AMERICAN WOOD PROTECTION ASSOCIATION

Durability of Capped Wood Plastic Composites

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ABSTRACT

Manufacturers of wood plastic composites (WPCs) have recently introduced capped decking to their product lines. These new materials have begun to take market share from the previous generation of uncapped products that possessed a homogenous composition throughout the thickness of their cross-section. These capped offerings have been introduced with claims that the pure polymer cap provides protection to the wood/polymer interior, helps keep the composite core dry preventing water ingress and protects it from weathering and issues associated with biological degradation. This paper briefly reviews moisture absorption in WPCs and then focus on recent results from laboratory and field evaluations of capped WPC material. Preliminary results of these tests will be discussed in the context of durability of these products and provide some early insight as to the potential susceptibility of this new class of materials to biological degradation.

INTRODUCTION

The Wood-Plastic Composite (WPC) market has grown significantly over the past twelve years as the presence of WPCs continues to expand in the residential construction market as an alternative to solid wood decking material (Morton 2003, Stanton 2005, and Freedonia 2009, 2014). These products are used in exterior, above-ground applications and marketed to last up to 25 years with little maintenance. In 2009 Freedonia Group estimated WPC decking market share to be 11.5% of the total decking market. This number increased to 18.6% in 2014 (Freedonia 2014). As the market share of these products has grown so have concerns regarding the long term durability of WPCs exposed in exterior environments. The issue of moisture absorption and durability pertaining to WPC products has been extensively examined (Gnatowski 2005, 2009, Ibach et al. 2003, 2011, 2013, Laks and Verhey 2000, Laks et al. 2001, Mankowski, et al. 2005, Mankowski and Morrell 2000, Manning and Ascherl 2007, Manning et al. 2009, Morris and Cooper 1998, Pendleton et al. 2002, Schauwecker et al. 2006, Simonsen et al. 2001, Verhey et al. 2001, Verhey and Laks 2002).

Although once thought that the polymer matrix provided protection of the wood component in a WPC, it is becoming apparent through long term field exposure studies that this is not the case. Through both laboratory and, more importantly, field data, it has been demonstrated that sufficient amounts of water can be absorbed into the wood component of an uncapped WPC and facilitate the growth of decay fungi in the absence of a wood preservative (Gnatowski 2005, 2009, Mankowski et al. 2005, Ibach et al. 2003, 2013).

Growth requirements for wood decay fungi are: a digestible substrate (wood), oxygen, favorable temperature range (15-45^{o}C), favorable pH range (pH 3-6), chemical growth factors (N, vitamins), and water (minimum of 25-30% moisture content) (Zabell and Morrell, 1992). In wood and wood based systems the key growth requirement often lacking is the requisite moisture content. If the wood component of a WPC is capable of achieving 25-30% MC, then it may eventually be susceptible to fungal decay unless a preservative treatment is utilized, chemical modification of the wood component is used to keep moisture content (MC) below fiber saturation point (Mankowski et al. 2005, Manning and Ascherl 2007, Manning et al. 2009, Ibach and Clemons 2007). This has been observed in field samples after approximately two years. Boards were found to have high moisture content and more importantly, fungal fruiting bodies were found on uncapped WPC samples that were not treated with any biocide (Figure 1). Microscopic examination of these samples showed fungal hyphae colonizing wood particles in the WPC matrix 5 mm below the surface (Figure 2).

Figure 1: WPC in field exposure in Hilo, HI with wood decay fungus fruiting body after 2-3 years.

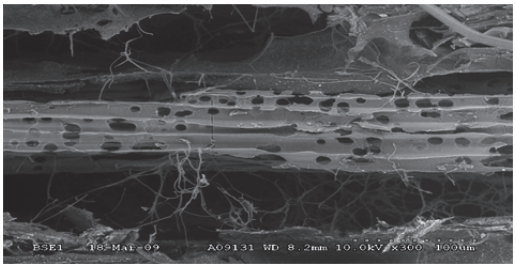

Figure 2: SEM image showing fungal hyphae at 5mm below surface of decayed WPC from field exposure in Hilo, HI after 2-3 years.

For wood plastic composites, artificial weathering tests carried out using industry accepted methods indicated low levels of moisture absorption occur (Gnatowski 2005, 2009, Ibach et al. 2003, Mankowski et al. 2005). This supported the idea that the % MC of the wood component is too low to initiate decay: ~5% versus the necessary minimum of 25% (Gnatowski 2005, 2009, Mankowski et al. 2005). However, analysis of the moisture content of large WPC boards exposed at field sites for less than 12 months in Hilo, HI showed moisture levels which are capable of initiating and supporting fungal decay (Gnatowski 2009, Mankowski et al. 2005) (Figure 1). To combat decay, some WPC producers use zinc borate as a fungicide. This biocide is added in the WPC manufacturing process and does not break down at high temperature or worker handling safety issues (Mankowski et al. 2005, Manning and Ascherl 2007, Manning et al. 2009). Recently an accelerated weathering test for conditioning WPC samples in the laboratory was standardized (AWPA, 2011). WPC samples exposed for 5 days at 70°C and then exposed to decay fungi showed similar weight losses to large WPC samples exposed in the field for 40 months (Ibach et al. 2013).

