Effect of Acetylated Wood Flour or Coupling Agent on Moisture, UV, and Biological Resistance of Extruded Woodfiber-Plastic Composites

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Abstract

Although moisture sorption in woodfiber-thermoplastic composites (WPCs) is slower than in unmodified solid wood, it still affects strength and ultimately results in decay of the material in moist outdoor exposure conditions. Chemical modification of the hydroxyl groups of wood with acetic anhydride esterifies the hydroxyl making the wood more hydrophobic and dimensionally stable. Coupling agents are known to promote bonding between the plastic and unmodified wood fibers when added to WPCs. The objective of this study was to investigate several methods of decreasing moisture sorption and, consequently, fungal degradation in WPCs. Three WPC blends were extruded into 3- by 12- by 90-mm specimens:

1. 50 percent high-density polyethylene (HDPE) and 50 percent western pine wood flour (WF);
2. 47 percent HDPE, 3 percent coupling agent (maleated polyethylene [MAPE]), and 50 percent WF; and
3. 50 percent HDPE and 50 percent acetylated WF.

In addition, a stearate lubricant was used in all three blends to aid processing. Specimens were preconditioned before running a modified ASTM D 1413 soil block test either by 2-week water soaking or 1,000 hour exposure in an ultraviolet weatherometer and then 2-week water soaking. Acetylation of the wood fiber decreased moisture content and fungal decay compared with unmodified WPC controls. Mechanical properties decreased initially in composites containing acetylated WF but were not further affected by preconditioning or decay compared with unmodified WPC controls.

Introduction

Demand for wood-plastic composite (WPC) and plastic lumber in the United States is predicted to increase 11 percent per year through 2009 to $3.5 billion (Staff 2006). Decking applications are expected to account for almost 40 percent of value demand in 2009. The main reasons for these gains are the removal of decking treated with chromated copper arsenate (CCA) and consumer expectations for improved performance characteristics, such as high durability, low maintenance requirements, and enhanced appearance. But, some of these improvements may still not meet consumer expectations.

It was first thought that mixing plastic and wood together would result in plastic encapsulation of wood, which would prevent moisture sorption and fungal decay. Morris and Cooper (1998), however, found evidence of fungal decay and discoloration on WPC decking in service. Since this first evidence, moisture, ultraviolet (UV), and biological degradation have been evaluated (Ibach et al. 2004). Shirp et al. (2006) reviewed the literature on biological degradation of WPCs and strategies for improving resistance.

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In outdoor conditions, WPCs are exposed not only to biological and water degradation but also UV, thermal, chemical, and mechanical degradations. Chemical modification of wood cell walls can prevent or slow these degradation reactions (Rowell 2005). Although WPCs have slower moisture sorption than wood (Rowell et al. 2002, Wang and Morrell 2004), water affects the strength and ultimately promotes biological decay of the material (Clemons and Ibach 2002, 2004; Shirp and Wolcott 2005).

Acetylation is one of the most studied wood modification chemistries. Reaction of acetic anhydride with wood results in esterification of accessible hydroxyl groups in the cell wall with acetyl groups. Because moisture plays a key role in fungal decay of WPCs, it is prudent to evaluate WPCs made with acetylated wood fiber (Glasser et al. 1999, Ibach and Clemons 2002, Khalil et al. 2002, Glasser 2004, Segerholm et al. 2005). Acetylated woodfiber-plastic composites that were compression molded had the best mechanical properties and water resistance compared with unmodified WPC controls (Glasser et al. 1999, Khalil et al. 2002). Acetylated woodfiber-plastic composites that were injection molded and extruded had decreased moisture content (MC) and were highly resistant to brown-rot decay compared with unmodified WPC controls (Segerholm et al. 2005). The acetylated fiber in this research was produced by grinding previously acetylated solid wood. Acetylation of ground wood fiber and then compression molding with high-density polyethylene (HDPE) into specimens decreased the equilibrium moisture content (EMC) and fungal decay of the WPC compared with chemical modification by butylene oxide or propylene oxide or with unmodified WPC controls (Ibach and Clemons 2002).

Coupling agents are incorporated into WPCs to improve the compatibility and adhesion between polar wood fibers and non-polar polymers (Bledzki et al. 1998, Lu et al. 2000, Bledzki and Omar 2003). The most common coupling agents are maleic anhydride grafted to polypropylene (MAPP) or polyethylene (MAPE). WPCs containing polypropylene and the coupling agent maleated MAPP were injection molded and their mechanical properties evaluated. MAPP improved polymer-wood-fiber adhesion and dispersion of panicles and lowered water absorption compared with composites without the coupling agent (Ichazo et al. 2001). MAPP enhanced the tensile modulus and yield stress and the Charpy impact strength (Hristov et al. 2004). MAPP caused greater strength increases with wood-fiber composites than with wood-flour composites (Stark and Rowlands 2003). MAPP with longer chain lengths and lower functionality gave the greatest benefit, supporting the chain entanglement mechanism proposed by Pickering and Ji (2004). Kazayawoko et al. (1999) attributed the improvement of mechanical properties with MAPP to the compatibilization effect, which decreases total wood-fiber surface free energy, thus improving polymer matrix impregnation, fiber dispersion, fiber orientation, and interfacial adhesion through mechanical interlocking.

The objective of this study was to determine moisture (both water and water vapor) and biological resistance and mechanical performance of chemically modified and unmodified extruded WPCs after accelerated preconditioning with either a 2-week water soak or UV and 2-week water soak exposure. Two different approaches of chemical modification (the use of the coupling agent MAPE or the use of acetylated wood fiber) were evaluated and results compared with those of unmodified WPCs.

