TESTING OF SELECTED GLUES FOR WOOD POLYMER COMPOSITES IN DRY AND WET USE

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ABSTRACT

Methyl methacrylate wood polymer composite was made from sugar maple. Six commercial adhesive formulations were used to glue the wood polymer composite before and after treatment. Shear block tests were done dry and wet after boiling. Controls were glued, untreated wood, solid wood, and solid wood polymer composite. Phenol-resorcinol adhesive gave high strength and wood failure values for all treatment and test conditions; and isocyanate, epoxy, and polyvinyl acetate formulations performed well in some combinations.

Keywords: Wood polymer composites, wood polymer combinations (WPC), adhesive, glue, shear test, phenol-resorcinol, polyvinyl acetate (PVA), emulsion isocyanate, emulsion polymer isocyanate, moisture cure isocyanate, testing, sugar maple.

INTRODUCTION

One important reason for the development of wood polymer composites (WPC) was to improve wood's dimensional stability (Schneider 1994). Uses where dimensional stability is important include those in cyclic wet and dry environments. Bathroom furnishings, kitchen utensils and furnishings, and flooring in public places are examples of room temperature use. Utensils that will be washed in dishwashers must be resistant to cyclic heat as well as moisture. Wood polymer composite products that will be made from laminated wood require adhesive bonds that will perform well. If bonding is done before treatment, the adhesive must be able to withstand the treating and curing process. When gluing is done after treatment, the adhesive must be able to bond to a changed material. After successfully producing a bond, the assembly must be able to perform in the end-use environment.

This study was undertaken to determine the performance of some adhesives in WPC assemblies made before and after the WPC was produced, and in dry and wet environments.

EXPERIMENTAL

Specimens to give shear strength values of the solid material (without gluelines) were made from sugar maple (*Acer saccharum* Marsh.) conditioned to 8% moisture content (MC). These specimens were nominally 250 mm long and 45 mm by 45 mm in cross section. One half of them were cut into shear block test samples of the same dimensions as the glued samples (ASTM 1989), but lacking the glue-

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TABLE 1. *Adhesives used in the study. All cure at room temperature.*

Type	Designation	Manufacturer
Phenol-resorcinol	RDL-058	Indspec Chemical Co
Emulsion polymer isocyanate	Isoset 320	Ashland Chemical Co
Emulsion polymer isocyanate	Isoset 312	Ashland Chemical Co
Moisture-cure isocyanate	Isogrip	Ashland Chemical Co
Epoxy	G-R	Industrial Formulators of Canada
PVA emulsion	50107 Carpenter's glue	Lepage Industrial

line, and tested. The other half was made into WPC, cut into shear blocks, and tested.

Wood polymer composite was made by impregnating 8% moisture content (MC) sugar maple with catalyzed methyl methacrylate (0.3% Dupont Vazo 64, 1% ethylene glycol dimethacrylate crosslinker) using mechanical vacuum followed by 1000 kPa (150 psi) pressure to refusal and curing at 70 C. A small amount (0.1%) of red dye in the monomer allowed treating continuity to be observed.

For block shear adhesive tests according to ASTM D905-89 (ASTM 1989), sugar maple pieces 250 mm long (along the grain), 45 mm wide (approximately tangential), and 25 mm thick were cut from mill-run lumber. They were conditioned to 8% MC, planed in a knife-type planer, and sanded with 80-grit sandpaper on a flat, marble plate to obtain flat surfaces before applying adhesive. Their final thickness was 20 mm. Two such pieces were glued together on their 45-mm-wide side to make up an assembly. Four shear block samples with a 5-mm offset and therefore a 45-mm by 40-mm shear area were cut from each cured assembly (ASTM 1989). Since six shear block samples were tested for each combination, some of the 250-mm-long assemblies were crosscut in half before making WPC, to provide the extra two samples for each set. Two-thirds of the samples were glued without treating the wood. One-half of this two-thirds was tested as controls, and WPC was made from the other half. The remaining one-third of the samples had been made into WPC before gluing. These WPC pieces were planed before treating and sanded afterwards. The sanding exposed well-treated surfaces. Sufficient glue was applied to get slight squeeze-out. Pressure between 1000 and 1300 kPa (150 and 200 psi) was applied to each assembly with screw clamps for 24 h.

Table 1 lists the adhesives used in the study. The phenol-resorcinol formaldehyde (PRF) formulation was chosen to be representative of highly water-resistant, crosslinked adhesives with long service record in wood products. The emulsion polymer isocyanate (EPI) glues have shown weather and creep resistance properties and produce light-colored gluelines. The moisture-cure isocyanate (MCI) adhesive was chosen because of its 100% solids and promise as strong bonding agent to wood and polymer in WPC. Preliminary delamination studies (8 h boil in water, drying) showed that these four adhesives had promise in producing exterior-type bonds with WPC made before and after glueup. Epoxy and polyvinyl acetate emulsion (PVA) type glues have not performed well through WPC manufacturing and in hot, wet environments during preliminary studies. They were used in this study as representatives of types that might be used to glue WPC for use in dry conditions.

Glued assemblies were conditioned to 14% MC after gluing. Those to be tested for heat and moisture resistance were boiled in water for 24 h, cooled, and tested wet. An Instron model 4206 testing machine at 0.6 mm/min crosshead speed was used to test in shear. Load at failure, measured bond area, and percent wood failure were recorded.

