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Section 4 **Processes and Properties**

Extruded wood plastic composites based on ACQ and MCQ-treated wood materials

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ABSTRACT

This paper deals with wood plastic composites manufactured using ACQ and MCQ-treated wood fibers recovered from a wood treatment plant. The goal was to investigate the effect of coupling treatments on the properties of manufactured wood plastic composites (WPCs) through injection molding and to manufacture co-extruded WPC with treated wood fibers. The result demonstrated sound mechanical properties and improved biological performance of both injection-molded and profile extruded WPCs with treated wood materials. The process offers a practical way to recycle treated wood into value-added composites.

Keywords: ACQ, MCQ, treated wood, recycling, WPC, extrusion, termite, decay

1. INTRODUCTION

New generation wood-based composites offer enhanced long-term durability for structures typically constructed with natural wood products. Among the composite products, wood-plastic composites (WPCs) are being developed for both structural and non-structural uses. These composites offer some inherent technical advantages over conventional composites, which would characterize them as “environmental friendly” or “green: (Clemons 2002, Clemons and Caulfield 2005). WPCs can be manufactured in a variety of colors, shapes and sizes, and with different surface textures. The current WPC products include decking/fencing materials, roof shingles, siding, facia, beadboards, and molding (Clemons and Caulfield 2005). WPCs do not normally require painting or other finishes, nor will they warp or rot significantly like wood does. However, WPCs can be degraded in outdoor environments. The wood in the WPCs can still be attacked by termites, rot and mold fungi, and sunlight can discolor and break down the plastic component (Laks et al. 2000, and Verhey et al. 2001). Various preservatives and treatments have been used in WPC manufacturing to enhance its biological performances (Simonsen et al. 2004)

Pressure-treated wood is widely used for durable outdoor applications. Proper disposal of the treated wood after its service life poses a significant industrial problem. Recycling treated wood fiber into WPC system offers advantages in recovering valuable wood resources and in helping create WPC products which are less biological and photo degradable. Previous work in the field limits to CCA-treated wood under compression molding (Kamdem et al 2004). A large quantity of ACQ/MCQ treated wood is available and extrusion is the most popular processing technique for WPC. Successful development of extruded products requires detailed information of the manufacturing variables and understanding of coupling system and coupling efficiency between treated wood fiber and plastics in the composite.

This work was done to investigate the feasibility of using ACQ and MCQ-treated wood fiber in manufacturing WPC. The objective of the work was 1) to investigate the effect of coupling treatments on the properties of manufactured WPC through injection moulding and 2) to develop a process for manufacturing co-extruded WPC with treated wood fibers.

2. MATERIAL AND METHODS

2.1 Preparation of Wood Fibers

Shaving from ACQ- and MCQ-treated and untreated southern yellow pine wood was collected from a local wood treatment plant in Louisiana. The wood shaving was granulated with a laboratory granulator to pass through a 12-mesh screen, and the ground material was dried to about 3% moisture content level prior to use. Samples from both ACQ and MCQ-treated wood were taken to perform copper loading analysis in accordance with standards set forth by the American Wood Preservers' Association manual. Table 1 shows the result of analysis. As shown, the ACQ treated wood particles selected had a higher copper and quat loading level compared with the MCQ-treated wood.

Table 1: Results of CuO/Quat analysis for ground treated wood fibers.

Sample ID	CuO (pcf)	Quat as DDAC (pcf)	Total (pcf)
MCQ Wood	0.175	Below Detection Limit	0.175
ACQ Wood	0.255	0.157	0.412
WPC Blend	0.093	Below Detection Limit	0.093

* The pcf for both samples was calculated using a density of 32.0 for Southern Yellow Pine.

2.2 WPC Manufacturing

Injection Moulding - The composite blends were prepared using a CW Brabender Intelli-torque twin-screw extruder with a screw speed of 60 rpm at 170ºC. Table 1 shows the design for various blends. Plastics (HDPE 6761 – 58.8% by weight), wood fiber (i.e., ACQ,

Table 2: Wood fiber and HDPE blend design for the study through injection molding.

Blend Number	Wood Type	Plastics HDPE6761(g)	Wood Fiber (g)	Coupling Agent Type and Loading (g) *			
				MAPE	EPR	EGMA	POE
1	ACQ-	750	500	25			
2	Treated	750	500		25		
3	SYP	750	500			25	
4	Wood	750	500				25
5	MCQ-	750	500	25			
6	Treated	750	500		25		
7	SYP	750	500			25	
8	Wood	750	500				25
9	Untreated	750	500	25			
10	SYP	750	500		25		
11	Wood	750	500			25	
12	Control	750	500				25

* MAPE: maleic anhydride grafted polyethylene; EPR: ethylene-propylene rubber; EGMA: polyethylene copolymer; and POE: polyolefin elastomer.

