Novel Interfacial Modifiers for Polyolefin Composites

Dr. Jeffrey J. Cernohous, Dr. Adam R. Pawloski, Steven K. Manfred and Neil R. Granlund
Interfacial Solutions, LLC. River Falls, WI

Abstract

Synthetic fiber reinforced thermoplastic composite materials have become staples for automotive, construction, defense, aerospace and consumer products. Most of these composites are derived from glass or carbon fiber reinforced engineering thermoplastics. However, polyolefin based composite materials are being applied in cost sensitive applications that demand higher performance. Examples include glass reinforced polypropylene (PP) composites and natural fiber reinforced polyolefin composites. Wood composite based products (WPC's) have rapidly penetrated non-structural wood applications because they offer the consumer low maintenance attributes and durability. However, the best wood composites on the market today are ½ the strength, twice the weight, and as much as five times the cost of pine and cedar! Additionally, there is a need for composites to have improved resistance to moisture and the elements. This work describes new interfacial modifiers for natural fiber and wood filled polyolefin composite materials that have been recently developed by Interfacial Solutions.

Introduction

Wood plastic composites (WPC's) have found broad application in the building and construction industry, especially for non-structural applications. These materials typically comprise a thermoplastic matrix filled with 20 to 80 wt % of a cellulosic fiber. As a result, the resultant composite is often very sensitive to moisture. When a composite component is exposed to high humidity conditions, it is not uncommon for it to adsorb as much as 10% of its mass in moisture. This can have an extremely deleterious effect on the composite's dimensional stability, color fastness and microbial resistance. While some applications and climates can tolerate this phenomenon, there is a need for WPC's that have improved moisture resistance. Coupling agents have been utilized extensively to improve the mechanical properties and moisture resistance of WPC's. However, conventional coupling agent technologies arguably do not provide adequate protection for these applications. Herein, we describe a new additive technology that dramatically improves the moisture resistance of a WPC when added to the formulation. We also demonstrate that this technology has a marked effect on the color fastness and mechanical properties of WPC's after accelerated aging conditions.

Materials

The materials that were utilized to formulate the composite materials described in this work are given in Table 1.

Table 1. Materials Description

MATERIAL	*DESCRIPTION*
Polypropylene	Ineos H12E
Wood Flour	Pine, 40 mesh
Coupling Agent	Polybond 3000, maleic anhydride grafted polypropylene (MAPP)
Multifunctional Coupling Agent (MFCA)	Proprietary additive

Experimental Section

Wood polymer composite (WPC) materials were prepared and characterized as described in the following sections.

Composite Formulations
Table 2 lists the compositions of formulations tested in these experiments.

Table 2. Wood Polymer Composite Formulations

	Formulations (wt%)					
Component	A	B	C	D	E	F
Polypropylene	70	69	65	60	68	63
Wood Flour	30	30	30	30	30	30
Coupling Agent (MAPP)		1	5	10		5
Multifunctional Coupling Agent (MFCA)					2	2

Formulation A provided a control sample, containing only polypropylene and wood flour. Formulations B, C, and D added a maleic anhydride grafted polypropylene (MAPP) at 1, 5, and 10wt%, respectively. Formulation E added a proprietary multifunctional coupling agent (MFCA) to the wood and polypropylene mixture, while formulation F combined both MCFA and MAPP.

Preparation and Characterization of Composite Samples
Composite samples were prepared and tested using the following protocol. Polypropylene pellets, coupling agent pellets, wood flour, and the proprietary multifunctional coupling agent were blended in a polyethylene bag. The resulting blend was volumetrically fed into the feed zone of a 27 mm co-rotating twin screw extruder fitted with three strand die (commercial available from American Leistritz Extruder Corporation, Sommerville, NJ). All samples were processed at 125 rpm screw speed using the following temperature profile: zone 1 = 170 °C, zone 2-7 = 180°C, and zone 8 = 160°C. The resulting strands were subsequently cooled in a water bath and pelletized into ~1/4" pellets to produce the composite formulation. The resulting pellets were injection molded into test specimens following ASTM D638 (tensile) and D790 (flexural) specification. Injection molding on composite formulations was performed using an 85 ton machine (commercially available from Engel Corporation, York, PA) having a barrel and nozzle temperature of 390 °F. The tensile and impact resistance properties were subsequently tested as specified in the ASTM methods.

