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Decay and termite resistance of medium density fiberboard (MDF) made from different wood species☆

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Abstract

Medium density fiberboard (MDF) production worldwide is increasing due to the development of new manufacturing technologies. As a result, MDF products are increasingly utilized in traditional wood applications that require fungal and insect resistance. This study evaluated the ability of white and brown rot fungi and termites to decompose MDF consisting of different wood species by measuring weight loss. Furnish in the boards was prepared from heart and sapwood portions of pine *(Pinus nigra* Arnold var. *pallasiana),* beech *(Fugus orientalis* Lipsky), and European oak *(Quercus robur* L.) species. Fungal decay resistance tests were performed according to ASTM D 2017-81 standard method using two brown-rot fungi, *Gloeophyllum trabeum* (Pers. ex Fr.) Murr. (Mad 617), *Postia placenta* (Fries) M. Larsen et Lombard (Mad 698), and one white-rot fungus, *Trametes versicolor* (L. ex Ft.) Pilat (Mad 697). MDF and wood specimens were also bioassayed against the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) in order to determine termite resistance of the specimens. MDF specimens containing oak and mixed furnish demonstrated increased durability against decay fungi. Only pine, oak, and mixed MDF specimens met the 25% or less weight loss limit to be classified resistant according to ASTM D 2017-81 standard method. Overall, MDF specimens made from oak showed better performance than oak solid wood specimens. Accelerated aging according to ASTM D 1037-96a standard method before fungal bioassay decreased fungal resistance of the specimens. In contrast to the fungal bioassay, MDF specimens made from beech and mixed furnish showed decreased weight losses from termite attack after 4 weeks. However, none of the MDF specimens were resistant to termite attack. In severe conditions, the MDFs may require the incorporation of chemical biocides prior to board production for increasing the resistance of MDF to termite attack.

Keywords: *Medium density fiberboard (MDF); Decay resistance; Termite resistance; Gloeophyllum trabeum; Postia placenta; Trametes versicolor; Reticulitermes flavipes*

1. Introduction

Medium density fiberboard (MDF) is a wood-based panel that is composed of wood fibers bonded together with resin under heat and pressure. MDFs have a specific gravity ranging from 0.50 to 0.88 and have a wide application for both structural and non-structural uses (Rowel1 et al., 1995). In recent years, great changes have taken place in the MDF industry. Production of MDF products has increased dramatically and new plants are planned worldwide. MDF is used extensively in factory-assembled and ready-to-assemble furniture, as well as cabinets, underlayment, drawer fronts, molding, and counter tops. MDF is also replacing thin plywood and wet-process hardboard in the production of molded and flush door-skins (Krzysik et al., 1999).

It is generally accepted that wood-based boards show a greater resistance to decay than solid wood, although these products are still susceptible to biological attack (Curling and Murphy, 1999). Chung et al. (1999) showed that wood-based composite boards were as susceptible to microorganisms as solid wood. Phenolic resin-bonded boards are preferred in building construction for protection against water and high humidify; however, fungal attack in the

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phenolic-bonded board has been shown to be as severe as that in urea bonded-boards (Chow et al., 1999). Experience with wood-based boards reflects the importance of water entrapment in promoting decay. Wood-based boards depend on adhesive bonds for their integrity and their susceptibility to biological degradation is first detected as adhesive bond failure (Vick et al., 1996; Wagner et al., 1996; Carl and Highley, 1999; Kartal and Clausen, 2001). On the other hand, improved decay resistance of MDF depends on the wood fiber used in board manufacturing. A number of researchers have found that increasing the proportion of naturally durable wood fiber used in board manufacturing results in more resistance against biological attack compared to non-durable wood fibers. Subterranean termites can cause extensive damage to wood and wood composites produced from non-durable wood species and therefore these products possess little inherent resistance to termite attack (Behr, 1972; Evans et al., 1997; Kard and Mallete, 1997; Evans et al., 2000). Barnes and Amburgey (1998) 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.

In this study, MDF specimens produced in a commercial plant from three different wood species and blends of these species were subjected to fungal decay tests and a bioassay using eastern subterranean termites. The aim of the study was to determine whether boards containing different wood species affected resistance to fungal and termite attack in laboratory conditions.