MCQ, and untreated control – 39.2% by weight), and coupling agent (e.g., MPAE – 2% by weight) were added to the extruder, which were thoroughly mixed, and then pelletized by a BT 25 Strand Pelletizer. The test samples were made through injection molding, using a Battenfeld PLUS 35 injection system at 190ºC with a mold temperature of 85ºC.

Profile Extrusion – Profile extrusion was done using a pilot-scale coextrusion system recently developed at the LSU AgCenter (Yao and Wu 2010). The system consists of a

Leistritz Micro-27 co-rotating parallel twin-screw extruder for core blends, a Brabender 32-mm conical twin-screw extruder for the shell layer, a specially-designed co-extrusion die, and a vacuum sizer for profile size control. The system produced a solid profile with a cross-section area of 13×50-mm. The ground MCQ-treated wood particles were used in combination with both virgin and recycled HDPE plastics for profile extrusion.

2.3 Mechanical and Biological Resistance Properties

Flexural and tensile properties were measured according to the ASTM D638 using an INSTRON machine. For each treatment level, five replicate samples were tested. A TINIUS 92T impact tester was used for the Izod impact strength test. All the samples were notched on the center of one longitudinal side according to the ASTM D256.

No-Choice Laboratory Termite Tests according to AWPA E1 was done using injection-molded samples. Five matched samples (31x18.0x3.5-mm) from each group and five untreated southern pine controls (25.4x25.4x6 mm) were used. Prior to each termite test, the blocks were oven-dried at 105°C for 24 hours and sample weight (W_1) and dimensions were measured. Each test bottle was autoclaved for 30 minutes at 105 kPa and dried. Autoclaved sand (150g) and distilled water (30mL) were added to each bottle. Finally, four hundred termites (360 workers and 40 soldiers) were added to the opposite sides of the test block in the container. All containers were maintained at room conditions for 4 weeks. The bottle cap was placed loosely. After testing, each bottle was dismantled. Live termites were counted, and test blocks were removed and cleaned. Each block was oven-dried again at 105°C for 24 hours to determine the dry sample weight (W_2). Sample weight loss [$(W_1-W_2)/W_1$] and termite mortalities were determined. The tested samples were ranked visually by five people on a scale of 1-10 with 10 as no-damage and 1 with the most damages.

Decay test using injection molded samples (31x18.0x3.5-mm) was performed in accordance with the AWPA Standard Method of Testing Wood Preservatives by Laboratory Soil-Block Cultures (E10-09). The brown rot fungus used is *Gloeophyllum trabeum*. The white rot fungus selected is *Trametes versicolor*. The white rot samples are being run for 24 weeks, and the brown rot samples are being run for 16 weeks. Weight loss data will be collected.

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties of Injection-molded Samples

Table 3 lists flexural, tensile, and impact properties of injection-molded samples with about 40% wood loading from treated and untreated wood. Figure 1 shows a typical plot of the mechanical properties (i.e., impact strength) for different coupling agent types. Samples with ACQ and MCQ-treated particles had comparable property values with those made of untreated wood particles. Thus, the blends with treated wood particle can be injection-molded very well. The different coupling agents used worked well for treated wood particles. In general, MAPE system led to better flexural and tensile properties, EPR system led to better impact strength as expected. The EGMA system led to the best bending and tensile strength, but it may not be very cost competitive at the similar loading level, compared with the MAPE coupling system.

Table 3: Summary of Mechanical Properties of Injection-molded WPC samples.