To test the effects of water on the composites, molded specimens were subjected to two types of tests. The first test measured water absorption by the composite. In this test, specimens were allowed to soak in a room temperature water bath for 35 days. Periodically, the samples were removed from the water bath, pat dried with a towel to remove surface moisture, and weighed. The second test was designed as an accelerated aging test. For this test, specimens were subjected to steam between 5 and 15 psi in a closed vessel in 8 hour increments.

Results and Discussion

Room Temperature Water Uptake
Figure 1 plots the percent water uptake for formulations A through F over the duration of the experiment. As seen in the plot, the addition of a MAPP coupling agent reduces rate of absorption of water by the specimen. The effect of MAPP coupling agents to reduce water uptake is well known in the wood polymer composite industry. Maleic anhydride grafts preferentially interface with the hydroxyl groups on the cellulose surface, improving the barrier to water absorption by the wood.

When a proprietary multifunctional coupling agent (MFCA) is added to polypropylene and wood, a reduction in water absorption is found. This demonstrates that when used alone, the MFCA imparts an improved barrier to water absorption by the wood. However, the reduction in water absorption afforded by 2% of the MFCA is not as effective as 1% of MAPP. When MFCA added with MAPP coupling agent, the rate of water absorption is essentially equivalent to that of the PP/wood/MAPP system without MFCA.

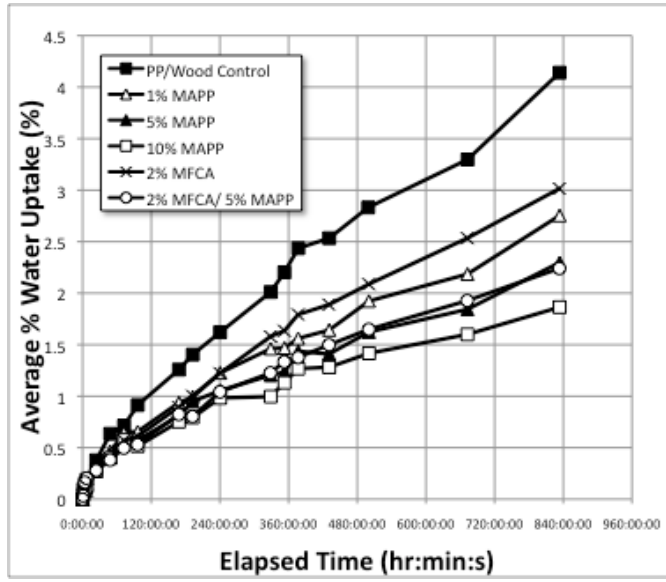

Figure 1. Room temperature water uptake

Although the addition of MFCA did not reduce the uptake of water by the molded specimens, a significantly improved surface finish was found for samples containing the MFCA. Samples containing MCFA exhibited less surface roughness and demonstrated less swelling of the wood fibers.

Mechanical Properties After Accelerated Aging
To simulate an accelerated aging of the polymer wood composites in a wet environment, molded test specimens were subjected to a low pressure steam bath for 8 hours. After 8 hours, the test specimens were allowed to condition in a 50% humidity environment for 48 hours prior to testing tensile and impact resistance properties. Table 3 lists the results from tensile tests, and Table 4 lists the results from impact resistance tests before and after steam treatment.

As seen from the data in Tables 3 and 4, the addition of MAPP coupling agent generally improves mechanical properties of tensile strength, modulus, and impact resistance, as one would expect. Increasing the concentration of MAPP increases tensile strength and impact resistance. This trend is preserved in the samples subjected to 8 hours of steam treatment, despite a significant drop in tensile properties after steam treatment. For example, formulation D containing 10% MAPP coupling agent looses about 10% of its tensile strength after 8 hours of steam treatment. Interestingly, results for impact resistance appear to be largely unaffected by the steam treatment process.

