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Properties of A Flake-Polymer Composite Particleboard

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ABSTRACT

Particleboards made from flake-polymer composites of red oak wood and two loadings of tertiary-butyl styrene (TBS) in combination with three binder resins were evaluated for performance in interior applications. The addition of TBS resulted in improved values for internal bond, hardness, abrasion resistance, and bending properties and greater dimensional stability than those of control boards. The inclusion of binder resins in addition to TBS had no consistent beneficial effect. Minimum commercial standards for Type 1, Class 1 medium-density particleboard were met or exceeded for internal bond, modulus of elasticity, and linear expansion.

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Properties of a Flake-Polymer Composite Particleboard

J. R. Hamilton, E. Y. Demetci, D. S. Mullenax,
and E. P. Jenkins

Many of the properties of whole wood may be enhanced by the *in situ* polymerization of various plastic materials. Recently, the properties of an aspen flakeboard impregnated with methyl methacrylate and then polymerized *in situ* were reported (2). The improved physical and mechanical properties of the flakeboard resulted not only from the presence of the polymer itself, but also from the more uniform distribution of loads among the flakes.

The properties of a flakeboard made from flake-polymer composites rather than a flakeboard-polymer composite are reported here. There are several advantages to this approach, the most obvious being the possibility of eliminating the need for a binder resin because of inter-flake bonding. The idea of particleboard using flakes impregnated with a chemical is not new (10, 11, 8, 3). Most articles report the use of low-molecular-weight formulations of bonding resins as the impregnant, and concentrate their examination on dimensional stability during changes in ambient moisture conditions and reduction of irreversible swell.

The objective of the research reported here was to examine the influence of polymer loadings and binder resins on several physical properties of an interior grade, medium-density particleboard made from flake-polymer composites of a high-density species.

Experimental Procedure

Commercially prepared red oak (*Quercus rubra* L.) flakes measuring 0.5 to 1.0 inch in length, 0.1 to 0.3 inch in width, and 0.01 to 0.05 inch in thickness were impregnated with tertiary-butyl styrene (TBS). The treating mixture consisted of a catalyst, 0.50 percent azobisisobutyronitrile; a cross linking agent, 6.00 percent ethylene glycol dimethacrylate; and a dye marker, 0.10 percent in combination with the monomeric TBS. These proportions had been used earlier by Kenaga (7). TBS was used because it possessed a number of desirable characteristics such as low volatility, low shrinkage on polymerization, low exotherm during polymerization, low density, and compatibility with a variety of dyes.

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Impregnation, to an excess of the retention level desired, was by steeping. Two monomer retention levels, 25 and 50 percent of flake-oven-dry weight, in addition to an untreated or 0 percent level, were obtained by centrifuging the flake-monomer mixture. Initial experimentation indicated that much of the liquid monomer was lost as squeeze-out when mats of the flake-monomer mixture were pressed. The monomer was stabilized by effecting a partial polymerization by heating the combination to 300° F for 15 minutes after the flakes were properly impregnated. The resulting flake-polymer composites did not adhere to one another, and all subsequent operations were facilitated.

Three liquid binder resins—a craze-resistant urea-formaldehyde, a phenol formaldehyde, and a low formaldehyde-urea—were used in combination with the polymer treatments. All were spray applied to the prepolymerized flake-polymer composites at a rate of 8 percent resin solids based on the oven-dry weight of the flakes. One series of boards was made without a binder resin.

The weight of flake-polymer composites and adhesive resin required to make a 9 x 9 x 1/2-inch, medium density (45 lbs./ft.³) board were formed in a mat and pressed to stops in a 15 x 15-inch press for 30 minutes at 250° F. There were three replicate boards for all possible combinations of binder resins and polymer treatments. Subsequently, the boards were cut into four 2 x 2-inch, two 2 x 4-inch, two 2 x 8-inch specimens which were conditioned to practical equilibrium at 69 ± 6° F and 65 ± 1 percent relative humidity. The periphery of the boards was discarded.