Co-extruded or capped decking has recently been introduced into this market to combat aesthetic issues caused by mold staining. In these materials, a core of wood plastic composite is surrounded by a shell of pure polymer to increase the products durability and lower its maintenance. Capped WPCs were introduced in 2010 and now have >80% share of the WPC decking market (Freedonia 2014). They consist of a 100% polymer cap co-extruded over the wood-plastic core. These products were designed to give increased performance against mold that commonly occurred and resulted in staining of uncapped WPCs. All WPC producers offer capped WPC lines and some now produce 100% capped material.

These new capped products appear to be less susceptible to moisture absorption and biological attack as was once thought with non-capped WPC products. Little to no information exists on performance of these products in long term field exposures or accelerated laboratory conditioning and decay tests. Although the polymer shell of the capped products should substantially protect the WPC core, the core can be exposed if this shell is broken particularly at a cross cut end on the WPC board. Many of the capped products are not capped on the bottom and this may lead to potential moisture uptake issues. Deformation attributed to moisture absorption at cut ends has been reported, but this study did not measure moisture levels (O'Neill 2011). Since WPCs absorb moisture slowly the potential for moisture to leave a WPC is also slow, thus increasing the ability for fungal metabolism if the exposed WPC has been colonized by decay fungi. Limited information exists on the potential long term impacts of moisture absorption and potential biological degradation on these materials.

In this study we expand on past work on the durability of uncapped WPCs by performing analogous field and laboratory tests on capped material. First, we performed a laboratory test examining varying amounts of cut surface exposure and accelerated conditioning on moisture content and decay using two white rot fungi isolated from WPC in the field. Secondly, we assessed moisture absorption and decay susceptibility of capped and uncapped WPCs exposed in the field for two years.

MATERIALS AND METHODS

Laboratory Testing

Laboratory testing used control samples of uncapped WPC with and without the biocide zinc borate manufactured at Washington State University, Wood Materials and Engineering Laboratory. The WSU samples were designated sample A and B. Sample A contained 0.0 % zinc borate and sample B contained 1.5% zinc borate. Samples were made with softwood wood flour.

These samples were used as a comparison to commercial uncapped and capped material also used in field tests. Two uncapped commercial samples produced by two different manufacturers, producer A and producer B were designated C and G. Two capped commercial products were from two different manufactures (A and B) were split into a series of three depending on cut surface exposure and degree of end sealing that will be described in the next section.. Series D, E, and F were samples from producer A's capped product and series H, I, and J were from producer B's capped product. Table 1 shows material used, treatment designation and the wood composition of all samples used in the tests.

Since the cut capped material had exposed edges, end sealing was performed to mask the cut ends of the samples. Edges were sealed with the polymer, acrylonitrile butadiene styrene (ABS). ABS was used as a sealant for cut areas of the capped material to simulate a cap. ABS pellets were dissolved in acetone and the liquefied plastic used to end seal cut edges of selected capped samples. Samples were stored in a desiccator prior to testing. All samples were cut to approximately 50mm x 20mm x 14mm.

Combinations of end sealed sides were used to determine how extensive moisture absorption would be with varying amounts of exposed surface area. Samples in groups E and I had limited end sealing, one and three sides, respectively. Samples in groups F and J have more extensive end sealing, three sides and complete encapsulation, respectively. Table 1 shows the treatment designations and amount of end sealed sides for the cut capped samples from producer A and B.

Table 1: Wood content and treatment designation of samples used in laboratory moisture absorption and decay test.

Treatment Designation	Treatment	Wood %
A	0.0 ZB	60
B	1.5 % ZB	60
C	Uncapped A	56.8
D	Capped A all sides open	60.7
E	Capped A 1 sealed side	60.7
F	Capped A 3 sealed sides	60.7
G	Uncapped B	50
H	Capped B all sides open	46.9
I	Capped B 3 sealed sides	46.9
J	Capped B all sides sealed	46.9

Note: Sample A and B are WPC produced at Washington State University. Samples C thru J are commercial boards; C, G are non-capped boards and D, E, F, H, I, J are capped boards with varying amount of exposed surface.

To examine the moisture uptake on the samples for the treatments shown in Table 1, samples were conditioned according to the conditioning procedure for WPC in AWPA Standard E10 to simulate field weathering conditions. Samples were grouped by type and selected samples submerged in 70°C deionised water for 120 hours. All samples were then autoclaved using a steam pressure autoclave at 121°C and 15 atm for 20 minutes. Moisture absorption after conditioning was recorded.

Another set of samples of the same treatments shown in Table 1 were exposed to decay fungi using a BS EN 113 decay test (BS EN 113 1997). To compare the effects of conditioning on moisture absorption and decay one set of samples was conditioned and a sister set was left unconditioned. All samples were first dried in an oven at 103°C for 18 hours. The set of samples to be conditioned were conditioned according to the previously described conditioning step.