2. Materials and methods

2.1. Manufacturing of MDF panels

MDF panels were manufactured in a commercial plant in Gebze, Turkey. Debarked pine (*Pinus nigra* Arnold var. *pallasiana),* beech (*Fagus orientalis* Lipsky), and European oak (*Quercus robur* L.) round wood samples containing both sapwood and heartwood were obtained from Geyve, Yalova, and Trakya, respectively (Table 1). A total of 12 MDF panels, three for each type of furnish and three samples composed of a 20:40:40 blend of pine, beech and European oak, were produced from chips having an average size of $20 \times 25 \times 5$ mm^3. The chip furnish consisting of appropriate levels of the various wood species was thermoplasticised in an Asplund defibrator using steam pressure at 7.6 kg cm^{-2} and 178°C for 5 min in order to obtain fiber furnish. Fibers were then blended with 1 1% urea–formaldehyde resin (oven dry solid wood basis), 1% wax (oven dry solid wood basis), and 0.8% NH_4Cl (dry resin basis) as hardener. Fiber mats at 10.5% moisture content were hot pressed at 206°C and 35-40 kg cm^{-2} for 4 min at a rate of 100 mm s^{-1} in a continuous press. MDF panels were then trimmed and sanded to a final size of $3660 \times 2230 \times 18$ mm^3 with a sequence of 150, 180, and 200 grit size following the cooling process (Ayrilmis, 2000).

Table 1
Composition and density of MDF and solid wood specimens

Specimen type	Composition	Density[a] (kg m^{-3})
MDF	100% pine	763
MDF	100% beech	758
MDF	100% oak	764
MDF	20% pine, 40% beech, 40% oak	767
Solid wood	Pine heartwood	561
Solid wood	Beech heartwood	660
Solid wood	Oak heartwood	683

[a]Air dry mass/air dry volume basis.

Table 2
Accelerated aging cycles in the ASTM D 1037-96a test method

Cycle	Exposure (°C)	Time (h)
1	Soaking in water, 49°C	1
2	Steaming, 93°C	3
3	Freezing, –12°C	20
4	Heating, 99°C	3
5	Steaming, 93°C	3
6	Heating, 99°C	18

2.2. Test specimens

Solid wood specimens, to serve as controls, were obtained from heartwood portions of trees used for the MDF production. MDF test specimens were subjected to a volatilization schedule to remove free formaldehyde and low molecular weight resin compounds. Solid wood specimens were also subjected to the same procedure.

2.3. Accelerated aging

Before fungal decay resistance tests, the MDF and solid wood specimens were subjected to six complete cycles of accelerated aging test according to ASTM D 1037-96a standard method (ASTM, 1998a) to reproduce the effects that would occur over time in service by using more aggressive conditions. Table 2 shows the cycles in the aging test. After the completion of six cycles of exposure, the MDF and wood specimens were conditioned at 20°C and 65% relative humidity (RH) for 48 h before fungal decay resistance tests.

2.4. Fungal bioassay

MDF and solid wood specimens, $25 \times 25 \times 9$ mm^3, were subjected to a modified decay resistance test. Twelve replicate specimens of each MDF and wood type were dried

Table 3
Decay resistance expressed as either weight loss or residual weight according to ASTM D 2017-81

Average weight loss (%)	Average residual weight (%)	Indicated class of resistance to a specified test fungus
0–10	90–100	Highly resistant
11–24	76–89	Resistant
25–44	56–75	Moderately resistant
45 or above	55 or less	Slightly resistant or non-resistant

to constant weight and steam-sterilized at 100°C, weighed, and exposed to two brown-rot fungi, *Gloeophyllum trabeum* (Pers. ex Fr.) Murr. (Mad 617) and *Postia placenta* (Fries) M. Larsen et Lombard (Mad 698) and white-rot fungus, *Trametes versicolor* (L. ex Fr.) Pilat (Mad 697) in a modified soil-block test according to ASTM D 2017-81 test method for solid wood (ASTM, 1998b). After 12 weeks of incubation at 27°C and 70% RH, the surface fungus mycelium was removed, the specimens were dried at 60"C, and weight losses were determined as percentage of total MDF and solid wood specimen mass. The percent weight loss in the test specimens provided a measure of the relative decay susceptibility or, inversely, of decay resistance of the sampled material. The specimens were classified after testing using the ranges described in Table 3.

