Article

Application of Laboratory Fungal Resistance Tests to Solid Wood and Wood–Plastic Composite

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ABSTRACT

The fungal resistance of high density polyethylene filled with 50% wood flour was investigated using laboratory soil block tests. Modifications to standard test methods were made to increase initial moisture content, increase exposure surface area, and track moisture content, mechanical properties, and weight loss over the exposure period. Mechanical properties decreased after 12 weeks exposure to *Gloeophyllum trabeum* and *Trametes versicolor.* However, irreversible damage due to water sorption made separating the effects of fungal attack and water sorption difficult. When compared on a dry basis, small weight reductions after fungal exposure suggest some attack by *G. trabeum.* Further modifications to test methodology are suggested.

INTRODUCTION

A growing number of companies are producing wood–plastic composite (WPC) profiles for exterior applications. While deck board manufacture is growing tremendously, other exterior applications such as railings, windows, siding, and roofing are also growing or are under development. Though WPCs are more expensive than traditional decking materials (e.g., treated lumber), WPC manufacturers claim increased durability, no warping or cracking, and low maintenance.

Little consistent infomation on fungal resistance is available in the literature. Morris and Cooper [1] reported fungal growth on WPC decking after 4 years of service in Florida. Mankowski and Morrell [2] evaluated several proprietary WPCs by laboratory soil block tests. Weight loss varied from 0.4% to 20.4% depending on the fungi used and type of composite. Researchers have also investigated the fungal resistance of model composites, but the literature to date is far from conclusive. Khavkine et al. [3] found that fungal attack caused little weight loss in polyethylene composites containing 40% to 70% wood, despite good fungal colonization on the composite surfaces and a conditioning procedure that included oven drying at 105°C (221°F) for 24 h, a 2-h boil, and a 24-h water soak. However, using a modified soil block procedure, Verhey et al. [4] found significant weight loss in composites containing 60% or greater wood content. In evaluating more complex formulations, Pendelton et al. [5] found that for formulations without zinc borate, weight loss occurred if wood content was 53% or greater. These conflicting and confusing results are not surprising considering the wide range of formulations evaluated (i.e., different types and quantities of fiber, plastic, and additives), as well as different processing and test methodologies.

Agencies involved in building codes tend to specify fungal resistance tests based on laboratory soil block tests for wood (e.g., ASTM D 1413 [6] or ASTM D2017 [7]). However, WPCs react quite differently from solid wood in a solid block environment. This paper focusus on preliminary research that attempts to better understand the differences between WPCs and solid wood as tested by a modified version of the ASTM D1413 test protocol.

EXPERIMENTAL METHODS

The plastic was high density polyethylene (HDPE) from reprocessed milk bottles, with a melt flow index of approximately 0.7g/10 min, obtained from H. Muehlstein and Co., Inc, (Roswell, GA).

The wood filler was mominal 40-mesh (420-µm) western pine wood flour from American Wood Fibers (Schofield, WI). The wood flour was dried and then compounded with HDPE in a 32-mm (1.3-inch) compounding, twin-screw extruder (Davis Standard, Pawcatuck, CT). The compounded pellets were then injection molded into flexural specimens, 3 by 13 by 127 mm (1/8 by 1/2 by 5 inches), using a 33-ton reciprocating-screw injection molder (Cincinnati Milacron, Batavia, OH). These specimens were cut to 89 mm (3.5 inches) and tested for fungal resistance according to a modified procedure based on ASTM D 1413 [6]. Southern pine sapwood specimens were also tested to compare the behavior of the solid wood and composite materials.