Experimental

Materials

The wood filler was western pine wood flour, nominal 40 mesh (420 µm), from American Wood Fiber (Schofield, WI). 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 minutes. The flour was modified with acetic anhydride from Aldrich Chemical Company (Milwaukee, WI). The coupling agent was MAPE, Polybond 3009, from Crompton Corporation (Middlebury, CT). The lubricant was TR251 from Struktol Company of America (Stow, OH). It is a complex oleochemical mixture containing mono- and di-amides and metal soap. It contains a blend of calcium stearate, a specialty amide, and ethylenebis-stearamide.

Acetylation of Wood Flour

The western pine flour was ovendried and then boiled in acetic anhydride in a 1-L glass reactor for 4 hours. The treated flour was washed and ovendried, and its weight gain percentage (WPG) was calculated. Percentage acetyl content was determined using anion exchange high-performance liquid chromatography (HPLC) with a suppressed conductivity detector. A previously described method was followed (Ibach et al. 2000).

Profile Extrusion

Profile extrusion was performed on a reconfigured 32-mm twin-screw extruder. All components were fed into the main feed throat. HDPE was melted and then blended with the wood flour. The material was then forced through a die into 3- by 13-mm specimens. Addition of 9 percent lubricant helped prevent tearing of the material as it exited the die. Blends of three different compositions were extruded (Table 1).

Modified Soil Block Test

Initial ovendried weight was determined by drying for 24 hours at 105°C in a forced-draft oven, cooling in a desiccator for 1 hour, and then weighing each specimen.

Table 1. – *Composition of three extruded WPC blends.*[a]

Blend	HDPE	Wood type	Wood content	Coupling agent–MAPE	Lubricant
	(weight %)			(weight %)	
1	41	Flour	50	0	9
2	38	Flour	50	3	9
3	41	Acetylated flour	50	0	9

[a] HDPH = high-density polyethylene; MAPE = maleated polyethylene

Three methods were used to precondition the specimens:

1. water soaking for 2 weeks (S),
2. exposure in a weatherometer for 1,000 hours (W), and
3. weatherometer for 1,000 hours followed by water soaking (WS).

The weatherometer exposure cycle included 102 minutes of UV light exposure and 18 minutes of simultaneous water spray and UV light exposure. Specimens were weighed after each of the three preconditioning methods, and MC was calculated. At the end of each preconditioning, five specimens of each blend were air dried for 24 hours, ovendried for 24 hours in a forced-draft oven, cooled for 1 hour in a desiccator, and then weighed. Percentage weight loss was calculated due to preconditioning.

A modified soil block test procedure based on ASTM D1413 (ASTM 1999) and outlined in Clemons and Ibach (2004) was used to evaluate the specimens. Five replicates of each blend and preconditioning method (S or WS) were autoclaved wet and then placed in horizontal soil bottles under one of three fungal exposure conditions:

1. No fungus (nf)
2. *G. trabeum*, a brown-rot fungus (br)
3. *C. versicolor*, a white-rot fungus (wr)

Because of their low MC (less than 1%) from the weathering cycle, specimens that had only been weathered (W) were not tested for fungal decay. After 12 weeks of exposure, specimens were taken out, wiped to remove fungal mycelium if present, weighed, ovendried for 24 hours at 105°C in a forced-draft oven, cooled in a desiccator for 1 hour, and weighed again. Weight loss and MC were calculated.

Water Vapor Sorption

Ovendried specimens were weighed and then placed in one of three controlled condition rooms: 30 percent relative humidity (RH), 65 percent RH, or 90 percent RH; all at 27°C. The specimens were weighed at various time periods up to 159 days. The change in weight resulting from water vapor sorption was calculated.

Flexural Testing

Third-point flexural tests were performed on ovendry specimens according to ASTM D790 (ASTM 1990). Initial tangent modulus, maximum strength, and work to maximum stress were determined.

Microscopy Analysis

The initial controls and WS and decayed specimens of all three blends were evaluated microscopically. Specimens were prepared by cutting and mounting a microtomed cross section. Specimens were mounted on aluminum specimen stubs using silver paste, coated with gold using a Denton Desk-1 sputter coater (Cherry Hill, NJ), and examined and photographed with a LEO EVO40 scanning electron microscope (SEM) (Carl Zeiss SMT, Inc., Thornwood, NY).

Results and Discussion

Acetylation of Wood Flour

Acetylation of the wood flour was straightforward, except for the calculation of weight gain. There was loss of fine flour particles during refluxing and removal of the acetic acid by-product by water washing, therefore percentage acetyl content was determined using HPLC (Ibach et al. 2000). Average acetyl content of acetylated wood flour was 22.04 percent ± 0.01 percent (average of 22 sample batches), and that of the unmodified flour was 2.29 percent ± 0.09 (average of two samples.)

Modified Soil Block Test

Weight loss of the specimens that occurred from preconditioning or fungal decay is presented in **Figure 1** and **Table 2.** For all three blends, little weight loss resulted from preconditioning with just S or water soaking (less than 0.7%). but more resulted with W or weathering (2.6%). When the specimens were weathered and then water soaked (WS), weight loss was greater for blends 1 and 2 (blend 1, 4.7%; blend 2, 4.3%) but not for blend 3 (2.5%). This is to be expected for blend 3 because of the hydrophobicity of acetylated wood flour. The MAPE (blend 2) did not help with moisture resistance because the hydroxyl groups are still present for hydrogen bonding.

