Laboratory Tests on Fungal Resistance of Wood Filled Polyethylene Composites

Craig M. Clemons, USDA Forest Service, Forest Products Laboratory
Rebecca E. Ibach, USDA Forest Service, Forest Products Laboratory

Abstract

A standard method for determining the durability of structural wood was modified for testing the fungal resistance of composites made from high density polyethylene filled with 50% wood flour. Moisture content, mechanical properties, and weight loss were measured over 12 weeks exposure to brown- and white-rot fungi. Mechanical properties were decreased, but irreversible damage due to water sorption made separating this effect from that of fungal attack difficult. Further modifications to test methodology are suggested.

Introduction

An increasing number of companies are producing wood–plastic composite profiles for exterior applications. The use of composites for decks is growing tremendously, and other exterior applications such as railings, windows, siding, and roofing are also being investigated. Although wood-plastic composites are more expensive than traditional decking materials (e.g., treated lumber), manufacturers of these composites claim increased durability, no warping or cracking, and low maintenance. Many studies have examined the mechanical properties of wood-plastic composites, but little information on their durability exists in the public domain. The objective of our study was to investigate laboratory test methodology for determining the fungal resistance of wood–plastic composites. We chose ASTM D1413 because it is commonly used to assess the durability of exterior building products. We modified the method to increase initial moisture content, increase exposure surface area, and track moisture content, mechanical properties, and weight loss over the exposure period.

Experimental Methods

The plastic material was high density polyethylene (HDPE) from reprocessed milk bottles (Muehlstein and Co., Inc., Roswell, GA), with a melt flow index of approximately 0.7 g per 10 min. The wood filler was a nominal 40 mesh (420 µm) western pine wood flour from American Wood Fibers (Schofield, WI).

wood flour was dried and then compounded with HDPE in a 32-mm compounding twin-screw extruder (Davis Standard, Pawcatuck, CT). The compounded pellets were injection molded into flexural specimens (3 by 13 by 127 mm) using a 33-ton reciprocating-screw injection molder (Cincinnati Milacron, Batavia, OH). The specimens were cut and tested for fungal resistance. For comparison, specimens cut from southern pine sapwood were also tested.

ASTM D1413 was modified to compare the behavior of solid wood and composite materials. In ASTM D1413, specimens are placed in a sterilized bottle containing moist soil and weight loss is measured after 12 weeks exposure to decay fungi.[1] To investigate fungal resistance of wood-plastic composites, ASTM D1413 was modified by (1) changing specimen size, (2) measuring weight loss after 4, 8, and 12 weeks exposure, (3) adding flexural tests, and (4) measuring moisture content.

Specimen size was changed from 19 by 19 by 19 mm to 3 by 13 by 89 mm to conform to span and depth requirements of ASTM D790–84.[2] The 89-mm 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: 2 weeks of leaching according to ASTM D1413 or cyclic boiling and drying, consisting of 5 cycles of a 2-h boil followed by 24 h of oven drying at 105°C. After conditioning, specimens were placed in a humidity room at 65% relative humidity and 27°C 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. There were two sets of controls: the original dry specimens and specimens exposed for 4, 8, and 12 weeks without fungal inoculation.

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[1]ASTM D1413, Annual Book of ASTM Standards, Vol. 8, American Society of Testing and Materials, West Conshohocken, PA, 1990.
[2]ASTM D790-84, Annual Book of ASTM Standards, Vol. 8, American Society of Testing and Materials, West Conshohockon, PA, 1990.

Flexural tests were performed to determine the effect of fungal attack on mechanical properties. Four-point flexural tests were performed on oven-dried specimens according to ASTM D790–84. Maximum strength was determined before and after 4, 8, and 12 weeks exposure. In all cases, failure occurred between the load points in the center third of the specimen.

Results and Discussion

Moisture Content

Untreated solid wood is included in soil block 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. Therefore, favorable performance of a material in a soil block test relative to the performance of untreated wood should not be used to justify suitability of the material for exterior use. Comparing the performance of solid wood and wood–plastic composites in soil block tests was nonetheless usefull in investigating test methodology.

Solid wood showed large increases in moisture content during fungal exposure (Fig. 1). Leached solid wood exposed to white-rot fungi absorbed the least amount of moisture (40%) in the 12-week exposure period. Wood exposed to white-rot fungi appeared to reach equilibrium within the first 4 weeks of the test. When exposed to brown-rot fungi, 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.[3]

Wood-plastic composites 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 the 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.[3] A moisture gradient may well exist through the thickness of the sample, resulting in more moisture near the surface. Based on moisture alone, wood-plastic composites represent a borderline case for fugal 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%–70%) in solid wood. Exposure to brown-rot fungi caused the greatest weight loss (Fig. 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 (Fig. 3). The greatest weight loss was about 3% for boiled composites exposed to the brown-rot fugus. 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.[4] Since wood flour is used as a filler in many wood–plastic composites, the sensitivity of the mechanical properties of these composites to fungal attack is probably not as great as that of solid wood. Nevertheless, loss in mechanical performance could help corroborate weight loss results.