French square jars were placed on their side and filled with potato dextrose agar to a depth of approximately 10 mm. Samples were placed inside of the jars, resting on top of plastic screens to prevent direct contact with the agar. Two white rot fungi *Pycnoporus sanguineus* (L.) Murrill and *Perenniporia tephropora* (Mont.) Ryvarden were used in this test. These two fungi had previously been found fruiting on a WPC board in a field exposure and were subsequently isolated for use in this test (Mankowski et al. 2005, Manning et al. 2009) Isolation of these two fungi was not from any of the WPC material used in the field tests associated with this particular study. This is the first known WPC decay study using fungi isolated from WPC in field exposures and an aspect of this study was to examine the rates of decay caused by these fungi in a laboratory test. Jars

were inoculated with either fungus. Because biological degradation of WPCs takes longer than solid wood the test period for the EN 113 test was extended to accommodate this. The duration of the decay test was 20 weeks for *P. tephropora* and 22 weeks for *P. sanguineus* (Figure 3). Since the agar in the jars begins to dry out after this period the test was halted. Moisture absorption and weight loss after decay were recorded for unconditioned and conditioned test samples.

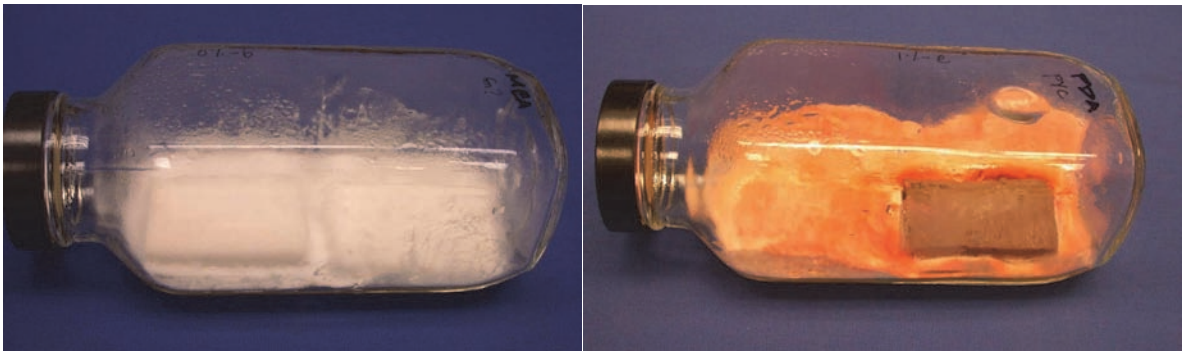

Figure 3: Example of EN 113 decay test with *Perenniporia tephropora* (left) and *Pycnoporus sanguineus* (right).

Field Samples and Testing with Uncapped and Capped Material

To examine moisture absorption and decay potential of capped material exposed in the field, commercial samples of capped and un-capped WPC produced by two producers (A and B) were purchased from a local commercial distributor. Sample WPC boards were cut to approximately 3 ft. in length and installed on above ground structures in two sites, sun and shade, in Hilo, Hawaii. The samples were given metal identification tags to ensure accurate identification. For six boards installation took place November 2010. Field sample collection took place after one year in November of 2011. One set of two boards of capped material was installed in 2009 and examined after two years exposure. A description of the samples and time of exposure is shown in Table 2.

Table 2: Description and field identification of commercial WPC in an above ground field exposure test in Hilo, Hi.

Sample and Exposure	Sample
Uncapped A One Year	1834
	1837
Capped A One Year	1841
	1842
Capped B One year	1821
	1825
Capped B Two Years	789
	791

Sample Collection and Moisture Content

Moisture analysis specimens were collected by cutting off a 3 inch cross sectional segment, along the exposed ends of the sample boards. To avoid moisture loss from the samples, cut sections were immediately wrapped in plastic shrink wrap and double bagged inside of air tight plastic zip bags. Samples were placed on dry ice and shipped to the laboratory where they were immediately frozen before analysis. Frozen samples were cut cross sectionally into wafers approximately 1.2mm thickness from the virgin edge (VE) surface of the board (Figure 4). This produced 11 sub samples that were then weighed and dried to determine moisture content throughout the board. To identify the distance between the locations of each wafer to the board surface, the thickness of each dry wafer was measured at five points and the average thickness was calculated. Thicknesses of each wafer were added together and subtracted from the measured thickness of the sample obtained prior to cutting. This difference was divided by the number of cuts used to waferize the sample and taken into account for the calculation of the saw kerf. With knowledge of the average wafer thickness and kerfs, the distance of the each wafer's centre from virgin edge surface was calculated. The cut wafers were quickly weighed, oven dried to constant weight at 103°C and reweighed to determine moisture content. This value was converted to % MC of the wood component of the WPC. Top and bottom edges of the fastening grove of the cut sample were also analyzed for moisture absorption following the above drying conditions but were not sectioned into wafers from the outside inward (Figure 4).