In ASTM D 1413 [6]. specimens are placed in a sterilized bottle containing moist soil and weight loss is measured after 12 weeks of exposure to decay fungi. To investigate the fungal resistance of the WPCs, changes were made to ASTM D 1413 in regard to specimen size, length of feeder strips, and number of inoculations [6]. Specimen size was changed from 19 by 19 by 19 mm (3/4 by 3/4 by 3/4 inches) to 3 by 13 by 89 mm (1/8 by 1/2 by 3½ inches) to conform to span and depth requirements for ASTM D 790-84 [8]. The longer length allowed the specimen to fit into a standard soil bottle turned on its side. Longer feeder strips and several fungal inoculations along the specimen length were also necessary. The decrease in specimen thickness increased the surface-to-volume ratio, facilitating moisture sorption and increasing fungal exposure area.

Two conditioning procedures were investigated to accelerate the moisture sorption of the composite samples: either 2 weeks of leaching according to ASTM D 1413 or cyclic boiling and drying, consisting of 5 cycles of a 2-h boil followed by 24 h oven drying at 105°C (221°F). After each conditioning procedure, the specimens were placed in a humidity mom at 65% relative humidity and 27°C (81°F) for 4 weeks.

Soil bottles were inoculated with the brown-rot fungus *Gloeophyllum trabeum* (Madison 617) or the white-rot fungus *Trametes versicolor* (Madison 697). At 4, 8, and 12 weeks of fungal exposure, specimens were removed from the bottles and their weight loss and moisture content were determined. Four-point flexural tests were performed on oven-dried specimens according to ASTM D 790-84 [8]. In all cases, failure occurred between the load points in the center third of the specimen.

RESULTS AND DISCUSSION

Because of its common use to assess susceptibility of exterior wood building products to decay, ASTM D 1413 was examined for assessing WPCs intended to replace these same wood products. However, WPCs absorb moisture very slowly, and both the 3-week conditioning time and 12-week incubation time arc insufficient for the samples to reach equilibrium for the sample size used in the standard (19-mm (3/4-inch) cubes). To develop an appropriate fungal exposure test method and to more fully explore material behavior during fungal exposure tests, modifications to ASTM D 1413 were made (see Experimental Methods).

Specimens were weighed before and after drying at different fungal exposure times to track changes in moisture content and weight loss (oven-dry basis) resulting from fungal attack. The loss in flexural performance was also investigated.

Moisture Content

Untreated solid wood is included in the soil bottle tests as a check for fungal activity. It can also be used as a relative benchmark for fungal decay. However, untreated solid wood must be stained or painted before use in exposed, exterior applications Favorable performance of a material in a soil bottle test relative to the performance of untreated wood should not be used to justify suitability of the material for exterior use. Nonetheless, comparing the performance of solid wood and WPCs in soil bottle tests is useful in investigating test methodology.

Solid wood showed large increases in moisture content during fungal exposure (Figure I). Leached solid wood exposed to *T. versicolor* absorbed the least amount of moisture (40%) in the 12-week exposure period. Wood exposed to this white-rot fungus appeared to reach equilibrium within the first 4 weeks of the test When exposed to the brow-rot fungus *G. trabeum*, solid wood continued to absorb water throughout the test, ending with moisture content in excess of 100%. Even at 4 weeks, all the solid wood samples had absorbed more than the approximately 25% to 30% moisture required for fungal attack [9].

The WPCs performed quite differently. Maximum moisture content was about 12% to 13% for both boiled and leached composites regardless of the fungus used. Boiled composites appeared to approach this maximum more quickly than did leached composites, but all composites reached maximum moisture content levels much later than did solid wood. Whether or not 12% to 13% moisture content represents the maximum moisture exposure is uncertain since the moisture content of some specimens appeared to be increasing, albeit slowly, at the end of the tests.

Assuming that all the moisture is absorbed by the wood flour, the moisture content of the wood flour in the composite would be about 25%. This is close to the critical moisture content of 25% to 30% necessary for fungal decay [9]. A moisture gradient may well exist through the thickness of the sample, resulting in more moisture near the sample surface. Based on moisture alone, WPCs represent a borderline case for fungal attack. Even if the critical moisture content is reached, it may be reached late in the test, leaving insufficient time for significant fungal attack. The long time for composites to absorb water continues to be a potential limitation of this modified test despite the use of thin specimens.