Weight loss of the soil block specimens with no fungal exposure gave results similar to those for preconditioning alone for all three blends. **Figure 1** shows S and WS for no fungus and both white- and brown-rot fungi for all

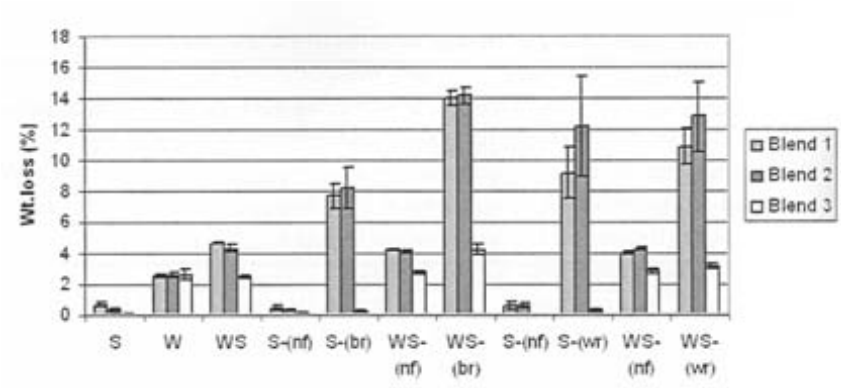

Figure 1. – *Average percentage weight loss of WPC specimens due to preconditioning and/or fungal decay. Blend 1, 50% wood flour:41% HDPE:9% lubricant; Blend 2, 50% wood flour:38% HDPE:9% lubricant:3% MAPE; Blend 3, 50% acetylated wood flour:41% HDPE:9% lubricant. S, 2-week water soak; W, 1,000 h weathering; WS, 1,000 h weathering then 2-week water soak. nf, no fungus; br, brown-rot fungus, G. trabeum; wr, white-rot fungus, C. versicolor.*

Table 2. – *Percentage weight loss and MC after preconditioning or fungal decay evaluations.*

Blend and exposure[a]	Weight loss	Standard deviation	MC	Standard deviation
	(%)		(%)	
1-S	0.70	0.12	16.21	0.71
1-W	2.61	0.10	0.82	0.46
1-WS	4.71	0.09	15.82	0.63
1-S-(nf)	0.51	0.19	20.58	2.05
1-S-(br)	7.67	0.82	29.57	0.97
1-WS-(nf)	4.26	0.04	22.00	0.75
1-WS-(br)	14.02	0.50	30.15	1.88
1-S-(nf)	0.54	0.30	19.08	0.62
1-S-(wr)	9.17	1.68	20.22	1.58
1-WS-(nf)	4.01	0.12	19.76	0.34
1-WS-(wr)	10.87	1.18	19.08	1.51
2-S	0.32	0.17	15.09	0.66
2-W	2.58	0.15	0.91	0.19
2-WS	4.32	0.24	18.33	1.07
2-S-(nf)	0.30	0.05	24.74	0.71
2-S-(br)	8.19	1.38	32.61	2.25
2-WS-(nf)	4.07	0.11	23.85	0.22
2-WS-(br)	14.15	0.53	34.47	2.04
2-S-(nf)	0.62	0.15	20.48	1.19
2-S(wr)	12.18	3.21	21.95	2.30
2-WS(nf)	4.29	0.11	20.99	0.84
2-WS-(wr)	12.81	2.21	23.28	2.41
3-S	-0.05	0.11	6.08	0.80
3-W	2.61	0.31	-4.48	0.70
3-WS	2.45	0.07	8.10	0.95
3-S-(nf)	0.11	0.05	7.85	0.37
3-S-(br)	0.24	0.05	10.42	0.77
3-WS-(nf)	2.78	0.07	9.18	0.18
3-WS-(br)	4.20	0.34	12.69	2.19
3-S-(nf)	-0.01	0.05	5.28	0.35
3-S-(wr)	0.27	0.10	6.48	0.30
3-WS-(nf)	2.84	0.14	7.83	0.54
3-WS-(wr)	3.17	0.18	8.51	0.67

[a] S = 2-week water soak: W = 1,000 hours of weathering; WS = 1,000 hours of weathering then 2-week water soak: nf = no fungus; br = brown-rot fungus, *G. trabeum;* wr = white-rot fungus, *C. versicolor.*

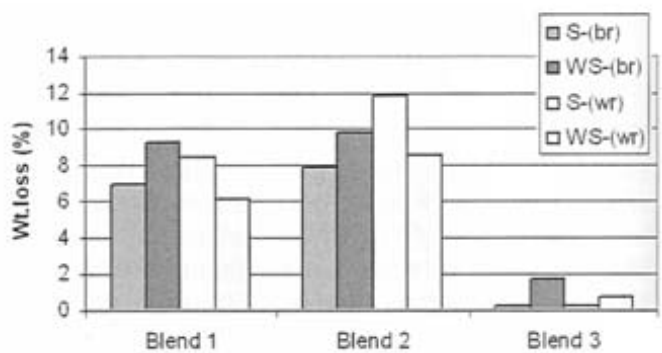

Figure 2. – *Weight loss from decay of three WPC blends exposed to brown- (br) or white-rot (wr) fungi after first preconditioning by either water soaking (S) or weathering and soaking (WS).*

three blends. Note the increased loss caused by additional weathering (WS).

Weight loss resulting from decay by brown- (br) or white-rot (wr) fungi is presented in **Figure 2.** Loss from preconditioning (S and WS) is subtracted from the overall weight loss from s, WS, and decay **(Fig. 1)** to determine the weight loss only from decay **(Fig. 2).** For blends 1 and 2, the weight losses are from 6 to 12 percent for the white- and brown-rot fungi. Assuming that only the wood component degrades, this equals 12 to 24 percent weight loss of just the wood component of the composite. MAPE (blend 2) did not help slow down or arrest weight loss from decay. Blend 3 shows less than 2 percent weight loss even after weathering, water soaking, and brown-rot exposure.