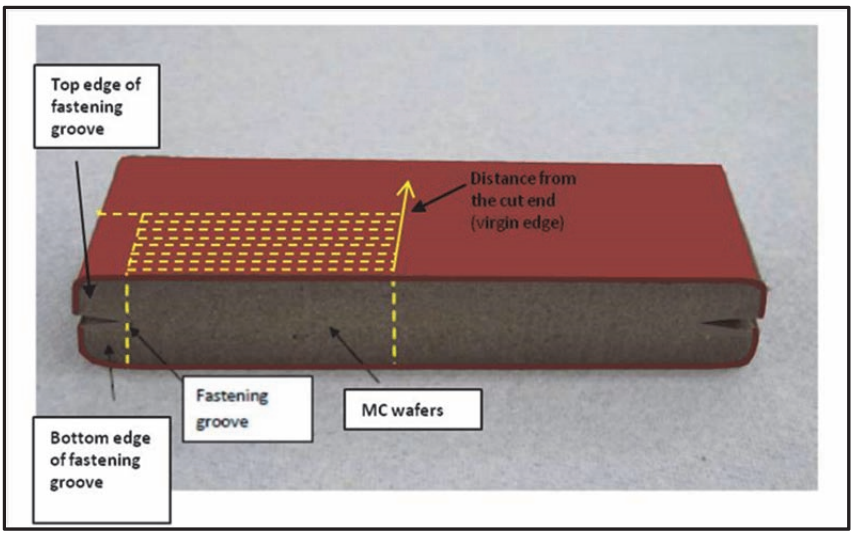

Figure 4: Example of capped WPC and designation of cuts made to analyze moisture content.

RESULTS AND DISCUSSION

Laboratory Moisture Absorption and Decay Test

Results from the conditioning test are shown in Figure 5. End sealing with a liquefied ABS paste, even on all cut ends, was insufficient to prevent moisture uptake. Uncapped conditioned samples A, B, C and G absorbed more moisture than capped material with varying amounts of exposure. Varying the amount of exposed surface via end sealing did not affect moisture absorption of the cut capped material with product groups A and B (D, E, F, H, I, J). Capped material from producer B (H, I, J) absorbed more moisture than capped material from producer A (D, E, F) regardless of capping or end sealing. It is important to note the performance difference between the capped and non-capped samples, when conditioned the capped samples had much lower moisture uptake.

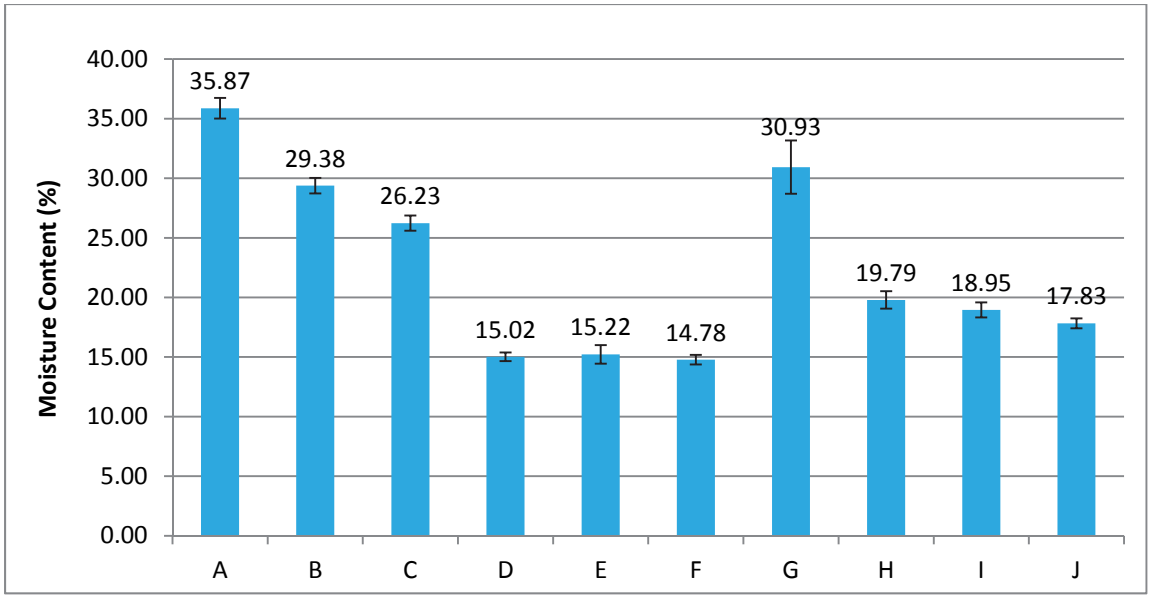

Figure 5: Percent moisture absorption of conditioned samples based on the percentage of wood in the sample after conditioning in de-ionized water for 5 days at 70°C.

Note: Sample A and B are WPC produced at Washington State University. Samples C thru J are commercial boards; C, G are non-capped boards and D, E, F, H, I, J are capped boards. Samples E, F, I, J are end sealed with ABS.

At the completion of the decay test for each fungus, samples were removed from test jars, fungal mycelia were removed, and a wet weight obtained. Samples were then placed into a drying oven at 80°C and allowed to reach a steady weight. This weight was recorded and used as the final weight. Percent weight loss was calculated by subtracting the final weight from the initial dry weight and then dividing by the initial weight and multiplying by 100; mass loss and moisture absorption for each fungus are shown in Figures 6 and 7.

