COMMENTS ON THE STATIC BENDING STRENGTH OF WOOD-PLASTIC COMPOSITES[1]

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ABSTRACT

Static bending strength values are reported for three wood-plastic composite (WPC) hardwoods. Elastic strength values became uniform after treatment, suggesting that limiting values were obtained. Uncertainties in determining WPC strength values caused by sample cross-section, soaking time in monomer, and moisture content are discussed.

Additional keywords: Acer saccharum, Quercus spp., *Fraxinus americana*, wood-polymer composites, WPC, monomer, polymer, swelling.

INTRODUCTION

A number of useful strength values are obtained from static bending tests on wood. As the interest in creating wood-plastic composites (WPC) increased, it was a natural consequence that the mechanical properties of WPC would be compared with wood. One of the more comprehensive analyses of static bending strength (Langwig et al. 1968) was performed on basswood; however, such a low-density species is costly to process because of the high polymer loading. Also, high temperatures produced from the exothermic conversion of the monomer may cause thermal degradation and discoloration of the wood, or at least a color change in some dyes used in the monomer.

Basswood WPC was also used by Siau (1968) to find the effect on the subsequent MOE value after soaking wood in monomer for prolonged periods. MOE increased gradually for a total change of 6% after about 9 weeks of soaking. Small basswood blocks (20-mm cubes) were later found to swell considerably (up to 9% volumetrically) from penetration of the cell walls by monomer (Siau 1969). Adams et al. (1970) soaked loblolly pine in methyl methacrylate (MMA) for 12 days before pressure treating, but the wood had been oven-dried and exposed to 12% EMC conditions at 30 C before treatment. We have noted distinct variations in the rate of swelling of wood as affected by species and moisture content. The interaction of these variables causes difficulty in interpretation of some published studies.

The objectives of this study were to (1) report static bending strength values of wood species used in commercial WPC processing, and (2) point out some procedural difficulties in obtaining valid WPC strength values.

EXPERIMENTAL PROCEDURE

In this study, three species were obtained in the kiln-dried condition: hard maple (*Acer saccharum* Marsh.), red oak (*Quercus* spp. [*Erythrobalanus* group]), and white ash (*Fraxinus americana* L.). Sixteen samples of each species were machined to $25 \times 25 \times 400$ mm ($1 \times 1 \times 16$ inches) for static bending tests as described

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TABLE 1. *Static bending values of untreated vs. treated WPC*

Parameter	White Ash		Hard Maple		Red Oak		Basswood[a]		Southern Pine[b]	
	Species									
Moisture Content (%)	6		6		6		7.2		12	
Mass Loading (%)[c]	61		49		31		170		75	
MOR (10^3psi)										
Untreated	15.2	**	22.7	***	16.0	***	10.7	***	19.6	**
Treated	23.9		24.6		20.4		18.9		24.9	
MOE (10^6 psi)										
Untreated	1.41	*	2.29	NS	1.56	***	1.36	***	2.2	**
Treated	2.20		2.25		2.10		1.69		2.6	
FSPL (10^3 psi)										
Untreated	6.87	**	11.4	NS	7.60	***	6.39	***	11.9	NR
Treated	11.1		11.3		10.5		11.6		11.9	

[a]Langwig et al. 1968

[b]Adams et al. 1970 (Average values calculated from data)

[c]Ratio of polymer to ovendry wood mass

*** Significant at 0.01 level
** Significant at 0.05 level
* Significant at 0.10 level
NS Not significant at 0.10 level
NR Not reported

in the secondary methods of ASTM D143-52 and equilibrated at 6% EMC. One-half of each species group was randomly selected for impregnation. The treated samples were filled with MMA using a commercial full-cell process (vacuum, backfill with monomer, superatmospheric pressure). Radiation polymerization to polymethyl methacrylate (PMMA) was carried out in a commercial Co-60 system at about 0.1 Mrad/h. After treatment, the samples were again equilibrated at 6% EMC. Average mass loading of polymer is given in Table 1. Static bending was performed on a Tinius Olsen testing machine with automatic recording of load vs. deflection. Standard formulas were used to calculate modulus of elasticity (MOE), fiber stress at the proportional limit (FSPL), and modulus of rupture (MOR).