MC determined after each preconditioning and fungal exposure is shown in **Figure 3** and **Table 2.** Both blends 1 and 2 preconditioned to MCs between 15 percent and 18 percent with weathering (W) and/or water soaking (S or WS). After the 12-week soil block test, moisture increased further, up to 34 percent for the blend 2 specimens that are weathered, water soaked, and then exposed to brown-rot fungi (see WS-(br) in **Fig. 3).** The acetylated specimens (blend 3) show lower MCs - between 5 percent and 12 percent. This is expected because acetyl groups re-

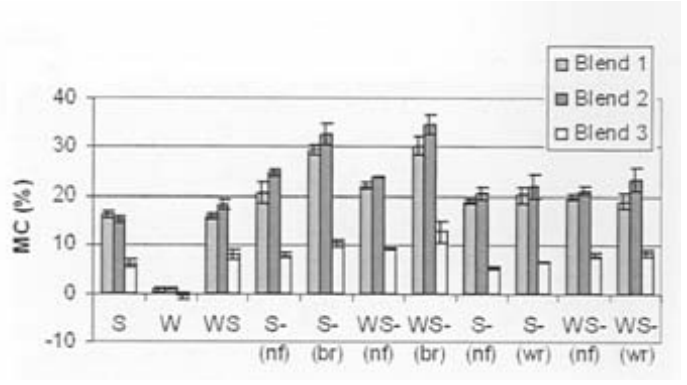

Figure 3. – *Average MC of specimens after preconditioning and/or fungal decay evaluations. Blend 1 = 50% wood flour:41% HDPE:9% lubricant; Blend 2 = 50% wood flour: 38% HDPE:9% lubricant:3% MAPE; Blend 3 = 50% acetylated wood flour:41% HDPE:9% lubricant. S = 2-week water soak; W= 1,000 hours of weathering; WS= 1,000 hours ofweathering then 2-week water soak. nf = no fungus; br = brown-rot fungus, G. trabeum; wr = white-rot fungus, C. versicolor.*

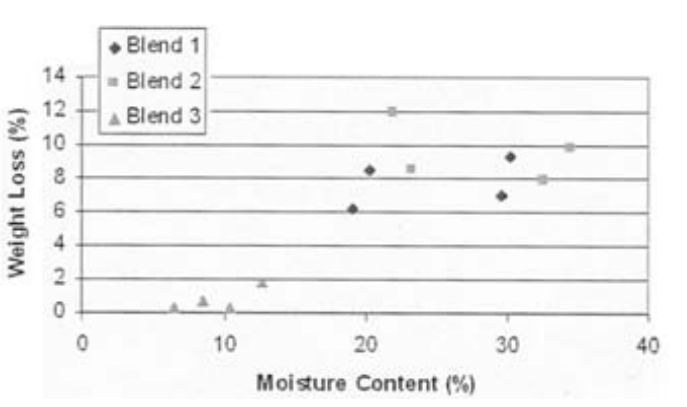

Figure 4. – *Average MC vs. weight loss due to decay of WPC specimens after removal from a 12-week soil block test. Blend 1 = 50% wood flour:41% HDPE:9% lubricant; Blend 2 = 50% wood flour:38% HDPE:9% lubricant:3% MAPE; Blend 3 = 50% acetylated wood flour:41% HDPE: 9% lubricant.*

placed hydroxyls, restricting the fiber from hydrogen bonding with water or bulking the cell wall with acetyl groups.

A plot comparing percentage MC and percentage weight loss of the brown- and white-rot fungus is presented in **Figure 4.** Keeping the MC of the WPC below about 12.5 percent (25% wood flour MC) limited weight loss resulting From fungal decay.

Water Vapor Sorption

Specimen MC of all three blends, measured periodically for 159 days in a 90 percent relative humidity (RH), 27°C conditioning room, is presented in **Figure 5.** Similar to the soil block MCs, blends 1 and 2 have higher MCs than the acetylated blend 3. This is expected because of

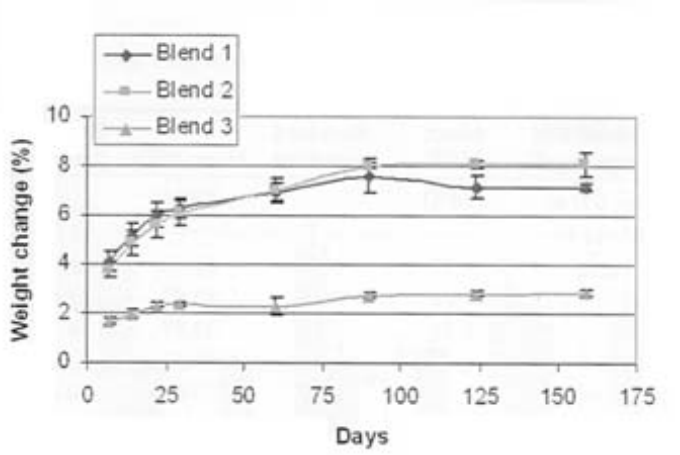

Figure 5. – *Change in weight of WPC specimens over time in a controlled conditions room (90% RH/27°C). Blend 1 = 50% wood flour:41% HDPE:9% lubricant; Blend 2 = 50% wood flour:38% HDPE:9% lubricant:3% MAPE; Blend 3 = 50% acetylated wood flour:41% HDPE:9% lubricant.*