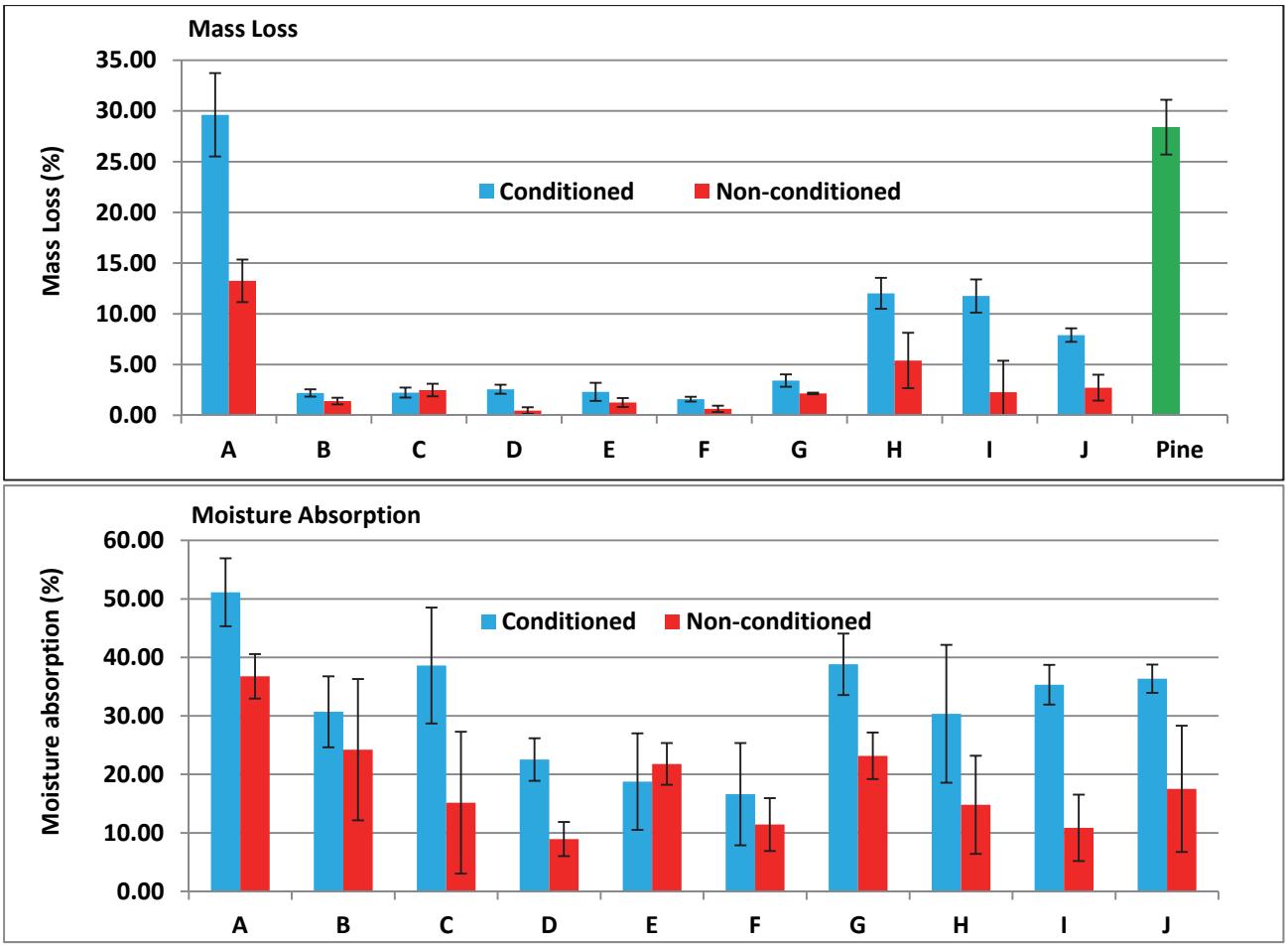

Figure 6: Mass Loss and moisture absorption (%) in conditioned and non-conditioned WPC samples exposed to *Perenniporia tephropora* for 20 Weeks