Mechanical and physical properties were evaluated according to the procedures detailed in ASTM D 1037-64 insofar as possible. The almost universal deviation from the specifications was with respect to specimen size. Comparison with the minimum standards for Type 1, Class 1 medium-density particleboard (CS 236-66) was made where applicable. One determination of density (based on volume at 68° F and 65 percent relative humidity) and two of internal bond were made on three of the 2-inch-square specimens. Hardness was determined on the specimen previously used for determining density. The Janka test was modified, at the suggestion of Loos (9), to the extent that the load was applied in increments of 250 pounds, and depth of penetration was measured following the application of each load increment and lapse of a 5-second relaxation period. Subsequently, the applicability to wood-plastic composites of the hardness modulus (ASTM D 1324-60) was brought to our attention (1). Estimates of hardness modulus were made from the data collected. Linear expansion and thickness swell were determined on one of the 2 x 8-inch specimens. Linear expansion is expressed as the percentage change in length of the specimen at 90 percent relative humidity (RH) based on the length at 50 percent RH. Linear springback is the percentage difference between the initial and final dimension of the specimen at 50 percent RH after having been cycled through 90 percent RH. Thickness swell and springback were determined in the same manner. The

specimens were conditioned for 20 days in each EMC condition prior to measurement. The flexural properties were determined on the second 2 x 8-inch specimen using a 6-inch span. Abrasion resistance was evaluated by means of a Teledyne-Tabor Abraser with H-18 abrading wheels, 250 grams abradent pressure and 250 revolutions, and is expressed as depth of wear in inches. Two of the 2 x 4-inch specimens were combined to form the abraded surface.

Results and Discussion

Nominal board density was 45 lbs./ft.³, but actual board densities ranged from 42.4 lbs./ft.³ to 50.5 lbs./ft.³. Although this was within the range of 37-50 lbs./ft.³ specified by the commercial standard for Type 1, Class 1 medium-density particleboard (CS 236-66), the data from all property evaluations were subjected to a covariate analysis with board density as the covariate. Hardness and static bending were found to be significantly correlated with board density; therefore, when hardness, hardness/modulus, modulus of rupture, and modulus of elasticity values are cited, they are adjusted for density variation. The results of all tests are given in Table 1.

Internal Bond

Incorporation of the polymer in both the 25 and 50 percent amounts greatly improved internal bond strength. The average value for boards made without the polymer but with an adhesive was 30.2 psi., as opposed to 128.7 psi. and 205.6 psi. for boards containing 25 and 50 percent polymer. Boards made without the polymer did not meet the minimum commercial standard of 70 psi., whereas those which contained the material exceeded the requirement.

The effect of the various binder resins was not entirely consistent when used in combination with the polymer. For both loadings, boards made with the urea-formaldehyde resin had smaller internal bond strengths than boards made without a binder resin. Use of both the phenol-formaldehyde and low formaldehyde urea resulted in boards which were stronger than the controls. The effect of these resins was less in boards containing 50 percent polymer than in boards with the smaller amount. In each case, however, the internal bond strength of boards made without the addition of the binder resin was adequate when compared with the commercial standard.

Static Bending

The strength values, obtained from static bending tests, show a marked increase as a result of inclusion of the polymer. There was no significant difference due to polymer loading or binder resin, however.

The average modulus of rupture (MOR) of 1,150 psi. for the boards made with treated flakes was somewhat less than the 1,600 psi. given as a minimum in

Table 1
The effect of polymer loading and binder resin on selected properties
of a flake-polymer composite particleboard.
Each value is the average of three replicates.