In all cases, failure occurred between the load points in the center third of the specimen. Flexural strength of solid wood decreased more than that of composites (Figs. 4 and 5). When exposed to brown-rot fungi, many solid wood specimens were so degraded after 8 weeks that they could not be tested. Not surprisingly, the strength of solid wood specimens in soil bottles without fungi was similar to that of the original wood.

Composite specimens showed significant, though small, losses in flexural strength over exposure time (Fig. 5). However, strength loss also occurred in specimens from soil bottles that had not been inoculated with fungus (Fig. 6). Since 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.

Since weight loss suggested little fungal decay, it is not surprising that strength loss due to fungal attack was also low. The greatest strength loss due to fungal attack was

[3] C.G. Carll and T.L. Highley, *Journal of Testing and Evaluation,* 27(2), 150–158, 1999.

[4] W. Wilcox, *Wood and Fiber,* 9(4), 525–257, 1978.

5% for boiled composites exposed to brown-rot fungi. Further investigation is warranted to better assess the sensitivity of mechanicial performance to fungal attack.

Research Needs

This investigation suggests several avenues for further study. Since most wood–plastic composites are extruded rather than injection molded, tests should be performed on specimens cut from extruded samples. This is especially important since wood flour is a compressible filler. Extrusion results in composites with lower density compared with the density of injection-molded composites. In addition, a polymer-rich surface layer does not form on extruded composites and water is more readily absorbed (Fig. 7). The higher moisture content of extruded composites may very well lead to greater fungal attack than that seen in the injection-molded composites in our study. Once a reasonable procedure has been developed for assessing fungal decay, treated wood samples should also be tested so that a relative comparison to composite materials can be made.

This investigation is part of a larger project on the durability of wood–plastic composites in exterior applications. Field tests on extruded composites, both in ground and above ground, are in progress in Mississippi and Wisconsin. Though these tests take considerable time, they represent a realistic exposure to attack from a variety of fungi and to stresses from other environmental effects (e.g., UV exposure, freeze cycles) at a specific location. Investigation of other durability issues, such as UV stability, is ongoing; results from combined fungal and UV exposures are forthcoming. Comparisons of wood–plastic composites with competing materials, such as treated wood, are also planned.

Conclusions

A standard method for determining durability was modified for testing the fungal resistance of wood–plastic composites. Our results show that further refinement of this method is necessary to overcome the difficulties posed by the slow moisture sorption of injection-molded wood–plastic composites. It may be possible to obtain better results with extruded composites, which absorb moisture more readily than do injection-molded composites. The results of this study should be combined with field tests to provide a more complete picture of fungal durability of wood–plastic composites.

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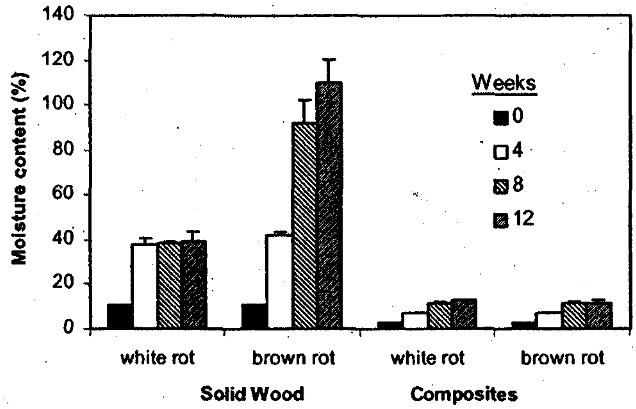

Figure 1—Water sorption of leached solid wood and wood–plastic composites exposed to white-rot (*T. versicolor*) and brown-rot (*G. trabeum*) fungi in soil block tests.

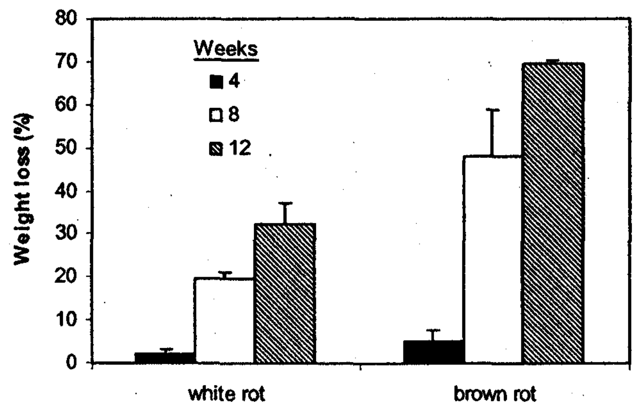

Figure 2—Weight loss of solid wood exposed to white- and brown-rot fungi in soil block tests.