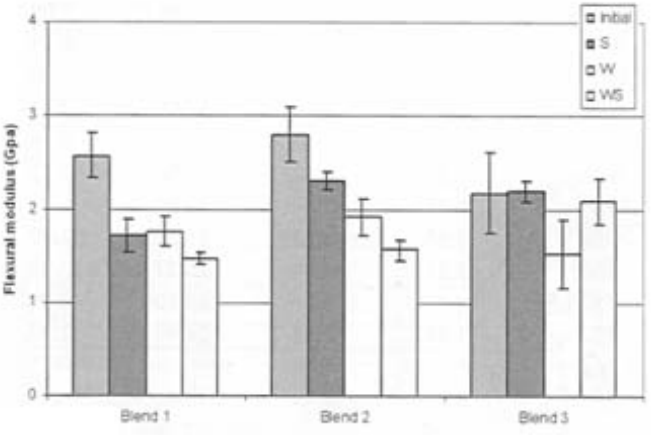

Figure 6. – *Effects of preconditioning WPC specimens on flexural modulus. Blend 1 = 50% wood flour:41 % HDPE: 9% lubricant; Blend 2 = 50% wood flour:38% HDPE:9% lubricant:3% MAPE; Blend 3 = 50% acetylated wood flour: 41% HDPE:9% lubricant, S = 2-week water soak; W = 1,000 hours of weathering; WS = 1,000 hours ofweathering then 2-week water soak.*

the loss of the hydroxyls on the wood flour to hydrogen bonding with water. The greatest change occurred within the first 25 days.

Flexural Testing and Microscopy

The flexural data is presented in **Table 3.** The effect of specimen preconditioning on the flexural modulus is presented in **Figure 6.** Blend 1 shows significant loss in modulus with just water exposure (S). weathering (W), or a combination of both (WS). Blend 2 shows an incremental decrease in modulus with water soaking, weathering, and then with both. Blend 3 shows a decrease in modulus with no preconditioning compared to blend 1, but it does

Table 3. – *Flexural modulus and strength after preconditioning or fungal decay evaluations*

Blend and exposure[a]	Mean MOE	Standard deviation	Mean MFS	Standard deviation
	(GPA)		(MPa)	
Blend 1				
Initial	2.57	0.24	51.96	8.02
S	1.72	0.18	36.87	2.28
W	1.75	0.16	33.77	1.76
WS	1.47	0.06	33.53	1.91
S-(nf)	1.65	0.10	33.83	0.82
S-(br)	1.07	0.11	29.64	1.82
WS-(nf)	1.27	0.16	29.59	0.74
WS-(br)	0.71	0.13	25.08	2.14
S-(nf)	1.70	0.24	35.67	1.45
S-(wr)	1.19	0.11	25.23	1.66
WS-(nf)	1.38	0.13	28.31	0.85
WS-(wr)	1.19	0.08	24.81	1.20
Blend 2				
Initial	2.80	0.29	41.62	2.49
S	2.30	0.10	39.61	1.02
W	1.91	0.20	33.15	2.25
WS	1.56	0.11	31.52	2.09
S-(nf)	2.06	0.19	33.07	2.67
S-(br)	1.19	0.17	32.55	6.28
WS-(nf)	1.31	0.10	26.45	1.52
WS-(br)	0.84	0.08	22.00	1.79
S-(nf)	1.85	0.23	31.63	2.97
S-(wr)	1.27	0.20	25.27	3.07
WS-(nf)	1.49	0.12	28.10	2.09
WS-(wr)	1.32	0.11	24.96	2.09
Blend3				
Initial	2.17	0.44	38.40	4.40
S	2.19	0.11	37.54	2.00
W	1.52	0.37	26.13	6.13
WS	2.09	0.25	33.25	2.40
S-(nf)	2.30	0.36	39.11	1.90
S-(br)	1.96	0.14	35.56	1.84
WS-(nf)	2.14	0.14	34.25	1.45
WS-(br)	1.78	0.17	34.73	0.88
S-(nf)	2.68	0.38	41.31	3.17
S-(wr))	2.39	0.34	39.84	2.70
WS-(nf)	2.02	0.23	33.20	0.87
WS-(wr)	1.89	0.45	32.37	3.23

[a] S = 2-week water soak; W = 1,000 hours of weathering; WS = 1,000 hours of weathering then 2-week water soak, nf = no fungus: br = brown-rot fungus, *G. trabeum*; wr = white-rot fungus, *C. versicolor.*

not show a decrease resulting from preconditioning, except for the weathered (W) specimens. At this time, we are not sure why this is lower, but a duplicate set of experiments is in progress to help explain. **Figure 7** shows the same decrease for flexural strength.

The effect of specimen preconditioning on flexural strength is presented in **Figure 7.** Strength decreased

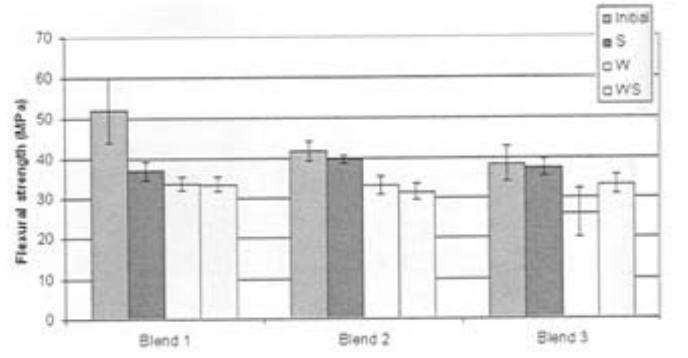

Figure 7. – *Effects of preconditioning WPC specimens on flexural strength. Blend 1 = 50% wood flour:41% HDPE: 9% lubricant; Blend 2 = 50% wood flour:38% HDPE:9% lubricant:3% MAPE; Blend 3 = 50% acetylated wood flour: 41% HDPE:9% lubricant. S = 2-week water soak; W = 1,000 hours of weathering; WS = 1,000 hours of weathering then 2-week water soak.*