Polymer loading (%)	Binder resin ¹	Density (pcf)	IB ² (psi)	MOR (psi)	MOE (1,000 psi)	Hardness ² (lb.)	Hardness modulus ² (psi)	Abrasion ³ (inch)	Thickness swelling		Linear Expansion	
									50 to 90% RH (%)	Spring-back (%)	50 to 90% RH (%)	Spring-back (%)
0	PF	47.6	18.8	273	122.2	1,251	2,891	0.005	33.1	22.1	0.82	0.49
	UF	45.6	29.0	641	147.5	1,209	2,818	0.005	25.9	17.7	0.59	0.35
	UF(1)	48.6	42.7	608	172.3	1,177	3,459	0.004	23.7	15.2	0.46	0.24
	None	42.4	0.4	445	106.9	1,097	1,440	—	63.3	44.1	2.28	2.16
25	PF	47.8	126.1	1,113	274.8	1,468	4,232	0.003	8.1	3.6	0.24	0.03
	UF	44.7	80.0	961	292.1	1,531	2,991	0.003	8.6	4.2	0.31	0.07
	UF(1)	48.0	179.9	1,091	290.7	1,407	3,989	0.003	7.3	3.3	0.25	0.09
	None	47.2	94.5	1,010	289.3	1,522	4,041	0.004	8.9	3.9	0.26	0.04
50	PF	48.8	241.2	1,316	276.3	1,246	4,788	0.002	6.0	2.8	0.26	0.03
	UF	48.8	171.0	1,138	286.3	1,173	4,507	0.003	5.9	2.6	0.24	0.04
	UF(1)	47.8	204.6	1,125	298.2	1,137	4,033	0.003	6.0	2.3	0.23	0.03
	None	48.2	199.0	1,435	326.1	1,442	5,059	0.004	6.0	2.3	0.16	0.00

¹PF, phenol-formaldehyde resin; UF, urea-formaldehyde resin; UF(1); low-release formaldehyde urea resin.

²Duplicate observations in each replicate.

³Quadruplicate observations in each replicate.

the commercial standards for medium-density particleboard. On the other hand, the modulus of elasticity (MOE) of our boards exceeded the stated minimum value of 250,000 psi.

The lowest MOR value computed for boards containing 25 percent polymer was in conjunction with the urea-formaldehyde resin. Although this effect was not different statistically from that of the other resins at this polymer concentration, it is interesting that the lowest internal bond was also associated with the same resin-polymer combination. These two tests both evaluate the flake-to-flake bonds. Some incompatibility between the urea resin and the polymer is suggested.

Hardness

Incorporation of 25 percent polymer resulted in boards which were on the average 25 percent harder than those which were made without its addition. The average hardness for the 0 percent loading was 1,184 pounds and that for the 25 percent loading was 1,477 pounds. There was no significant effect of any of the binder resins when used in conjunction with the polymer. The hardness of boards containing 50 percent polymer was on the average less than that for boards which contained 25 percent. This anomaly is misleading because it is the result of cracking of the specimens during testing.

Penetration at the initial 250-pound load was on the average 0.086 inch, 0.050 inch, and 0.034 inch for the boards with 0, 25, and 50 percent polymer loadings. These figures indicate that the initial resistance offered by the boards containing the most polymer was more than twice as great as that offered by boards without the polymer. At a load of 500 pounds, penetration was more nearly the same for the three polymer loadings. At loads greater than this, the depth of penetration in boards containing 50 percent polymer increased—indicating that cracks had occurred. Beall, Witt, and Bosco (1) suggest that the hardness modulus (ASTM D 1324-60), a value used to quantify the hardness of modified woods, is a valid means of comparing the hardness of modified particleboards. Our estimate of the hardness modulus indicated that boards containing 50 percent polymer were not only harder than untreated boards but were on the average 20 percent harder than those containing 25 percent polymer. Direct comparison of our values for hardness modulus with that of other authors is not entirely valid. The 5-second relaxation period employed by us resulted in lower computed values for hardness modulus than the values obtained by those making use of instantaneous measurements of penetration.

Abrasion

The inclusion of 25 and 50 percent polymer significantly improved the abrasion resistance of the boards. The amount of wear measured was 33 percent less in these boards than in those without polymer. There was no significant

improvement associated with the use of 50 percent rather than 25 percent polymer, and there was no consistent effect as a result of the addition of a binder resin.