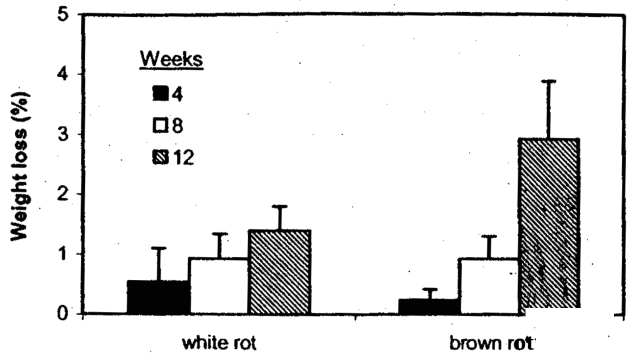

Figure 3—Weight loss of wood–plastic composites exposed to brown- and white-rot fungi in soil block tests.

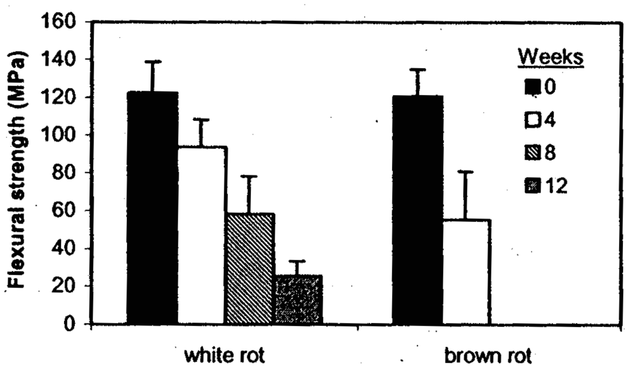

Figure 4—Strength loss for solid wood exposed to brown and white-rot fungi during soil block tests (boiled samples). Specimens exposed to brown-rot fungi for 8 and 12 weeks were too degraded to test.

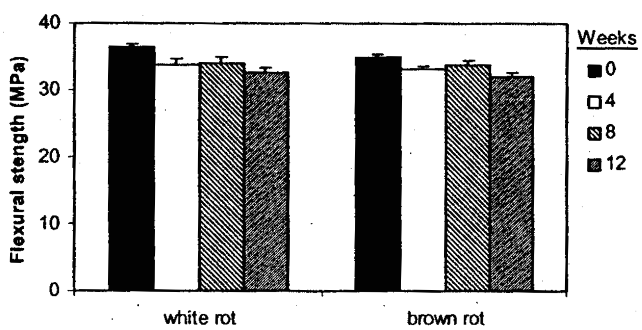

Figure 5 — Strength loss for wood–plastic composites exposed to white- and brown-rot fungi during soil block tests (boiled samples).

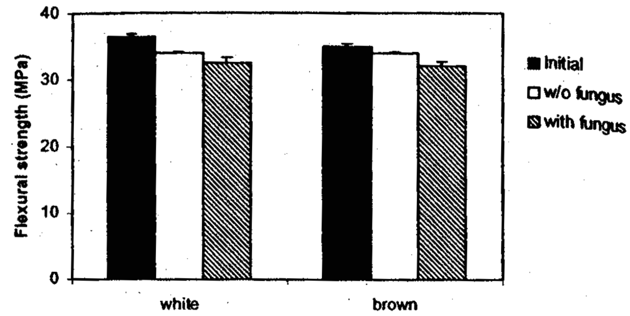

Figure 6—Strength of wood–plastic composites before and after 12-week exposure to fungi (leached samples).

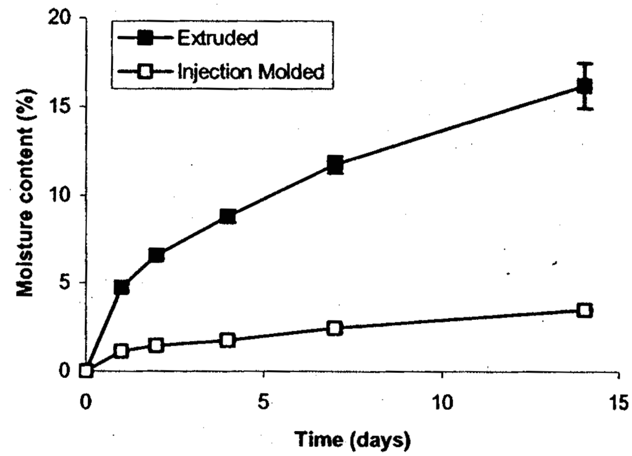

Figure 7 — Moisture sorption of wood–plastic composites processed by different methods.

Key words: fungal resistance, composites, soil block test, wood flour.

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