Table 3. Tensile Properties of Polymer Wood Composites Before and After 8 Hour Steam Treatment

	Tensile Strength (psi)	SD	Elongation (%)	SD	Tensile Modulus (psi)	SD
Before Steam Treatment						
A	4360	477	---	---	---	---
B	4320	107	2.1	0.1	501000	41200
C	4870	90	2.1	0.2	526000	27000
D	5220	140	2.5	0.1	491000	36700
E	4520	201	2.3	0.3	487000	58100
F	5710	52	3.5	0.1	475000	24800
After 8 Hour Steam Treatment						
	Tensile Strength (psi)	SD	Elongation (%)	SD	Tensile Modulus (psi)	SD
A	3850	19	2.6	0.4	427000	28500
B	4030	26	2.8	0.2	415000	16400
C	4440	21	2.4	0.0	431000	23900
D	4730	8	2.6	0.1	448000	38700
E	3820	43	3.2	0.5	404000	74400
F	5610	62	4.5	0.1	417000	14000

Table 4. Impact Resistance of Polymer Wood Composites Before and After 8 Hour Steam Treatment

	Unnotched Impact Resistance (ft-lb/in)	SD	Type of Break
Before Steam Treatment			
A	1.99	0.25	Complete
B	2.07	0.33	Complete
C	2.34	0.23	Complete
D	2.59	0.12	Complete
E	2.57	0.14	Complete
F	3.55	0.28	Complete
After 8 Hour Steam Treatment			
	Unnotched Impact Resistance (ft-lb/in)	StDev	Type of Break
A	2.46	0.33	Complete
B	2.22	0.35	Complete
C	2.04	0.00	Complete
D	2.97	0.17	Complete
E	2.83	0.36	Complete
F	4.08	0.68	Complete

Sample E containing MFCA (without MAPP) exhibits properties very close to those of the control formulation A, both before and after steam treatment. However, the use of both the MFCA and the MAPP coupling agent for formulation F significantly improves mechanical properties over all other formulations. The improvement is substantially greater than MAPP alone, even when added at significantly higher concentration. Formulation F demonstrates a 30% increase in tensile strength above the control formulation A and about 17% increase over formulation C that contains the same concentration of MAPP. The results for impact resistance are even more substantial with more than a 50% increase over formulation A and more than 40% increase over formulation C. Furthermore, after steam treatment, the tensile and impact resistance properties for formulation F are largely unchanged.

The mechanical property results for formulation F before and after 8 hour steam treatment demonstrate the capability of this formulation to coat, encapsulate, compatibilize, and protect the wood fiber within the composite formulation. The MFCA serves to chemically bond the MAPP coupling agent to the cellulose surface of the wood fiber. This enhanced bonding promotes both better mechanical properties and greater resistance to water.

Surface Appearance After Steam Treatment

A rapid screening process was used to evaluate the effects of heat and moisture on the surface appearance of the composites. For these tests, samples were placed in a pressurized steam bath between 10-15 psi pressure for intervals of 8, 16, and 32 hours. After steam treatment the samples were removed, allowed to dry, and photographed. Figure 2 displays photographs of samples from formulations A, C, and F prior to and after steam treatment at various intervals. As seen by the photographs, the addition of the MFCA dramatically improved the surface appearance of the composite. Even after 32 hours of steam treatment, formulation F exhibits a smooth surface finish with minimal swelling of wood fibers. Some darkening of the samples was observed across all of the samples, but this is likely due to the leeching of organic components out of the wood fiber.