RESULTS AND DISCUSSION

The static bending values from this study are given in Table 1 together with those previously reported. In the previous studies, basswood had shown highly significant increases in all strength values, but the changes for southern pine were less dramatic. In this study, the results were initially difficult to reconcile since the change in elastic parameters (MOE and FSPL) after treatment was not consistent among the three species. However, when these values were compared within treated and untreated groups (Table 2), the four significant differences in MOE and FSPL among untreated samples were reduced to one for the corresponding treated samples.

Of particular interest are the similar FSPL values for all five treated species in Table 1. It can be seen from Table 2 that the FSPL values for treated maple, oak, and ash were not significantly different. The value for basswood was apparently not significantly different from these three, but the preparation and processing differences between studies make such a comparison uncertain. FSPL for treated southern pine was probably not significantly different from that of the controls, although the statistical data were not given in the paper (Adams et al. 1970). The moisture gradient could have caused a nonuniform monomer penetration into the cell walls, producing an abnormal polymer distribution superposed on an unknown resulting moisture gradient. A comparison of strength values between such treated and untreated specimens would not be valid for commercially produced WPC. In the case of the four hardwoods in Table 1, similar values of FSPL for treated samples contrast with the variation in untreated values. This suggests that PMMA supports the cell walls to minimize stress concentrations and permits the samples to approach a limiting elastic value that may be independent of wood anatomy.

TABLE 2. *Levels of significance for untreated and treated static bending values. Vertical lines connect significant values. No connection indicates lack of significance at 0.10 level*

Treatment and Species	Strength Value (psi) MOR (10^3)		MOE (10^6)		FSPL (10^3)	
Untreated						
White Ash	15.2	***	1.41	**	6.87	***
Hard Maple	22.7	***	2.29	***	11.4	***
Red Oak	16.0		1.56		7.60	
Treated						
White Ash	23.9		2.20		11.1	
Hard Maple	24.6	**	2.25	**	11.3	
Red Oak	20.4		2.10		10.5	

*** Significant at 0.01 level
** Significant at 0.05 level
* Significant at 0.10 level

OBSERVATIONS AND RECOMMENDATIONS

On the basis of the past research on WPC properties, there appear to be some viable areas of potential study to clarify the role of certain variables in observed changes of mechanical (and other) properties:

Sample cross-sectional area: The static bending values for 25- × 25-mm wood specimens (ASTM secondary standards) are considered comparable to 50- × 50-mm specimens (ASTM primary standards), but the validity of this has not been tested on WPC. Unpublished static bending test results of the writers for 50-mm red oak specimens showed no significant difference after PMMA treatment, whereas a significant difference was found between 25-mm samples in this study (Table 1).

Moisture content: Samples must be impregnated with monomer using a full-cell method to obtain maximum filling, but the evacuation period can cause an appreciable loss of moisture, creating a gradient. Equilibration of treated samples to compensate for moisture loss requires an extended period at elevated temperatures since moisture diffusion occurs predominantly in the cell-wall mode. Perhaps the only practical way to assure a uniform moisture gradient is through cooling the samples before evacuation and by using the shortest possible vacuum cycle. This could somewhat limit studies of purely moisture content effects to those woods that are easily penetrated.

Monomer swelling: After impregnation and during the polymerization period, MMA penetrates the cell wall and swells the wood. This occurs to a slightly lesser extent with styrene and very little with tertiary-butyl styrene (Siau 1969). The use of swelling and nonswelling monomers can provide complementary information from which the true nature of the composite could be analyzed. The presence of a moisture gradient causes nonuniform penetration of monomer into the cell wall, which causes greater swelling for lower moisture contents (greatest at 0% MC), although much more rapid swelling for higher moisture contents. This has been reported by Siau (1969) for basswood and confirmed by the writers for hard maple. The writers also observed that hard maple had a T/R monomer swelling ratio of nearly 2.0 over the range 0 and 12% MC. One of the complications introduced by nonuniform swelling is that, in some cases, samples have been remachined to obtain the desired cross-section (Langwig et al. 1968). It is then unclear whether the treated samples, which contain less cell-wall material in the same cross-section as untreated controls, are at a disadvantage in static bending tests where the depth of the beam is very important in the calculation of strength values.

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