2.5. Termite bioassay

MDF specimens, 34 × 28 × 3 mm^3, were obtained from outer and inner parts of the MDF boards (Fig. 1) and subjected to termite bioassay according to no-choice test procedure based upon AWPA El-97 (AWPA, 1999) and ASTM D 3345-74 (ASTM, 1998c) standard methods. Solid wood specimens from heartwood portions of the trees were also tested for comparison. Five specimens for each MDF and solid wood group were tested. Test specimens were placed in the center of a cylindrical plastic container (50 mm in diameter and 38 mm in height) with 1 g of eastern subterranean termites, *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae) (undifferentiated, nymphal, soldier forms). The specimens were set upon 1 g of washed sand and covered with a wet 42.5 mm Whatman filter paper circle as a food source and to maintain humidity. The containers were maintained at 25°C and 80% RH for 4 weeks. At the end of the bioassay, MDF and wood specimens were removed from the containers, cleaned, oven-dried and reweighed to determine weight losses and termite survival rates were recorded. In addition, each specimen was examined and visually rated using a standard rating system (AWPA, 1999; ASTM, 1998c) (Table 4).

Table 4
Rating system for visual examination of termite damage in the specimens

Rating	Severity of termite attack
10	Sound, surface nibbles permitted
9	Light attack
7	Moderate attack, penetration
4	Heavy attack
0	Failure

3. Results and discussion

3.1. Fungal bioassay

Average weight losses of the MDF and solid wood specimens exposed to accelerated aging and test fungi *G. trabeum, P. placenta,* and *T. versicolor* for 12 weeks are given in Figs. 2, 3, and 4, respectively. There was a significant effect of board composition on the susceptibility of MDF specimens to G. *trabeum* attack (Fig. 2). MDF specimens made from oak and mixed furnish were more resistant to *G. trabeum* attack than pine and beech MDF specimens. Average weight loss in MDF specimens containing 100% oak was 11.3%, while the average weight loss in MDF specimens produced from mixed furnish was 13.6%. MDF specimens containing beech were the least resistant compared to other MDF specimens. In addition, accelerated aging in both MDF and solid wood specimens caused more weight loss. Despite lower percentage weight losses of MDF specimens, higher weight losses were determined in solid wood specimens exposed to *G. trabeum.* When compared to MDF specimens, the effect of accelerated aging was lower in solid wood specimens. This comparison of aged and unprocessed MDF and solid wood specimens should be helpful in determining the effects of water, steam, and temperature during the accelerated aging procedure.

Compared to *G. trabeum, P. placenta* caused lower weight losses in all MDF and solid wood specimens with few exceptions (Fig. 3). MDF specimens containing pine showed similar weight losses to MDF specimens produced from oak and mixed species against *P. placenta.* MDF

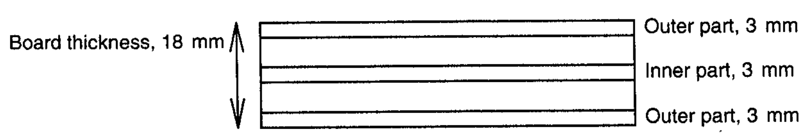

Fig. 1. Outer and inner MDF parts obtained from the boards for termite bioassays.