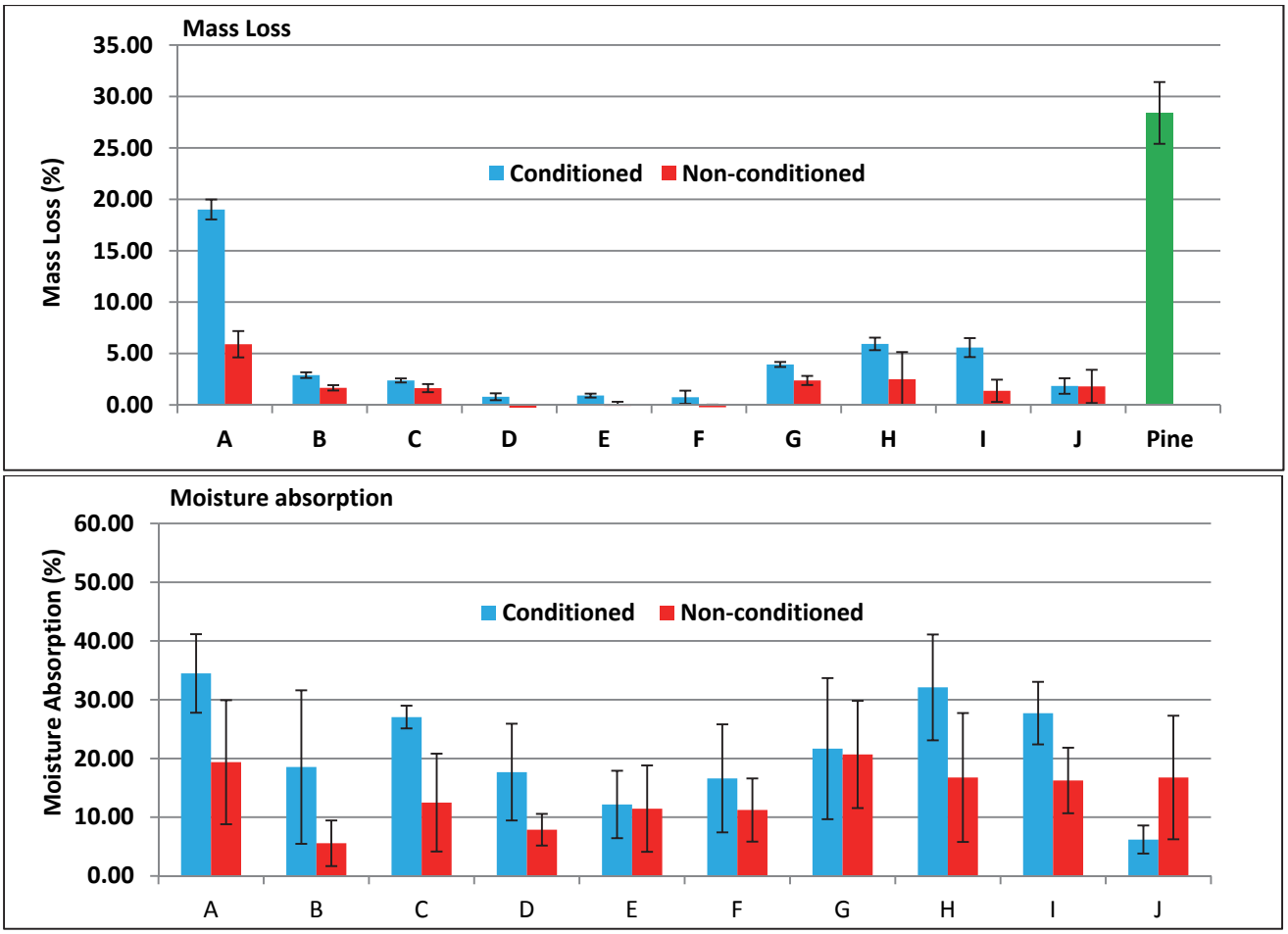

Figure 7: Mass Loss and moisture absorption (%) in conditioned and non-conditioned WPC samples exposed to *Pycnoporus sanguineus* for 22 Weeks.

Uncapped WPC boards without any biocide (Treatment A) demonstrated the greatest susceptibility to attack from decay fungi. The fungus *Perenniporia tephropora* caused greater weight loss than *Pycnoporus sanguineus*. Conditioning also helped to improve attack, as conditioned samples generally lost more mass than their non-conditioned counterparts. This is in line with previous studies showing that, albeit slowly, WPC boards are susceptible to moisture uptake and can reach moisture levels capable of supporting decay fungi. Although it has not been shown, it is also important to note that WPC boards do not dry as quickly as traditional lumber, thus potentially prolonging the time to be attacked.

Analysis of Field Specimens

Figure 8 shows a comparison of moisture content between uncapped board 1834 and capped board 1841 after one year. Results for the other six boards in this field test showed similar moisture distribution patterns. Significant moisture was detected in the analyzed WPCs regardless of capping. Moisture was concentrated near the board ends and edges of capped WPCs. Moisture content around the edges approached and exceeded 25% MC in some cases.

Figure 9 shows the moisture content in the top and bottom edges of the test boards sampled. A notable amount of moisture was observed in both the top and bottom edges of the uncapped boards 1834 and 1837 from producer A after one year. Capped boards from producer A showed high moisture after one year in the bottom edge compared to the top edge. Capped boards from producer B showed increasing moisture in both the top and bottom edges over two years.