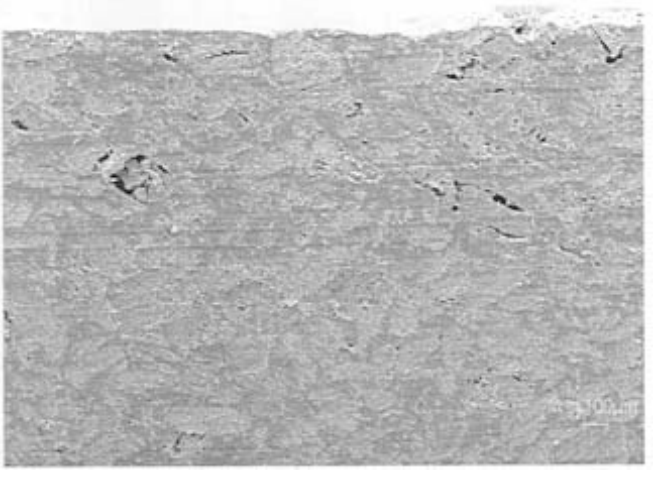

Figure 8. – *SEM micrograph of a microtomed cross section of blend 1 without preconditioning or fungal exposure showing fairly good adhesion (100x).*

similarly with each of the preconditionings with blend 1. Unexpectedly, blend 2 had less initial strength with the 3 percent coupling agent than blend 1 with no coupling agent. This is a result of interference between the MAPE and the lubricant, unknown at the start of this research. Subsequent studies have corrected for this incompatibility. Blend 3 also has decreased initial strength compared with blend 1. **Figure 8** shows blend 1 with fairly good contact between the wood and plastic before any exposure conditions. **Figure 9** shows blend 2 (with coupling agent) with small holes throughout, which could contribute to the decrease in strength. **Figure 10** shows blend 3 (acetylated wood flour) with fewer but larger holes, which could also contribute to the decrease in strength.

Flexural modulus after fungal exposure is presented in **Figure 11.** Blends 1 and 2 show significant decreases in modulus after fungal exposure to both brown- and

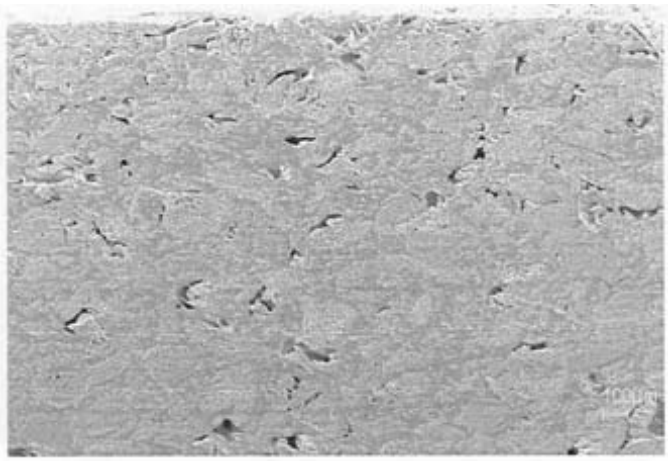

Figure 9. – *SEM micrograph of a microtomed cross section ofblend 2 (with coupling agent) without preconditioning or fungal exposure showing small holes throughout the composite (100x).*

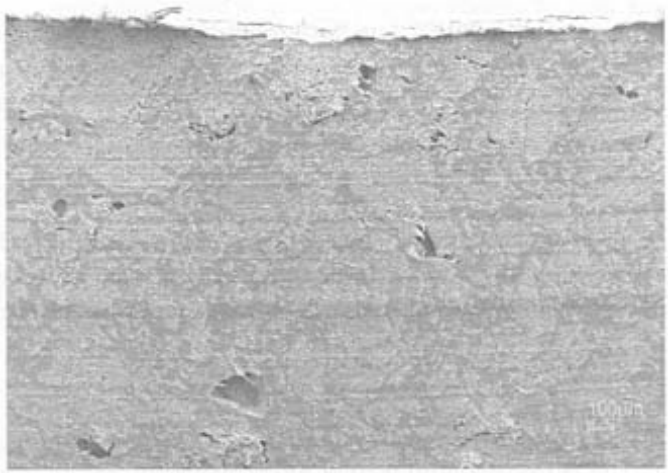

Figure 10. – *SEM micrograph of a microtomed cross section of blend 3 (acetylated wood flour) without preconditioning or fungal exposure showing a few large holes (100x).*

white-rot fungus. Blend 3 again shows lower initial modulus but little decrease from fungal exposure.