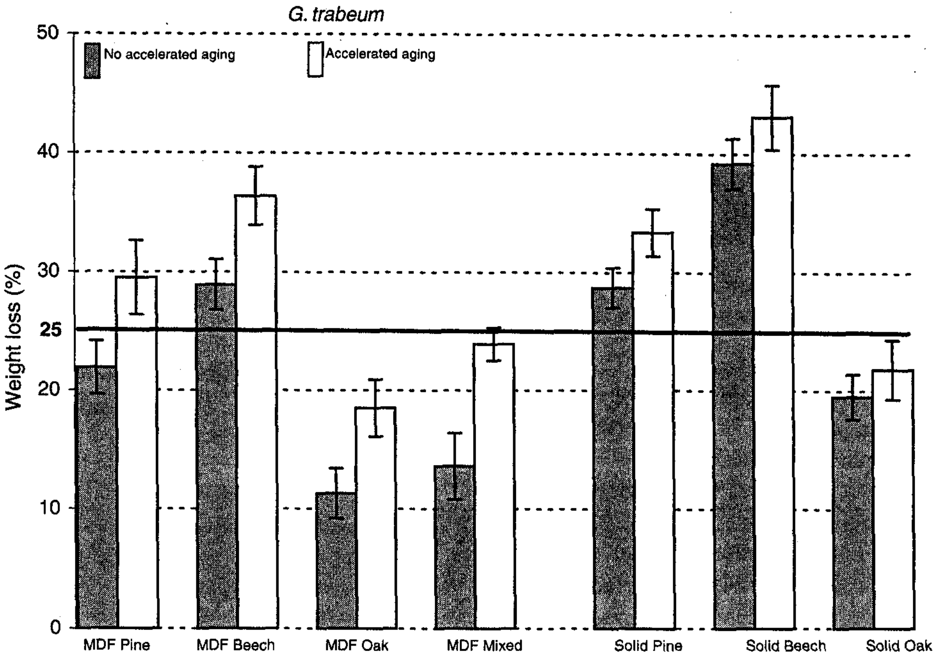

Fig. 2. Weight losses in MDF and solid wood specimens after 12-week exposure against G. trabeum. Each value represents the means of 12 replications. Specimen with weight loss of < 25% is classified resistant.

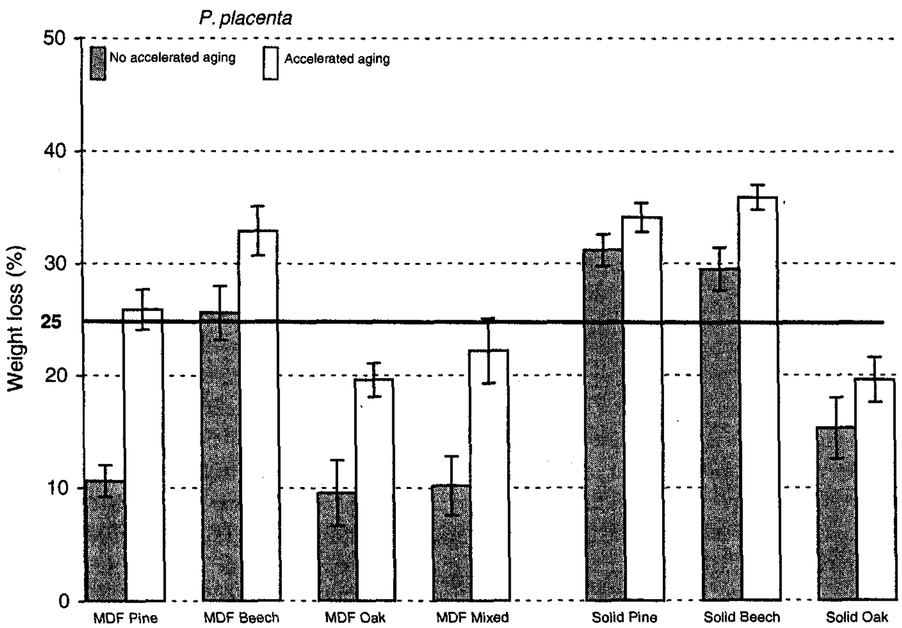

Fig. 3. Weight losses in MDF and solid wood specimens after 12-week exposures against *P. placenta.* Each value represents the means of 12 replications. Specimen with weight loss of < 25% is classified resistant.

specimens containing beech were the least resistant to *P. placenta,* and showed weight losses similar to solid beech. Compared to *G. trabeum,* accelerated aging had a similar effect on weight losses of MDF specimens made from pine, oak, and mixed furnish.

T. versicolor caused decreased weight losses in MDF specimens produced from pine, oak, and mixed furnish compared to the brown-rot fungus, *G. trabeum* (Fig. 4). Weight losses in pine and oak solid wood specimens exposed to *T. versicolor* were greatly decreased compared to *G. trabeum,* while weight losses in beech solid wood specimens greatly increased. In the *T. versicolor* bioassay, MDF specimens containing beech furnish and beech wood specimens showed the least resistance, i.e. greatest weight