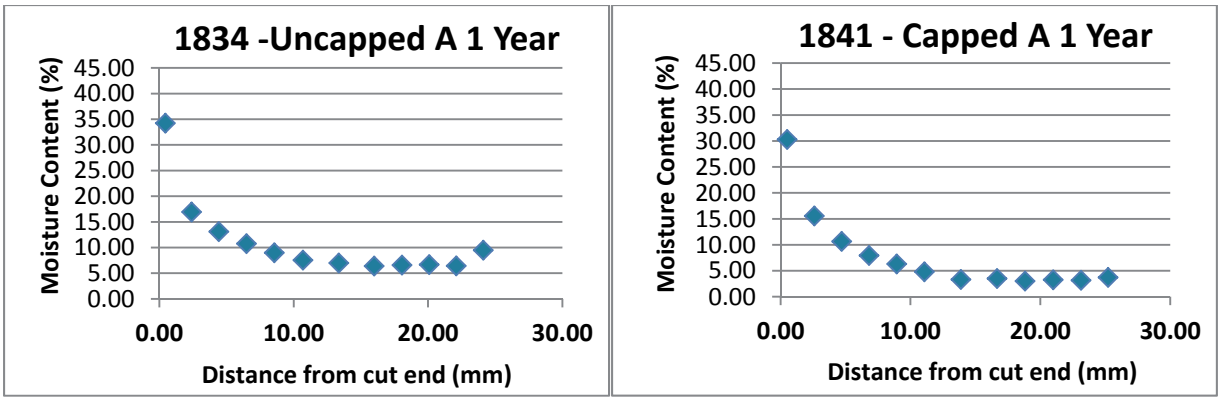

Figure 8: Moisture content in cut end of field sampled uncapped and capped WPC boards

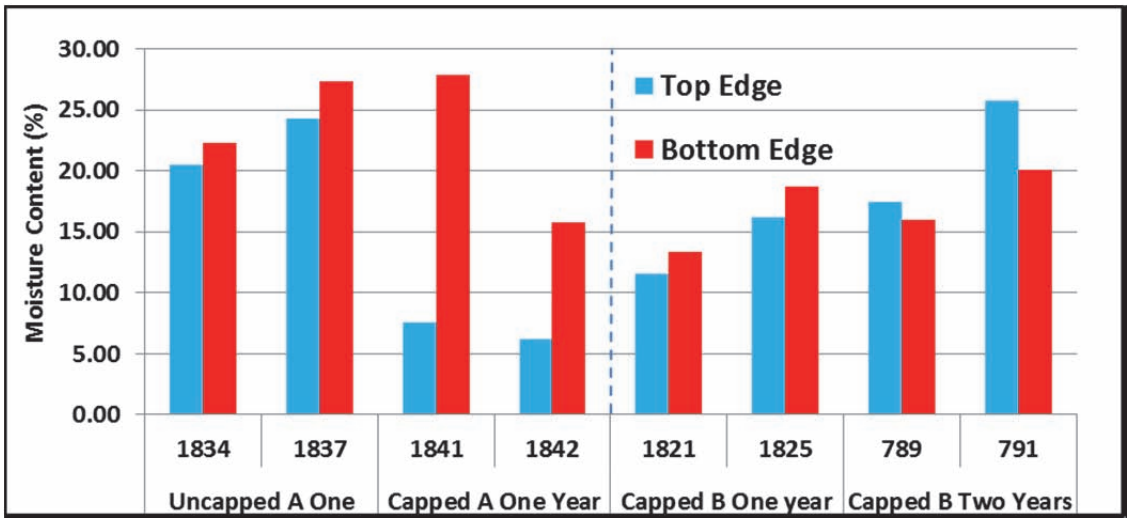

Figure 9: Moisture content in top and bottom edges of field sampled uncapped and capped WPC boards

CONCLUSIONS

Technology in the market of wood plastic composites has increased since their emergence. Advancements such as injection molding, compression molding and co-extrusion have already shown great improvements for WPCs. These advancements however have not eliminated the threat of biodeteriorating organisms due to increased moisture content.

Conditioning laboratory samples helped to simulate field exposure in that it increased moisture absorption and thus increased decay. Capped WPCs can absorb moisture similarly to uncapped material especially at board ends and the top and bottom edges of boards. Capped material is susceptible to fungal attack and weight loss particularly at exposed ends or areas of attachment.

In this study we used fungi isolated from WPC boards in the field in the hope that these fungi would incur significant weight loss in laboratory tests. Although both fungi caused mass loss, particularly in the conditioned and uncapped samples, these fungi may not be the optimal fungi to use for decay testing. Wood species used in WPC may have an effect on fungal colonization. Future studies should focus on conditioning samples, but also finding an optimal fungal species to use in laboratory tests. Continuing work should examine which fungi are optimal for WPCs and also why those and the fungi used in this test prefer to colonize and exploit WPC as a food source.

REFERENCES

1. AWPA. 2011. American Wood Protection Association. Standard E10-11 Standard method of testing wood preservatives by laboratory soil-block cultures. Fort Lauderdale FL, p. 387-396.
2. BS EN 113. 1997. Wood preservatives - Test method for determining the protective effectiveness against wood destroying basidiomycetes – Determination of the toxic values. European Committee for Standardization (CEN).