Flexural strength after fungal exposure is presented in **Figure 12.** As with preconditioning, strength significantly decreased after fungal exposure to both brown- and white-rot fungi for blend 1. **Figure 13** shows the SEM micrograph of blend 1 with preconditioning and brown-rot fungal exposure. Deterioration is seen on the surface and decay by the brown-rot fungus *G. trabeum* into the composite. Similar to the unexposed specimens, blend 2 has lower initial strength than blend 1, but it has decreased strength as a result of fungal exposure as well, which is seen in **Figure 14.** Blend 3 has lower initial strength, probably as a result of the processing, but does

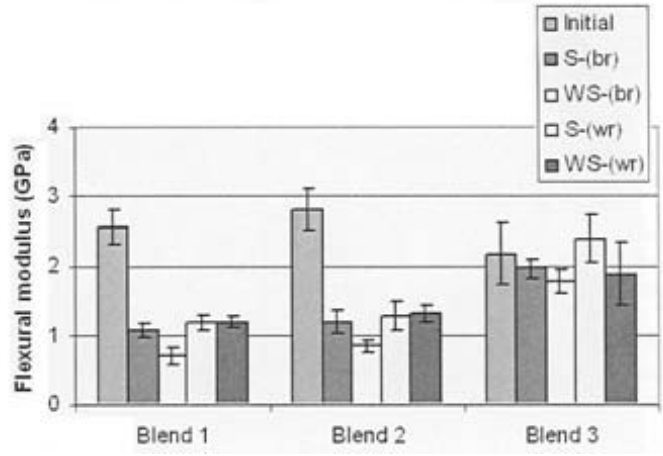

Figure 11. – *Effect of 12-week fungal exposure on flexural modulus. Blend 1 = 50% wood flour:41% HDPE:9% lubricant; Blend 2 = 50% wood flour:38% HDPE:9% lubricant: 3% MAPE; Blend 3 = 50% acetylated wood flour:41% HDPE:9% lubricant. S = 2-week wafer soak; W = 1,000 hours ofweathering: WS = 1,000 hours ofweathering then 2-week water soak. nf = no fungus; br = brown-rot fungus, G. trabeum; wr = white-rot fungus, C. versicolor.*

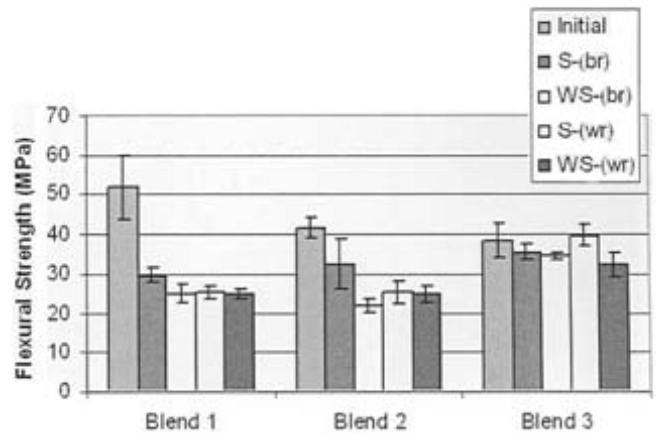

Figure 12. – *Effect of 12-week fungal exposure on flexural strength. Blend 1 = 50% wood flour:41% HDPE:9% lubricant: Blend 2 = 50% wood flour:38% HDPE:9% lubricant:3% MAPE; Blend 3 = 50% acetylated wood flour:41% HDPE:9% lubricant. S = 2-week water soak; W = 1,000 hours of weathering; WS = 1,000 hours of weathering then 2-week water soak. nf = no fungus; br = brown-rot fungus, G. trabeum; wr = white-rot fungus, C. versicolor.*

not show a decrease in strength as a result of preconditioning or fungal exposure. **Figure 15** shows no visible signs of decay and a fairly smooth surface for blend 3, the acetylated composite.

Conclusions

Extruded WPC made with acetylated wood flour (blend 3) decreased the MC and fungal decay of the speci-

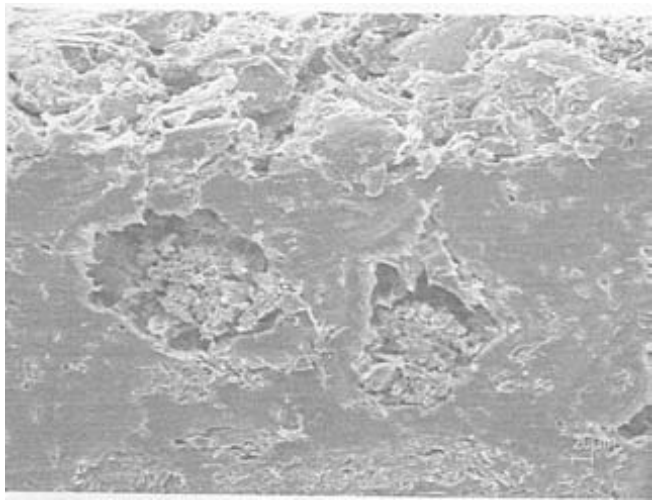

Figure 13. – *SEM micrograph of a microtomed cross section of blend 1 with preconditioning and fungal exposure. Deterioration is seen on the surface (top), as well as decay by the brown-rot fungus G. trabeum into the composite (416x).*

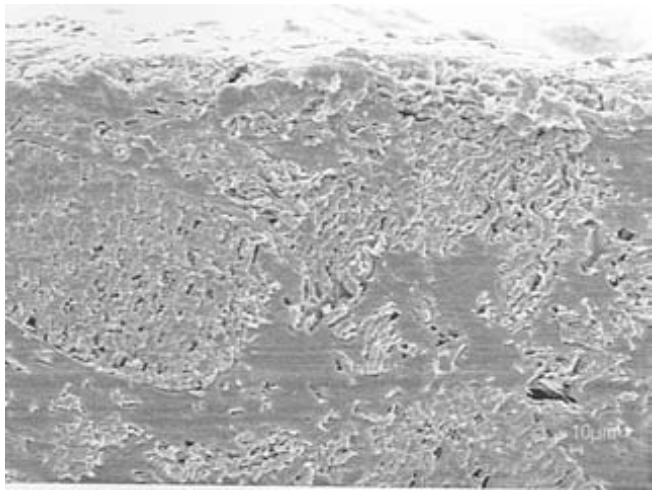

Figure 15. – *SEM micrograph of a microtomed cross section of blend 3 (acetylated wood flour) with preconditioning and fungal exposure by the brown-rot fungus G. trabeum. Surface is fairly smooth and no visible sign of decay (416x).*