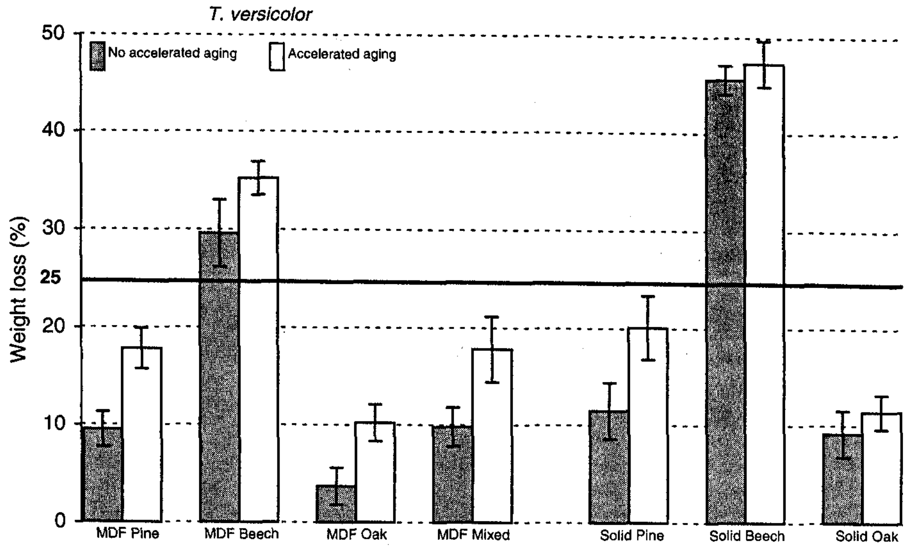

Fig. 4. Weight losses in MDF and solid wood specimens after 12-week exposure against *T. versicolor.* Each value represents the means of 12 replications. Specimen with weight loss of < 25% is classified resistant.

losses among the specimens tested (29.6% and 45.6%, respectively).

According to ASTM D 2017-81 (ASTM, 1998b) (Table 3), MDF specimens made from oak were "highly resistant" to *P. placenta* and *T. versicolor.* In addition, MDF specimens containing mixed furnish were "resistant" to *G. trabeum* and *P. placenta,* and "highly resistant" to *T. versicolor.* MDF specimens produced from beech wood were "moderately resistant" to decay with these specified fungi.

Studies show that composite materials made from durable wood species are resistant to decay by wood degrading fungi (Okoro et al., 1984; Kamdem and Sean, 1994; Evans et al., 1997). In our study, it was found that MDF specimens made from oak and mixed furnish (40% oak) showed more resistance to both brown and white-rot fungi although oak wood showed greater weight loss. Oak wood is generally known to be resistant or moderately resistant to wood-degrading fungi due to high tannin content in heartwood portions which contribute to protect wood. Also the heartwood of white oak is occluded with tyloses. Blocking cell cavities by tyloses in the vessel may explain the greater durability of oak heartwood (Panshin and Zeeuw, 1980). On the other hand, accelerated aging decreased decay resistance of MDF and solid wood specimens. This could possibly result from the increased porosity of the MDF specimens due to hyphal penetration and consequent increased degradation because of the aging interacting with the urea formaldehyde resin and weakened wood fibers. Since urea formaldehyde resins are not water resistant, specimen swelling provides greater access to wood fiber after accelerated aging. In other words, wood-degrading fungi cannot readily penetrate the urea formaldehyde resin-bonded specimens to gain access to the wood fiber before aging. In addition to these factors, prolonged soaking in water may result in leaching of the water-soluble substances and hence reduce decay resistance. Reduction in decay resistance by heat application varies from insignificant to considerable, depending on the wood species, and intensity and duration of heat application (Panshin and Zeeuw, 1980).

3.2. Termite bioassay

Average weight losses and percentage survival of termites of MDF and solid wood specimens during the termite bioassays are shown in Table 5. There was no significant effect of board composition on the susceptibility of MDF specimens to termite attack during the 4-week termite bioassay. Weight losses in MDF specimens made from beech and mixed furnish were lower than those in MDF specimens containing pine and oak furnish. Average weight loss in the outer parts of MDF specimens containing beech where a 75% of termite survival rate was obtained was 15.2%.

Despite the lower percentage weight loss (6.3%) in oak solid wood, termites caused more weight losses (34.4%) in MDF specimens made from oak furnish. Weight losses in MDF specimens containing beech furnish and beech solid wood were similar in accordance with percentage weight losses in MDF and solid wood from oak (Table 5).

It was observed that mixed outer MDF parts were susceptible to mould growth during termite bioassays although no mould can grow on the MDF specimens in soil bottle tests due to sterile conditions.