Type of Wood	Coupling agent	Strength			Modulus	
		Flexural (MPa)	Tensile (MPa)	Impact (KJ/m2)	Flexural (GPa)	Tensile (GPa)
ACQ Treated SYP Wood	MAPE	36.85 (0.36)	20.79 (0.34)	2.96 (0.09)	2.05 (0.03)	2.80 (.027)
	EPR	28.41 (0.20)	14.13 (0.43)	3.27 (0.18)	1.91 (0.06)	2.64 (0.90)
	EGMA	40.63 (0.41)	23.52 (0.21)	3.32 (0.26)	1.97 (0.05)	2.67 (0.15)
	POE	28.13 (0.26)	14.18 (0.37)	3.25 (0.16)	1.82 (0.03)	2.50 (0.23)
MCQ Treated SYP Wood	MAPE	30.54 (0.18)	16.39 (0.41)	3.59 (0.31)	1.75 (0.02)	2.73 (0.25)
	EPR	28.12 (0.19)	14.36 (0.42)	3.93 (0.11)	1.72 (0.02)	2.44 (0.33)
	EGMA	36.23 (0.27)	20.05 (0.20)	3.75 (0.27)	1.83 (0.02)	3.07 (1.01)
	POE	27.99 (0.35)	14.07 (0.40)	3.99 (0.39)	1.73 (0.04)	2.33 (0.30)
Untreated SYP Wood Control	MAPE	36.22 (0.23)	20.80 (0.21)	3.22 (0.16)	1.92 (0.03)	2.33 (0.27)
	EPR	34.07 (0.36)	19.95 (0.19)	3.19 (0.49)	1.83 (0.03)	2.43 (0.56)
	EGMA	41.45 (0.54)	25.20 (0.30)	3.58 (0.69)	1.90 (0.03)	2.35 (0.19)
	POE	32.54 (0.57)	17.99 (0.46)	3.19 (0.38)	1.86 (0.05)	3.01 (0.60)

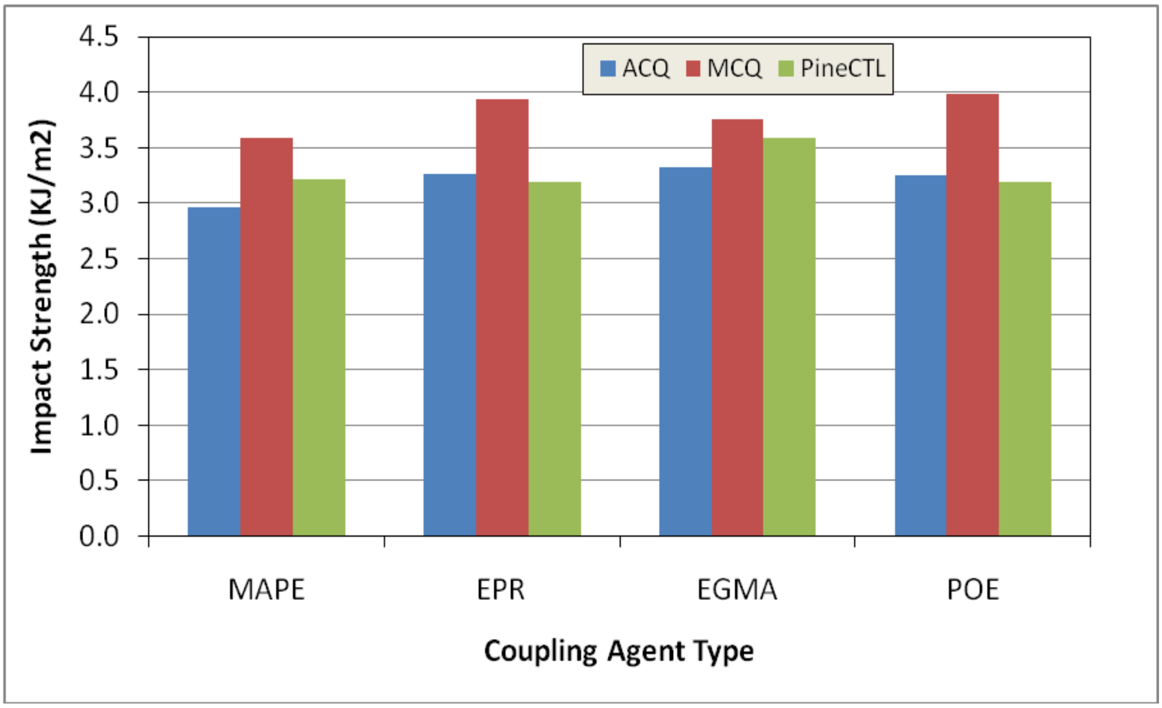

Figure 1: Effect of coupling agent types on impact strength for various samples.

3.2 Biological Properties of Injection-molded Samples

Table 4 summarizes the E1 termite test data (mortality, weight loss and damage rating with statistical ranking) of injection-molded samples in comparison with these from untreated solid wood controls and pure HDPE. All wood plastic composite and pure HDPE samples performed well, while solid wood controls had large weight loss (37%) and low sample damage rating. Among the two groups of WPC samples with treated wood fibers, samples with ACQ-treated wood had less weight loss compared with these from MCQ. This may be due to higher copper and Quat loading in the wood as shown in Table 1. The composite group with untreated wood had a slightly larger weight loss.

Table 4. Summary of termite test data for injection molded samples with ACQ- and MCQ treated and untreated SYP wood fibers.