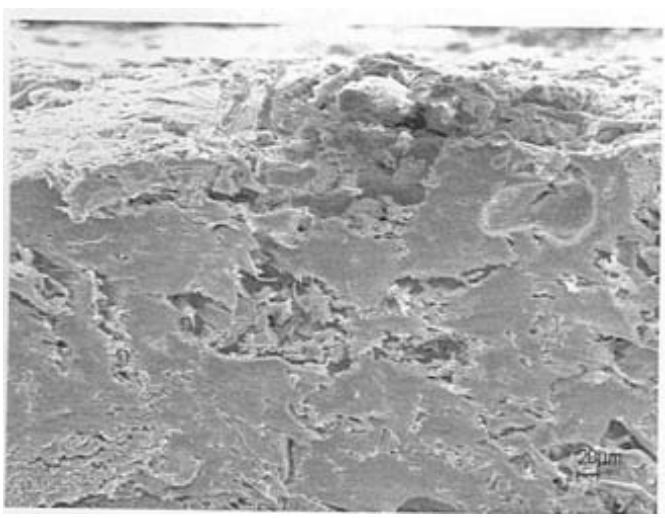

Figure 14. – *SEM micrograph of a microtomed cross section ofblend 2 (with coupling agent) with preconditioning and fungal exposure. Deterioration is seen on the surface, as well as decay by the brown-rot fungus G. trabeum into the composite (416x).*

mens compared with the unmodified (blend 1) and coupling agent (blend 2) WPC. Both blends 1 and 2 had significant weight loss from decay by brown- or white-rot fungi and increased moisture sorption compared with blend 3. Initial strength was decreased for the acetylated blend 3, in part due to holes found in the composite cross section in the SEM, but was not decreased further from the preconditioning and fungal exposure. Modulus and strength both decreased significantly with the unmodified (blend 1) and coupling agent (blend 2) WPCs for both preconditioning and fungal exposure conditions. The WPC with coupling agent gave results similar to those for the unmodified WPC but, because of interaction with the lubricant, is being further investigated. Outdoor field studies are in progress in Wisconsin and Mississippi to test these composites in outdoor exposures.

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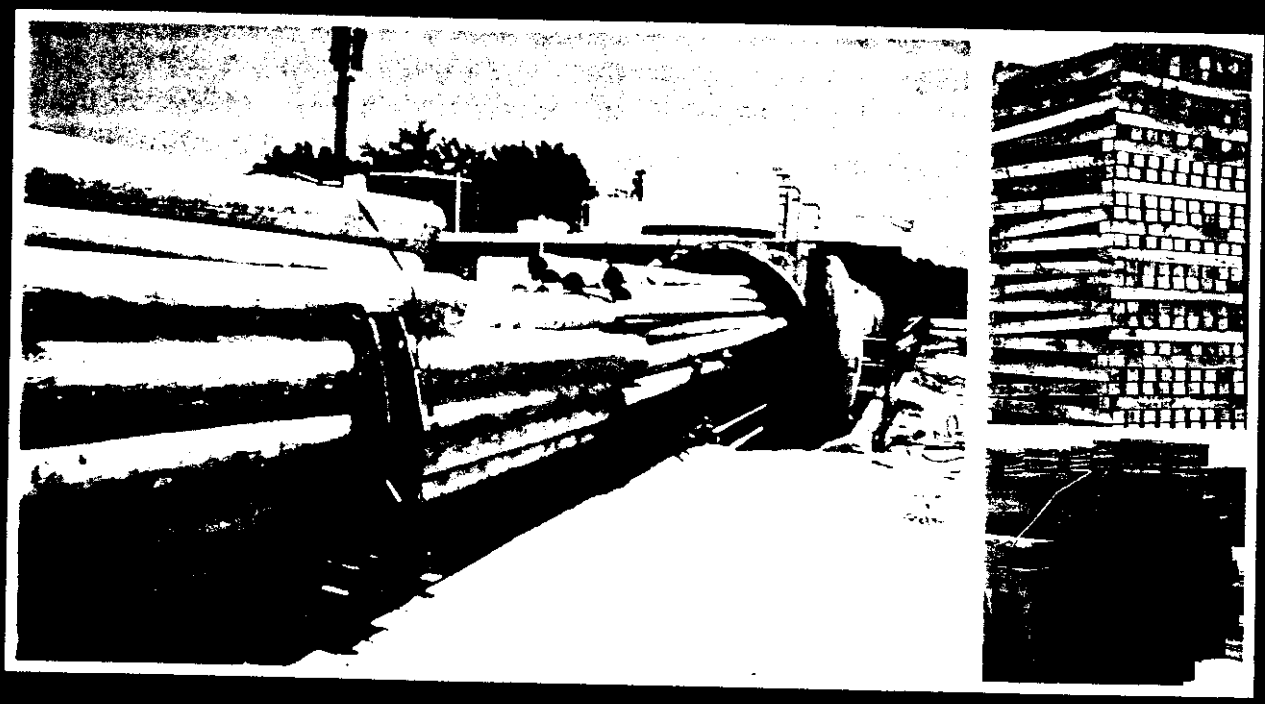

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