Average visual rating of the specimens reflected weight losses of all specimens (Table 5). Termite survival rate is not related to weight loss at all. Termite deaths did not occur in the containers with one exception in the outer parts of MDF

Table 5
Weight losses and termite survival of MDF and wood specimens during the termite assay[a]

Specimen type	Composition	Initial weight (g)	Final weight (g)	Weight loss (g)	Weight loss	Termite survival (%)	Average visual rating
MDF	100% pine						
outer		2.7 (0.04)	1.7 (0.11)	1.0 (0.09)	38.2 (3.63)	100.0 (0.00)	2.4
inner		2.1 (0.02)	1.0 (0.33)	1.0 (0.32)	49.9 (15.60)	100.0 (0.00)	1.0
					Average: 44.1		
MDF	100% beech						
outer		2.5 (0.04)	2.1 (0.23)	0.4 (0.26)	15.2 (10.24)	75.0 (38.19)	8.0
inner		2.2 (0.02)	1.5 (0.11)	0.7 (0.11)	32.1 (5.14)	100.0 (0.00)	1.0
					Average: 23.7		
MDF	100% oak						
outer		2.6 (0.03)	1.6 (0.17)	1.0 (0.14)	38.0 (5.97)	100.0 (0.00)	1.0
inner		2.2 (0.06)	1.5 (0.20)	0.7 (0.21)	30.7 (9.56)	100.0 (0.00)	1.6
					Average: 34.4		
MDF	Mixed						
outer		2.5 (0.21)	1.9 (0.21)	0.6 (0.11)	24.3 (4.63)	100.0 (0.00)	2.0
inner		2.2 (0.25)	1.6 (0.34)	0.6 (0.16)	27.4 (8.79)	100.0 (0.00)	0.8
					Average: 25.9		
Solid wood	Pine heartwood	1.8 (0.06)	1.2 (0.09)	0.6 (0.06)	32.5 (3.95)	100.0 (0.00)	0.6
Solid wood	Beech heartwood	2.0 (0.08)	1.7 (0.14)	0.3 (0.17)	15.1 (8.37)	100.0 (0.00)	7.4
Solid wood	Oak heartwood	2.5 (0.19)	2.3 (0.28)	0.1 (0.11)	6.3 (5.17)	100.0 (0.00)	9.0

[a]Each value represents the means of 5 replications. Values in parentheses are standard deviations.

specimens made from beech. MDF specimens from oak and pine furnish were preferred as a food source by termites used in the tests, but even other MDF specimens and pine solid wood were susceptible to termite damage caused by the feeding of termites. Results of the present study show that although MDF specimens made from oak and mixed furnish showed resistance against wood-degrading fungi, the same specimens were attacked by the termites. Panshin and Zeeuw (1980) stated that wood resistant to fungal attack may or may not be durable when subjected to attack by insects or marine borers.

4. Conclusions

MDF specimens produced from pine, beech, oak, mixed species and solid wood specimens were exposed to fungal bioassay using the brown-rot fungi, *G. trabeum* (Pers. ex Fr.) Murr. (Mad 617) and *P. placenta* (Fries) M. Larsen et Lombard (Mad 698), and the white-rot fungus, *T. versicolor* (L. ex Fr.) Pilat (Mad 697) and termite bioassay based on no-choice test using the subterranean termite, *R. flavipes* (Kollar). In the fungal bioassays, MDF specimens made from oak and mixed furnish (20% pine, 40% beech, and 40% oak) showed more resistance against all fungi tested. Accelerated aging before fungal bioassay made the MDF specimens less resistant to fungal decay. Although higher weight losses were determined in MDF specimens containing beech furnish compared to other MDF specimens, MDF specimens produced from beech and mixed furnish showed lower weight losses in the termite bioassays. This could possibly result from the feeding behavior of the termites. Ohmura et al. (1999) stated that while heartwood extractives are known to exhibit strong feeding-deterrence of woods to termites, some kinds of wood components affect the feeding-preference activities of some termite species. Our results showed that European oak heartwood was the most resistant to termite attack. Oak wood belonging to the white oak group are "highly resistant" or "resistant" to wood degrading fungi due to heartwood extractives and tyloses in the vessels (Panshin and Zeeuw, 1980).

Since pressure to restrict the use of wood preservatives in wood products has been increasing, alternative approaches to increasing the resistance of composite products are important. It is possible to increase the resistance of MDF products to biodegradation especially in regions of low to moderate decay hazard using naturally durable wood species. The results of this study show that decay resistance of MDF products may be enhanced by adding oak wood to wood furnish. On the other hand, termites still can degrade MDF specimens made from oak wood. Thus, addition of environmentally benign biocides to MDF furnish prior to board manufacture will help increase the resistance of MDFs to biodegradation in areas of severe decay and termite hazard.

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