the particleboard specimens against the brown-rot fungi. The lowest mass loss in the specimens was obtained for *P. placenta* (0.3-2.5%). Mass loss values for the white rot fungi were higher then brown rot fungi. *T. versicolor* caused increased mass losses in particleboard specimens (30.2-42.8%).

Compared to brown-rot fungi, white-rot fungi caused higher weight losses in all MDF and particleboard specimens. Mass losses in the specimens exposed to the white rot fungi *T. versicolor* and *P.ostreatus* decreased as the amount of pinecone increased. These results suggest that the pinecone particles in the particleboard and MDF composition did not provide protection against the fungi tested in this research.

To the naked eye, it appeared that both wood and pinecone particles in the matrix were degraded by brown and white-rot fungi but no microscopic evaluations were performed to confirm this.

Average mass losses in the particleboard and MDF specimens exposed to *Coptotermes formosanus* attack for 3-weeks are shown in Figs. 1 and 2. There were inconsistent differences between the controls and the panels containing pinecone furnish. These results suggested that all specimens were acceptable as a food source for the termites used in the study.

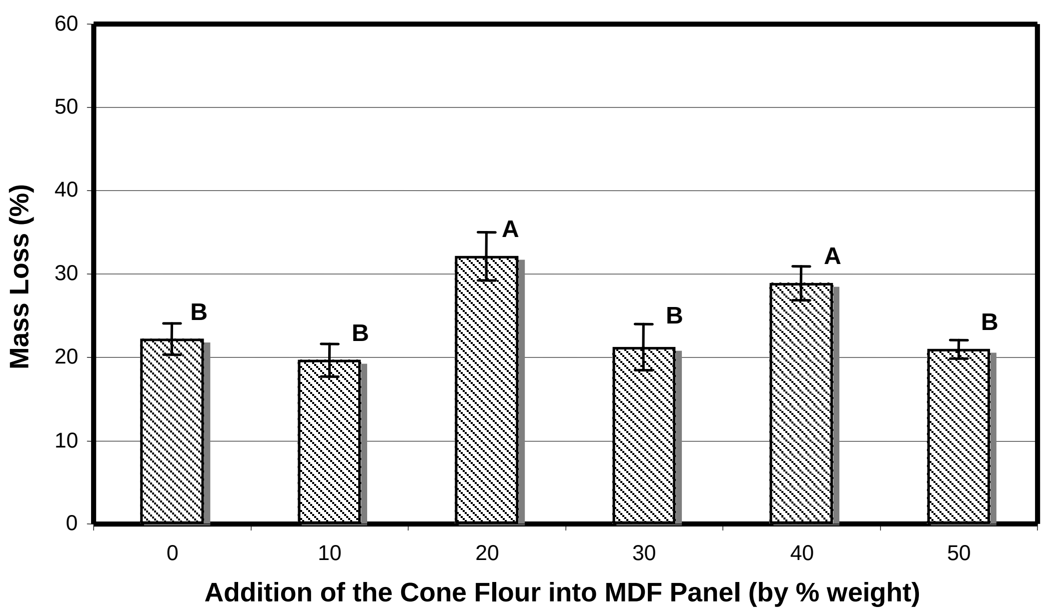

Fig. 1. Mass losses (%) in the MDF specimens in termite resistance tests. The same letters on each bar indicate that there is no statistical difference between the specimens according to Duncan's multiply range test ($p<0.05$). One or two dead termites were seen in each group. Average mass losses in Scots pine solid wood and Sugi solid wood were 21.1% and 29.6%, respectively.