Weight Loss

Decay caused large weight losses (12% to 70%) in solid wood. The largest weight losses were for solid wood exposed to *G. trabeum* (Figure 2). This aggressive attack on softwood sapwood is why brown-rot fungi such as *G. trabeum* are often used in soil block tests.

Weight losses for composite samples were much smaller than those for solid wood (Figure 3). The greatest weight loss was about 3% for boiled composites exposed to *G. trabeum.* Since decay fungi do not attack HDPE, this corresponds to about a 6% weight loss in wood flour.

Flexural Testing

Researchers have used loss in mechanical performance of wood as a sensitive measure of incipient fungal attack [e.g., 10]. Because wood flour rather than wood fiber is often used as a filler in many WPCs, the sensitivity of WPC mechanical properties to fungal attack is probably not as great as that of solid wood. Nevertheless, loss in mechanical performance could help corroborate weight loss results. Flexural tests were performed to determine how the mechanical properties of WPCs are affected by fungal attack. Modulus maximum stress and work required to reach maximum stress were determined in soil block tests before exposure and after 4, 8, and 12 weeks of exposoure.

Flexural strength of solid wood decreased more than that of the composites (Figures 4 and 5). When exposed to *G. trabeum,* many solid wood specimens were so degraded after only 8 weeks that they could not be tested. Not surprisingly, the strength of solid wood specimens in soil bottles without fungi was similar after drying to their strength before exposure,

AS expected, WPCs performed quite differently from solid wood specimens. The WPCs showed small but significant losses in flexural strength over exposure time (Figure 5). However, strength loss also occurred in specimens from soil bottles that had not been inoculated with fungus (Figure 6). Because strength comparisons were made on a dry basis, these results suggest irreversible damage due to moisture sorption. Hence, to determine the effect of fungal attack, the flexural strength of composites exposed to fungi should be compared with that of unexposed composites. This comparison assumes that the composites (with or without fungi) have similar moisture sorption histories.

Because weight losses suggest little fungal decay, it is not surprising that strength loss due to fungal attack was also low. The largest strength loss due to fungal attack was 5% for boiled composites exposed to *G. trabeum.* Further investigation is warranted to better assess the sensitivity of mechanical performance to fungal attack

Research Needs

This investigation suggests several avenues for further study. Because most WPCs are extruded rather than injection molded, tests should be performed on extruded samples. This is especially important since wood flour is a compressible tiller. Extrusion results in composites with lower density compared with that of injection molded composites. In addition, a polymer-rich surface layer does not form on extruded composites and, consequently, water is more readily absorbed (Figure 7). The higher moisture content of extruded composites may very well lead to greater fungal attack than that observed in the present investigation. Research on extruded composites is ongoing [11].

Whether WPCs are susceptible to fungal attack in laboratory tests is only one piece of information in the full assessment of fungal durability. If WPCs do show some susceptibility to fugal attack in laboratory tests, in what service environments does this susceptibility become a problem? This investigation is part of a larger project that is beginning to answer this question. Field tests on extruded composites, both in- and above-ground, have begun in Mississippi and Wisconsin. Though these field tests take considerable time, they represent an exposure more representative of in-service conditions where there is a variety of fungi as well as stresses from other environmental exposures (e.g., ultraviolet radiation, freeze-thaw cycles). These combined exposures may provide a harsher environment as a result of synergism and more rapid degradation than that caused by a single type of exposure.

Concluding Remarks

Though current fungal resistance standards are appropriate for solid wood, slow moisture sorption creates difficulties in their use for wood-plastic composites (WPCs). In this study, a modified test was developed and evaluated for use with WPCs. Further refinement of this method is necessary, especially to overcome difficulties posed by the slow moisture sorption of WPCs. Tests are currently being performed on extruded composites. which absorb moisture more readily and thus may prove more prone to decay. Ultimately, these results should be combined with field tests to provide a more complete picture of fungal durability,

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REFERENCES

1. Morris, P.I. and P. Cooper, "Recycled Plastic/Wood Composite Lumber Attacked by Fungi," *Forest Products Journal,* **48(1):** 86—88 (1998).