Dimensional Stability

Boards containing a binder resin but not the polymer increased an average of 28 percent in thickness and 0.62 percent in length upon exposure to the high EMC conditions. Polymer treatment at the 25 percent level resulted in a reduction of the amount of swelling to 8 percent in thickness and 0.27 percent in length. Doubling the amount of the plastic caused a further reduction of thickness swell (to 6 percent), but had no effect on linear expansion. There was no effect attributable to the type of binder resin used, or, in fact, to the use of any of these resins when the polymer was also present.

Inclusion of the polymer also reduced significantly the amount of irreversible thickness swelling and linear expansion or springback. The percentage loading had an effect on the amount of thickness springback but not linear springback. There were some differential effects of the various binder resins, but they were generally quite small. Thickness springback was reduced from an average of 18 percent in boards with a binder resin but no polymer to under 3 percent in boards containing 50 percent polymer and a resin. Linear springback was reduced by a factor of 10 from 0.36 percent to 0.03 percent as the result of inclusion of both the polymer and the resin.

The data demonstrate that although the flakeboards made from flake-polymer composites are subject to similar reversible and irreversible dimensional changes associated with other lignocellulose products, the magnitude of such changes are reduced in extent. The average of 0.26 percent linear expansion measured in boards containing the polymer compares favorably with the 0.35 percent permitted by the commercial standards.

Cursory examination of the composites indicated that the polymer was located principally in the lumina of the cells and as a coating on each flake. Timmons, Meyer, and Coté (12) noted that up to 19 percent of MMA in wood-polymer combinations may be located in the cell walls, with the remainder being in the lumina. It is suggested that polymer concentration in the cell wall would be even less with TBS than with MMA because of the difference in the degree of polarity. The action of the TBS appears to be through a retardation of moisture movement and through an improvement of the strength of the flake-to-flake bonds.

All physical properties of particleboards made of flake-polymer composites were improved over similar properties of boards made with untreated flakes or control boards. Most properties of the control boards were quite low, and as a result their usefulness in comparisons may be limited. It is well known that to obtain a given level of strength in particleboards made with high-density wood

the board density must exceed the wood density. Hse (6) has pointed out that there is a high degree of correlation between the compaction ratio (ratio of board density to wood density) and many of the properties of flake-boards. Our control boards had average compaction ratios of 1.28. Hse found a ratio of this magnitude to be adequate for meeting the target values for IB, MOR, and MOE established by the Planning Force for structural exterior flakeboard (Hse *et al.*, 5). We did not find this to be the case with our boards. The compaction ratios of boards made with flake-polymer composites (1.31) were only slightly higher than those of the control boards, but all strength properties were much improved. The relationship between strength and compaction ratio apparently is changed when the polymer is included in the board. Compaction ratios of a considerably higher magnitude would be needed for our boards to meet the standards for exterior, structural flakeboard. The difference between our results and those of Hse are probably related to flake geometry. Hse used flakes which were 3 inches long, 3/8 inch wide, and 0.015 inch thick.

Comparison of the properties of our flake-polymer composite particleboards with others made of red oak (4, 6) indicates equivalence in dimensional stability and internal bond strength, but lower values for our boards in static bending.

Conclusions

The results of this study indicate that it is technically feasible to make particleboard from flake-polymer composites utilizing red oak wood. Particleboard made in this way has properties which exceed the commercial standards requirements for linear expansion, internal bond, and modulus of elasticity, and come close to meeting the modulus of rupture requirements for Type 1, Class 1, medium-density particleboard. For most properties, high-performance boards result from incorporation of the polymer at 25 percent loadings without the addition of any binder resin. Somewhat enhanced property values were obtained by inclusion of 50 percent polymer, but the improvement realized may not justify the increased cost of the polymer used.

As has been pointed out (Beall, Young and Witt, 2), the combination of wood, polymer and dye often results in an esthetically pleasing product, which in combination with certain minimum levels of physical performance, may find wide acceptance in a market which is different from that for the usual particleboard.

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