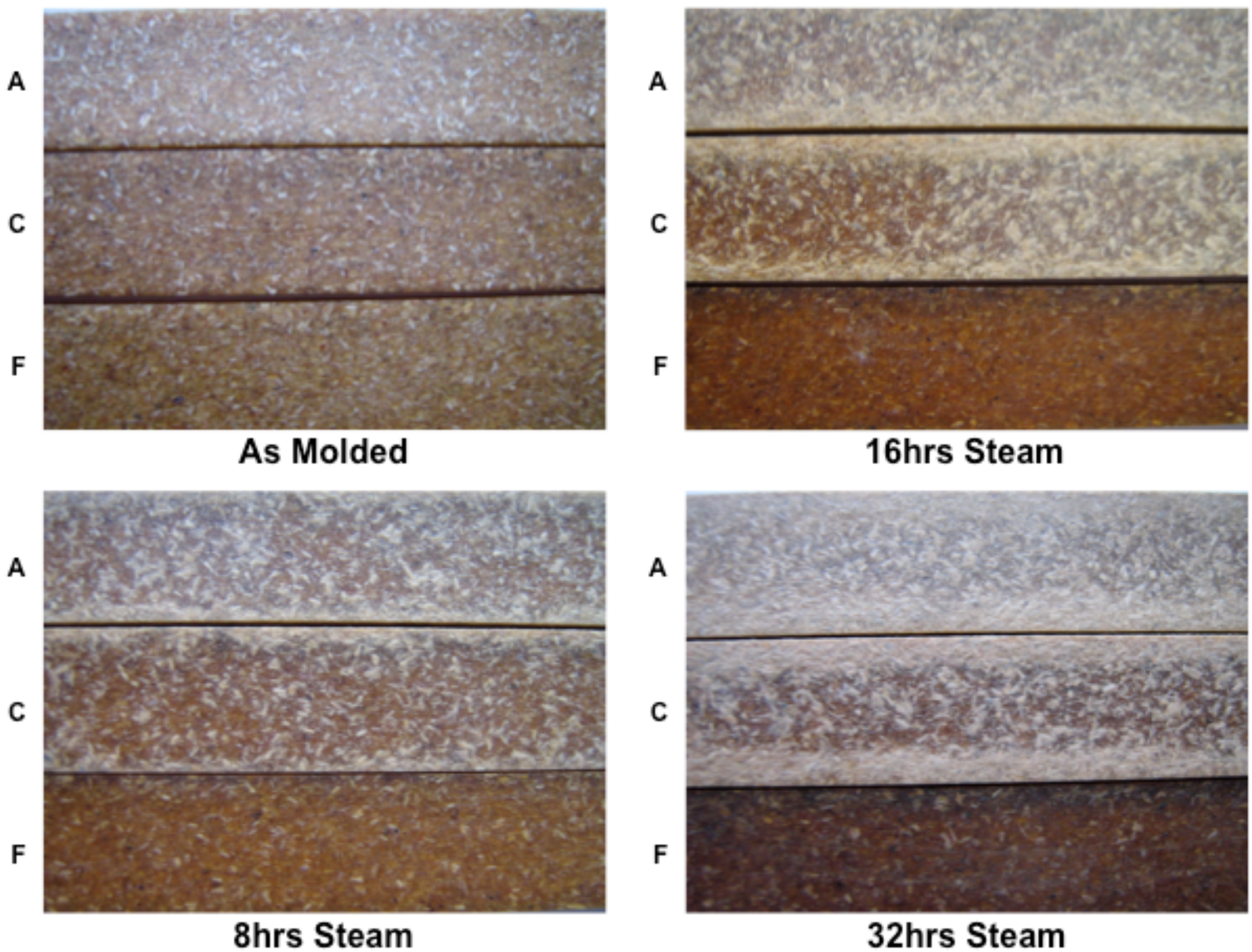

Figure 2. Photographs before and after steam treatment for formulations A (PP/wood control), C (5% MAPP), and F (2% MFCA and 5% MAPP).

Conclusions

In summary, this work has shown that the proprietary coupling agents developed by Interfacial Solutions dramatically improved the moisture resistance of composite formulations at room and elevated temperatures. Composite formulations containing the proprietary formulation also showed greater retention of mechanical properties after steam exposure. Interestingly, composite formulations containing the proprietary additive technology showed slight darkening rather than lightening in color after steam exposure. Generally, the additives provided better color retention and fastness when compared to conventional composite formualtions.