RESULTS AND DISCUSSION

Table 2 gives the shear strength of the solid WPC and the wood from which it was made.

TABLE 2. *Average shear strength and standard deviation (6 samples) of 14% MC solid sugar maple and maple WPC made with catalyzed methyl methacrylate and cured using heat. Shear blocks were made with same dimensions as glued blocks, but without a glueline, and tested in the same way as the glued blocks.*

Species	Average	Standard deviation
Solid maple	16.0 mPa	0.49
Maple WPC	28.9 mPa	3.99

Table 3 gives the results of the glueline shear testing. The highest shear strength and percent wood failure (wf) in untreated maple tested dry were obtained with PRF and epoxy adhesives. Tested wet, untreated wood glued with PRF and the number 320 emulsion polymer isocyanate (EPI 320) performed best. When the wood was made into WPC, glued, and tested dry (treated, glued, dry), the PRF adhesive performed best; but the EPI 312, the epoxy, and the polyvinyl acetate (PVA) emulsion were nearly as good. Tested wet (treated, glued, wetted), the best performing adhesive was PRF, although the EPI 320 had acceptable shear strength. In the case where the wood was glued, WPC made, and the assemblies tested wet (glued, treated, dry), PRF and EPI 312 were best performers, with EPI 320 very close. Tested wet (glued, treated, wetted), PRF was best with EPI 320 giving the same shear strength but exhibiting 100% glueline failure (0% wf).

The best-performing adhesives with dry, untreated wood (Table 3) gave consistent shear values near 20 mPa compared to 16 mPa for wood with no glueline (Table 2). Treating increased shear strength, with the best glued values (treating after gluing—Table 3) approximately the same (about 28 mPa) as that for maple WPC with no glueline (Table 2).

Phenol- and resorcinol-formaldehyde resins used as adhesives typically are highly cross-linked polymers that have high shear strength (Marra 1992). Because of the extent of cross-linking, they do not change mechanical properties very much in the presence of solvents, moisture, and heat. These properties are consistent with the 100% failure in the substrate (none in the glueline) in every test using the PRF glue. During treating, the adhesive resisted the monomer sufficiently to hold assemblies together. When tested wet, the adhesive was still stronger than the wood. The only other adhesive in the study that was consistently stronger than the wood was the epoxy, and that only in the dry condition. Epoxies can be formulated to be highly cross-linked and glassy and thus behave like PRF under some conditions; however, they may remain sensitive to moisture and heat.

TABLE 3. *Shear block strength (Str), in mPa, and percent wood failure for untreated glued wood and WPC made before and after gluing and tested dry or wetted. The six adhesives are phenol-resorcinol, two emulsion polymer isocyanate, moisture cure isocyanate, epoxy and polyvinyl acetate emulsion formulations. WPC was made using catalyzed methyl methacrylate and was heat-cured. High test values are in boldface type.*

Treatment and test		PRF	EPI 320	EPI 312	MCI	Epoxy	PVA
Untreated, dry	Str	**21.0**	**20.7**	17.5	11.5	**20.2**	**21.2**
	% wf	**100**	56	67	1	**100**	51
Untreated, wet	Str	**7.7**	**7.1**	3.9	2.7		
	% wf	**100**	0	0	0		
Treat, glue, dry	Str	**20.7**	17.4	**19.9**	12.4	**21.0**	**18.9**
	% wf	**74**	38	**50**	0	**48**	**50**
Treat, glue, wet	Str	**9.9**	7.6	4.3	2.6		
	% wf	**100**	0	0	0		
Glue, treat, dry	Str	**23.9**	**26.3**	**28.5**	13.6		
	% wf	**92**	54	**93**	0		
Glue, treat, wet	Str	**10.8**	**10.2**	8.8	6.5		
	% wf	**100**	0	0	0		

Polyvinyl acetate adhesives are latexes, the solid polymer particles of which are linear, thermoplastic polymers. Polyvinyl acetate thus creeps under steady, long-term stress and has less shear strength than a highly cross-linked polymer (Marra 1992). The emulsion polymer isocyanate is cross-linked (Pagel and Luckman 1984), but apparently not sufficiently to produce glue shear strength quite as high as PRF. This appears as less-than-100% wood failure percentages in Table 3. The lower wf is also evident for the PVA for the same reason.

Polyvinyl acetate bonds strongly to dry wood through hydrogen bonds that are susceptible to breakage in the presence of moisture; PVA is thus moisture-sensitive. Emulsion polymer isocyanate and moisture cure isocyanate may bond to wood through covalent bonds between isocyanate groups in the adhesive and hydroxyl groups in the wood. This would help account for the high shear strength values for these adhesives in Table 3. The formulation of MCI used in this study remained a tough, rubbery solid (rather than a glassy solid like PRF) after curing. Thus, while it showed high adhesion, nearly all of its failures were in the glue itself (0% wf). Presumably, an MCI formulation that would give a more glassy adhesive would produce more wf.

CONCLUSIONS

Five of the six adhesives tested performed well with wood polymer composites under some assembly and test conditions. Many bonds had equivalent shear strength to solid material (without gluelines). A phenol-resorcinol formaldehyde glue formulation performed consistently highly in all combinations of assembly and test conditions. Emulsion polymer isocyanate glues performed well in several combinations.

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