2. Mankowski, M. and J.J. Morrell, "Patterns of Fungal Attack in Wood–Plastic Composites Following Exposure in a Soil Block Test", *Wood and Fiber Science.* **32(3):** 341–345(2000).

3. Khavkine, M., M. Kazayawoko, S. Law, and J J. Balatinecz, "Durability of Wood Flour–Thermoplastic Composites Under Extreme Environmental Conditions and Fungal Exposure", *International Journal of Polymeric Materials,* **26:** 255–269 (2001).

4. Verhey, S., P. Laks, and D. Richter, "Laboratory Decay Resistance of Woodfiber/Thermoplastic Composites," *Forest Products Journal,* **51(9):** 44-49 (2001).

5. Pendleton, D. E., T. A. Hoffard, T. Adcock, B. Woodward, and M.P. Wolcott, "Durability of an Extruded HDPE/Wood Composite," *Forest Products Journal,* **52(6);** 21–27(2002).

6. ASTM International, "Standard Test Method for Wood Preservatives by Laboratory Soil-Block Cultures," ASTM D 1413-99, *Annual Book of Standards, Vol. 4.10,* West Conshohockon, PA (2002).

7. ASTM International, "Standard Test Method for Accelerated Laboratory Test of Natural Decay Resistance of Woods," ASTM D 2017–94,*Annual Book of Standards. Vol. 4.10,* West Conshohockon, PA (2002).

8. ASTM International, "Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials," ASTM D 790-84, *Annual Book of Standards,* West Conshohockon, PA (1990).

9. Carll C. G. and T. L. Highley, "Decay of Wood and Wood-Based Products Above Ground in Buildings." *Journal of Testing and Evaluation,* **27(2):** 150–158(1999).

10. W. Wilcox, "Review of Literature on the Effects of Early Stages of Decay on Wood Strength," *Wood and Fiber,* **9(4):** 252–257(1978).

11. Clemons, C. M. and R E. bach. "Effects of Processing Method and Moisture History on Laboratory Fungal Resistance of Wood–HDPE Composites," submitted to *Forest Products Journal.*

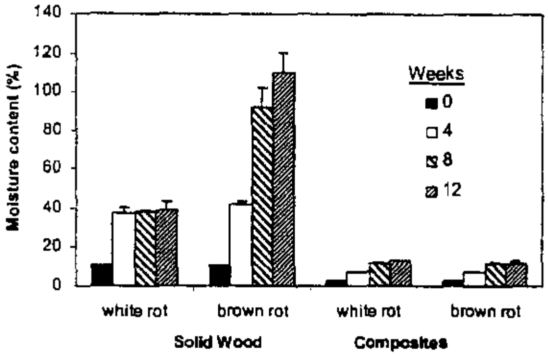

Figure 1. Water sorption of leached solid wood and WPCs exposed to the white-rot fungus *T. versicolor* and the brown-rot fungus *G. trabeum* in soil bottle tests.

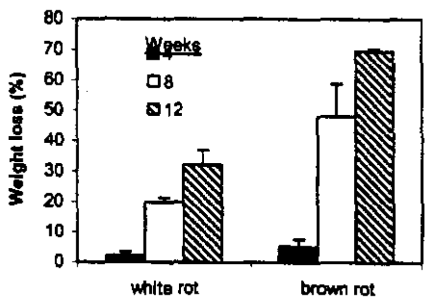

Figure 2. Weight loss of solid wood exposed to white- and brown-rot fungi in soil bottle tests (boiled samples).