3. Freedonia Group. 2009. Wood-Plastic Composite & Plastic Lumber Industry Study 2534, 302 pages. The Freedonia Group Inc. Cleveland, OH.
4. Freedonia Group. 2014. Wood-Plastic Composite & Plastic Lumber Industry Study 3145, 364 pages. The Freedonia Group Inc. Cleveland, OH.
5. Gnatowski, M. 2005. Water Absorption by Wood-Plastic Composites in Exterior Exposure. In: Proc. The Eighth International Conference on Woodfiber-Plastic Composites. Forest Products Society. Madison, WI. pp. 249-256.
6. Gnatowski, M. 2009. Water absorbsion and durability of wood-plastic composites. 10th International conference on wood & biofiber plastic composites. Madison, WI. 2009 p90-102.
7. Ibach, R. E., Clemons, C., Stark, N. 2003. Combined Ultraviolet and Water Exposure as a Preconditioning Method in Laboratory Fungal Durability Testing. In: Proc. The Seventh International Conference on Woodfiber-Plastic Composites. Forest Products Society. Madison, WI. pp. 61-67.
8. Ibach, R.E. and Clemons, C.M. 2007. Effect of acetylated wood flour or coupling agent on moisture, UV, and biological resistance of extruded wood-fiber–plastic composites. *In:* Wood Protection 2006 Proceedings. New Orleans, LA: Forest Products Society (FPS). pp. 139-147.
9. Ibach, R., Gnatowski, M, Hui, G. 2011. Laboratory and field evaluation of the decay resistance of wood plastic composites. 11th International Conference on Wood and Biofiber Plastic Composites. Madison, WI May 2011.
10. Ibach, R., Gnatowski, M., Sun, G. 2013. Field and Laboratory Decay Evaluations of Wood-Plastic Composites. Forest Prod. J. 63(3/4):76-87.
11. Laks, P.E. and Verhey, S.A. 2000. Decay and Termite Resistance of Thermoplastic/Wood Fiber Composites. Paper presented at 5th Pacific Rim Bio-Based Composites Symposium. Canberra, Australia, December 2000.
12. Laks, P.E., Richter, D.L. Larkin, G.M. 2001. Preservative Systems for Wood Composites. In: Proc. 21st Annual Meeting of the Canadian Wood Preservation Association. pp. 177-187.
13. Mankowski, M. and Morrell, J.J. 2000. Patterns of Fungal Attack in Wood-Plastic Composites Following Exposure in a Soil Block Test. Wood and Fiber Science, 32(3):340-345.
14. Mankowski, M.E., Ascherl, F.M., Manning, M.J. 2005. Durability of Wood Plastic Composites Relative to Natural Weathering and Preservative Treatment with Zinc Borate. IRG/WP 05-40316. 36th IRG Conference. Bangalore, India. April 2005.
15. Manning, M.J. and F.M. Ascherl. 2007. Wood-Plastic Composite Durability and the Compelling Case for Field Testing. In: Proc. The Ninth International Conference on Woodfiber-Plastic Composites. Forest Products Society. Madison, WI. pp. 217-224.
16. Manning, M.J., Ascherl, F.M., Mankowski ME. 2009. Issues impacting long-term durability for WPCs. 10th International conference on wood & biofiber plastic composites. pp. 76-83.
17. Morris, P.I. and Cooper, P. 1998. Recycled Plastic/Wood Composite Lumber Attacked by Fungi. Forest Prod. J., 48(1):86-88
18. Morton, J. 2003. Current and Emerging Applications for Natural & Wood Fiber Composites. Paper presented at The 7th International Conference of Woodfiber-Plastic Composites (and other natural fibers). Madison, WI. May 19-20, 2003.
19. O'Neill, S. 2011. Capstock: Tough as Nails, Or a Death Nail? Principia WPC2011Conference: Charlotte, NC. October, 3-4 2011.
20. Pendleton, D.E., Hoffard, T.A., Adcock, T., Woodward B. Wolcott, M.P. 2002. Durability of an Extruded HDPE/Wood Composite. Forest Prod. J., 52(6):21-27.
21. Schauwecker, C., Morrell, J.J., McDonald A.G., Fabiyi, J.S. 2006. Degradation of a wood-plastic composite exposed under tropical conditions. Forest Prod. J., 56 (11/12):123-129.
22. Simonsen, J., Frietag, C.M., Morrell, J.J. 2001. Effect of Wood-Plastic Ratio on the Performance of Borate Biocides Against Brown Rot Fungi. In: Proc. The Sixth International Conference on Woodfiber-Plastic Composites. Forest Products Society. Madison, WI. pp. 69-72.
23. Stanton, H. 2005. Keeping Pace with the Market Appetite for Wood Polymer Composites. In: Proc. Wood-Plastic and Natural Fiber Composites Conference 2005, Principia Partners. Baltimore, MD. Oct. 24-26, 2005.
24. Verhey, S.A., Laks, P.E., Richter, D.L. 2001. The Effect of Composition on the Decay Resistance of Model Woodfiber-Thermoplastic Composites. In: Proc. The Sixth International Conference on Woodfiber-Plastic Composites. Forest Products Society. Madison, WI. pp. 79-86.
25. Verhey, S.A. and Laks, P.E. 2002. Wood Particle Size Affects the Decay Resistance of Woodfiber/Thermoplastic Composites. Forest Prod. J., 52 (11/12):78-81.
26. Zabel, R. A. and Morrell, J.J. 1992. Wood Microbiology: Decay and Its Prevention. Academic Press, San Diego.

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