Sample Group	Type of Wood Used	Mortality (%)	Weight Loss (%)	Ratings (0-10)
WPC-MAPE	ACQ-	2.65% (AB)	0.37% (A)	8.9 (D)
WPC-EPR	Treated	3.35% (ABC)	0.36% (A)	9.3 (D)
WPC-EGMA	SYP	4.05% (ABCD)	0.25% (A)	9.3 (D)
WPC-POE	Wood	8.25% (CDE)	0.93% (A)	8.8 (D)
WPC-MAPE	ACQ-	9.95% (E)	3.25% (B)	7.9 (B)
WPC-EPR	Treated	8.80% (DE)	3.38% (B)	7.9 (BC)
WPC-EGMA	SYP	9.75% (E)	3.65% (BC)	8.9 (D)
WPC-POE	Wood	7.40% (BCDE)	4.61% (BCD)	8.3 (BC)
WPC-MAPE	Untreated	6.80% (ABCDE)	4.61% (CD)	8.7 (D)
WPC-EPR	SYP	6.80% (ABCDE)	4.92% (D)	8.7 (D)
WPC-EGMA	Wood	6.20% (ABCDE)	3.43% (B)	8.1 (C)
WPC-POE	Control	7.15% (ABCDE)	4.94% (D)	8.1 (BC)
Pure HDPE	No Wood	7.25% (ABCDE)	0% (A)	10.0 (E)
Solid Wood	Untreated Wood	2.15% (A)	37.09% (E)	0.0 (A)

Figure 2 shows selected photographs of the on-going decay test for injection-molded samples. The photos A, B, C, and D show test samples made of ACQ wood-HDPE, MCQ wood-HDPE, untreated wood-HDPE, and pure HDPE, respectively.

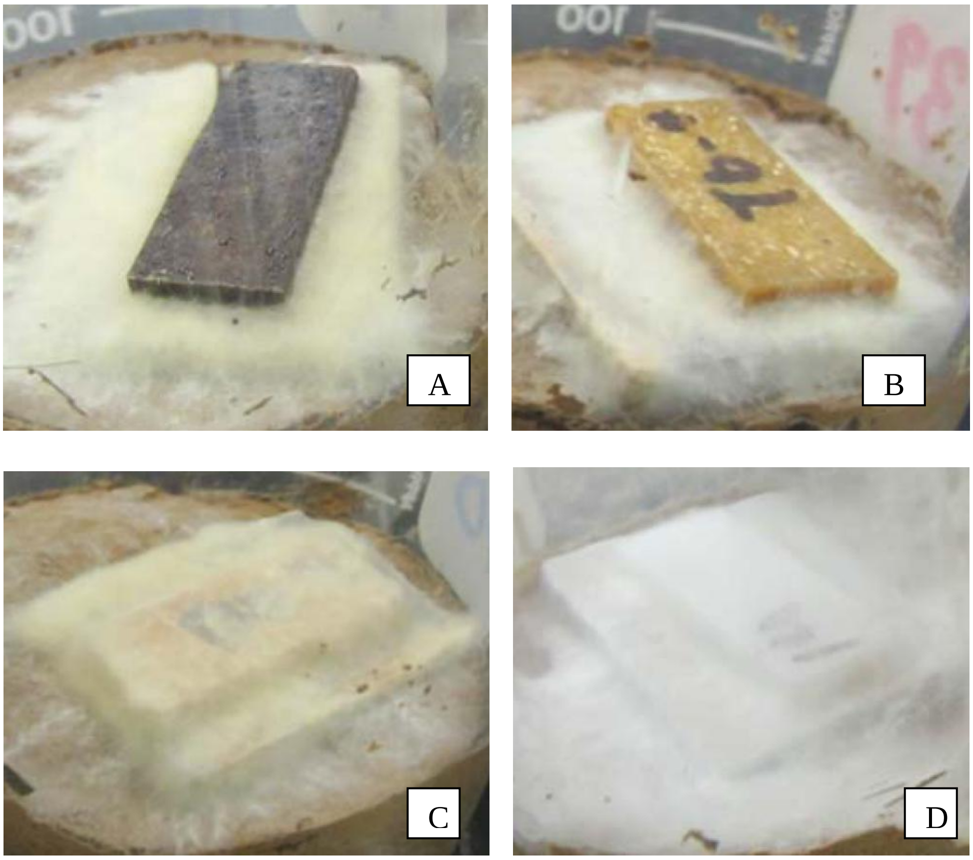

Figure 2: Pictures of on-going decay test based on the AWPA E10 protocol.