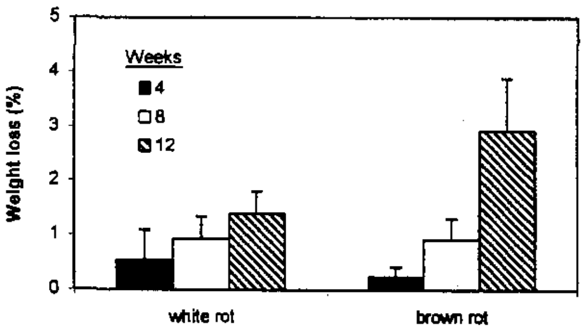

Figure 3. Weight loss of WPCs exposed to white- and brown-rot fungi in soil bottle tests (boiled samples).

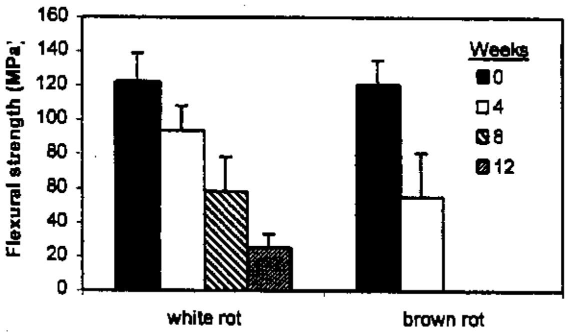

Figure 4. Strength loss of solid wood exposed to white- and brown-rot fungi in soil block tests (boiled samples). Specimens exposed to brown-rot fungus for 8 and 12 weeks were too degraded to test.

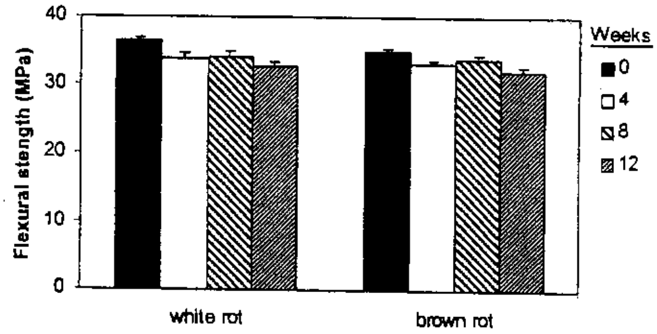

Figure 5. Strength loss of WPCs exposed to white- and brown-rot fungi in soil block tests (boiled samples).

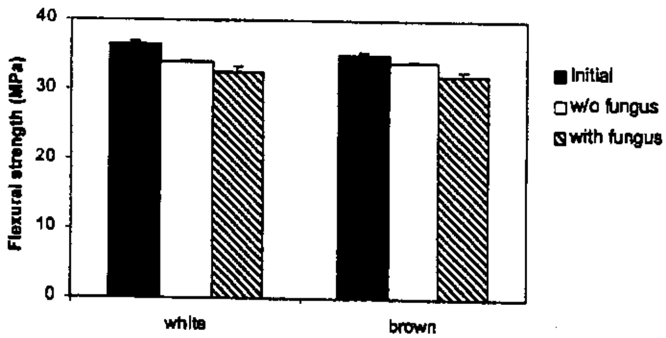

Figure 6. Flexural strength of WPCs before and after 12-week exposure to fungi (leached samples).

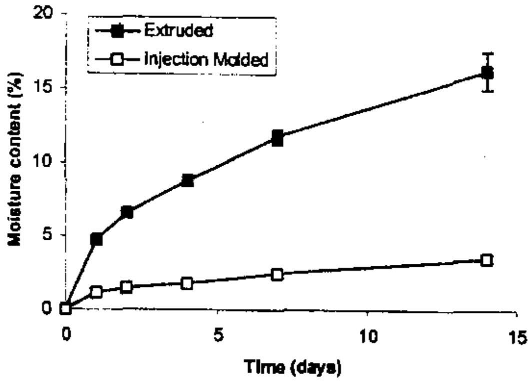

Figure 7. Moisture sorption of WPCs processed by several methods.

Source: Plastics in Building Construction, Feb2003, Vol. 27 Issue 2, p7-14, 8p, 7 graphs