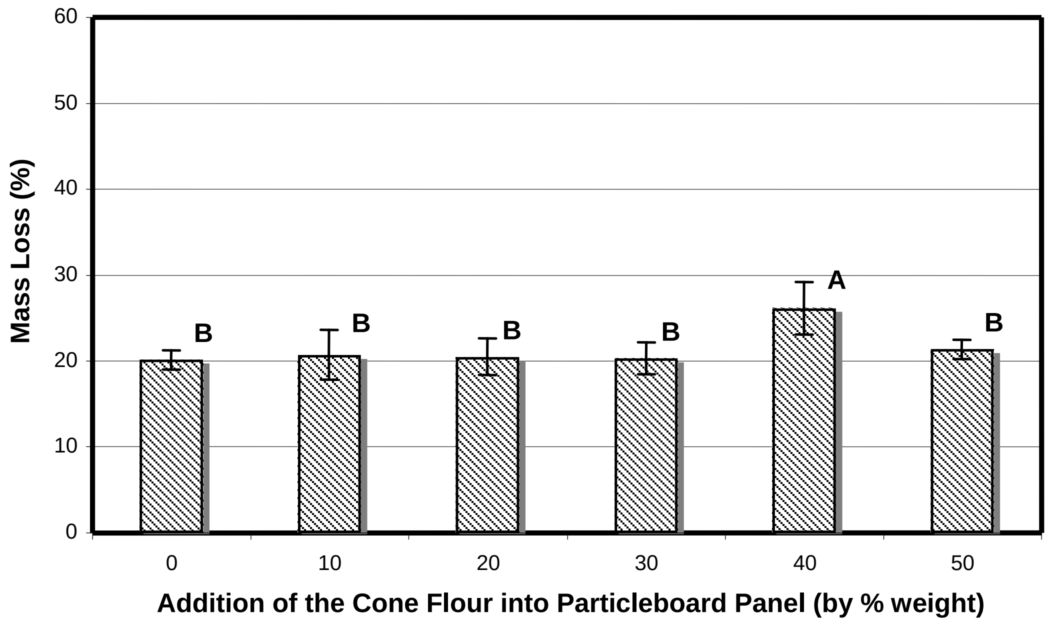

Fig. 2. Mass losses (%) in the particleboard specimens in termite resistance tests. The same letters on each bar indicate that there is no statistical difference between the specimens according to Duncan's multiply range test ($p<0.05$). One or two dead termites were seen in each group. Average mass losses in Scots pine solid wood and Sugi solid wood were 21.1% and 29.6%, respectively.

The durability of wood-based boards against biological agents is affected by the fiber properties (Carll and Highley 1999; Wagner et al. 1996; Kartal and Clausen 2001; Vick et al. 1996). Studies have showed that naturally durable fiber sources increased resistance against biological attack compared to non-durable wood fibers (Evans et al. 2000; Evans et al. 2001; Behr 1972; Kard and Mallette 1997). Barnes and Amburgey (1998) have stated that composites produced from furnish containing wood from both naturally susceptible and naturally durable species are more resistant to both fungi and insects than are those made from furnish consisting of wood from only naturally susceptible species. Kartal and Green (2003) found that MDF specimens containing oak in a mixed furnish had increased durability against decay fungi. Amusant et al. (2009) showed that OSB panels made from cypress had more resistance against the tested fungi and that the decay resistance decreased as the percentage of pine increased. Likewise, in the termite bioassays, OSB panels made from cypress showed more resistance and the resistance decreased as the percentage of pine increased. It is generally possible to increase the resistance of wood based products to biodegradation using naturally durable wood and agricultural fiber sources. Pinecone is also accepted to be naturally durable to mold, sapstain, and wood-decay fungi due to its high extractive content (Micales 1994; Gonultas 2008); however, the results of this study showed that no considerable decay, and termite resistance of particleboard and MDF panels produced by mixing wood furnish with pinecones was seen. MDF and particleboard panels consisting of pinecone increased resistance against white-rot fungi although panels showed greater mass loss.

CONCLUSIONS

1. Pinecone material in the furnish had no considerable effect on the decay resistance of particleboard and MDF specimens subjected to the brown-rot fungi; however, mass losses in the specimens exposed to the white-rot fungi gradually decreased as pinecone ratio in the furnish increased.
2. No considerable termite resistance of particleboard and MDF panels produced by mixing wood furnish with pinecones was seen.
3. Wood-based composites and panels with pinecone furnish may be used for indoor applications or in the areas with low decay and termite hazard.

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