Samples with treated wood particles (A and B) showed very little decay fungi growth on the surfaces, while samples with untreated wood (C) and even pure HDPE (D) had significant fungi growth on the surfaces. Thus, it is expected that the treated wood samples will have a significantly less weight loss – showing enhanced decay resistance.

3.3 Performance Properties of co-Extruded Samples

The extruded material with 50% wood loading contained about 0.093 PCF of CuO as shown in Table 1 from X-ray analysis with finely ground particles. This is close to the 50% level of the copper loading in the wood particles (Table 1). The difference is due to the between-sample variability. Table 5 lists bending strength, bending modulus and impact strength of profile extruded samples. The bending property value compared well with commercial WPC products, while the impact strength is 3 to 4 times higher. By using a shell layer, water absorption and thickness swelling of the co-extruded samples were reduced significantly in comparison with pure core layer (Figure 3). The solid shell layer with less wood loading will also have potential to prevent chemicals within treated wood in the core layer from leaching – leading to long term protection of the product.

Table 5: Summary of mechanical property data for profile-extruded samples with MCQ treated wood fibers.

Sample Group	Plastic Type	Formulation*		Bending MOE (GPa)	Bending MOR (MPa)	Impact Strength (KJ/m2)
		Shell	Core			
1	Virgin HDPE	Av	Cv	2.34 (0.05)	28.24 (0.48)	8.13 (0.48)
2		Bv		2.36 (0.07)	28.05 (0.89)	8.07 (0.81)
3	Recycled HDPE	Ar	Cr	2.29 (0.08)	28.82 (0.66)	8.70 (0.39)
4		Br		2.54 (0.04)	29.79 (0.39)	8.84 (0.78)

* **Av and Ar: 10%** wood/88% HDPE (v/r)/0.8% MAPE/1.2% Lubricant
Bv and Br: 20% wood/76% HDPE (v/r)/1.6% MAPE/2.4% Lubricant
Cv and Cr: 50% wood/40% HDPE (v/r)/4.0% MAPE/6.0% Lubricant

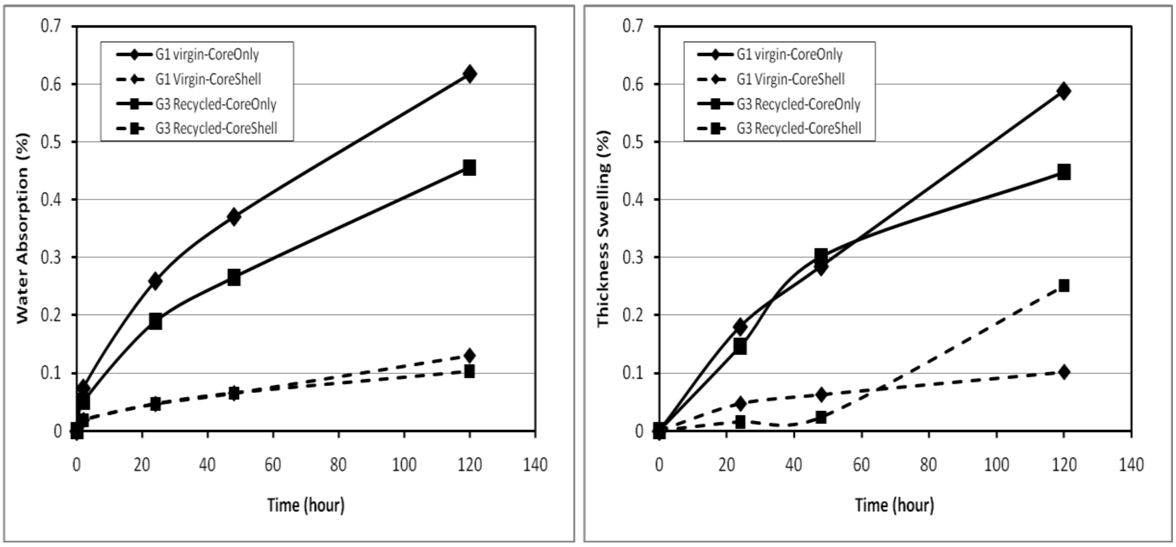

Figure 3: Water absorption and thickness swelling data of profile extruded composites.

4. CONCLUSIONS

Both ACQ- and MCQ-treated wood particles can be successfully used to make WPC with sound mechanical properties and improved biological performance. MCQ-treated wood led to a significantly lighter WPC product (compared with ACQ-treated wood), similar to these with untreated wood fibers. The profile extrusion led to a product with enhanced mechanical and dimensional stability properties and potentially less chemical leaching due to a solid protection shell. Further testing and development of the co-extruded WPC products using treated wood fibers are currently on-going.

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