EFFECT OF RESIN PARTICLE SIZE ON WAFERBOARD ADHESIVE EFFICIENCY

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ABSTRACT

A powdered phenol-formaldehyde resin was synthesized incorporating a fluorescent dye. The resin was sieved to produce five different particle-size fractions. Each of the resin fractions was used in the fabrication of waferboard panels from *Populus tremuloides* flakes. Fluorescence microscopy was used to observe the cured glue-lines following an embedding and polishing sample preparation technique. All of the panel strength properties determined (modulus of rupture, modulus of elasticity, and internal bond strength) displayed better values when smaller resin particle-size fractions were used. Panels produced using smaller resin particle-size fractions exhibited less sensitivity to moisture as demonstrated by lower thickness swelling values and a greater retention of bending properties after an accelerated aging treatment. Fluorescence microscopy showed that more continuous glue-lines and better flake coverages were achieved with smaller resin particle-size fractions than with larger size fractions.

Keywords: Waferboard, phenol-formaldehyde, resin efficiency, fluorescence microscopy.

INTRODUCTION

The distribution of adhesive on wood flakes achieved during production of waferboard and oriented strandboard has long been considered of prime importance to the final panel properties. Ideally, the adhesive would be located only where the wood flakes are in intimate contact and no adhesive would be wasted in non-bonding situations. However, this is an unrealistic goal due, in part, to the process of forming the flake mat. Therefore, it is of great interest to determine the distribution of adhesive on the flakes that will provide the optimal final panel properties. A key issue is whether, for a given quantity of adhesive, better panel properties are achieved by distributing the adhesive as a lesser number of larger entities or as a greater number of smaller entities.

Marian (1958) suggested that in particle board manufacture the liquid adhesive should ideally be distributed as a continuous film rather than as discrete droplets. Burrows (1961) found higher internal bond (IB) strengths in flakeboard bonded using a fine spray of phenol-formaldehyde adhesive rather than a coarse spray at a resin loading of 2% but found slightly higher IB strengths for the coarse spray at a resin loading of 6%. No significant effect of spray droplet size on modulus of rupture (MOR) was observed. No quantitative analysis of the spray droplet size was performed. In their discussion of the importance of every flake being covered with adhesive, Carroll and McVey (1962) noted that a uniform deposition of an extremely large number of fine droplets approximated the ideal situation proposed by Marian (1958). It was suggested that the thin film coverage advocated by Marian (1958) could lead to starvation of the glue-lines at the level of adhesive loading used in flakeboard production. They proposed that the "spot welds" produced by a large number of small particles might be superior to the total flake coverage achieved by a continuous film. In his studies with urea-formaldehyde and phenol-

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formaldehyde adhesives, Lehmann (1965, 1968, 1970) showed that a finer spray produced more continuous glue-lines between flakes in a pressed board than did a coarse spray. The fine spray produced superior bending properties and IB strengths to the coarse spray at the same resin loading. Christensen and Robitschek (1974) found a rapid drop in IB strength of flakeboard as the droplet size of a liquid adhesive increased. Wilson and Krahmer (1976) proposed that if resin droplets are too small, they may reside in the lumen of a cell at the surface of a flake where they would not easily come into contact with an adjacent wood particle. They supported a uniform distribution of droplets over all particles as the practical optimal situation and suggested that the optimal droplet size would depend on the texture of the wood surface.

When powdered adhesives are used in waferboard manufacture, the resin particles soften and melt under the conditions experienced at the glue-lines. Some molten flow of the adhesive occurs and the adhesive wets the wood substrate. Penetration of the adhesive into the wood then occurs to some extent and the adhesive cures. Although some flow of the adhesive occurs at the glue-line, the flow of the powdered resin does not approach the level of liquid resins whereby a continuous glue-line can often result. Therefore, it is quite possible that the particle size of the powdered resin is a more critical controlling parameter in determining the properties of the finished panel than is the droplet size when a liquid adhesive is used.

It has been suggested that the shape of the particles of powder adhesives is important since spherical particles may tend to roll off flakes during tumbling in the blending process and that for a particle to stick to the surface of the wood an irregular shape may be required. Others have suggested that particle size itself is the key factor and that spherical particles, if of a sufficiently small and uniform size, will cling to the wood flakes as adequately as irregularly shaped particles (Lambuth 1987).

Several authors have studied the distribution of urea-formaldehyde and phenol-formaldehyde resins in waferboard and hardboard using fluorescence microscopy (Lehmann 1968; Furuno et al. 1984; Murmanis et al. 1986; Youngquist et al. 1987). While there may be some inherent disadvantages to the technique of applying a fluorescent label to the adhesive prior to pressing, it is still considered that such dying techniques are useful for providing approximate resin distributions at glue-lines after hot-pressing (Wilson and Krahmer 1976).

The objectives of this study were to determine the effects of the particle-size fraction of a powdered phenol-formaldehyde adhesive on the properties of waferboard and to observe the distribution of the adhesive at the glue-lines of the finished waferboard panels.

METHODS

Phenol, formaldehyde, and sodium hydroxide (molar ratio 1.0:2.0:0.2) were reacted in a 4-L resin kettle. The phenol, 90% of the formaldehyde solution, 50% of the sodium hydroxide, and water to make 40% solids were charged and held at 60 C for 30 minutes. The balance of the formaldehyde content and 25% of the sodium hydroxide was then added, and the mixture was heated to 85 C. After 30 minutes the remaining 25% of the sodium hydroxide was added, and the reaction mixture was then maintained at 85 C until the final desired viscosity (Gardner Holt H at 25 C) had been reached, at which point the reaction mixture was rapidly cooled. The percentage solids content of the liquid resin was determined, and a fluorescent dye was added (Rhodamine B, 0.5% based on resin solids) prior to drying. The liquid resin was then freeze-dried and ground. The resin was then sieved to produce five particle-size fractions (150–212 μm, 106–150 μm, 75–106 μm, 45–75 μm, and <45 μm).

Disc-cut flakes of trembling aspen (*Populus tremuloides*) were obtained from the Alberta Research Council, Edmonton. These flakes were 0.4 to 0.6 mm thick, 15 to 30 mm wide, and approximately 105 mm long. The powdered adhesive was applied at 5% solids, based on the dry weight of the flakes without the

addition of wax. Flakes were hand-felted into a mat measuring 54 cm × 54 cm. The mats were pressed at 200 C for 6 minutes to a thickness of 12.7 mm. The time to stops was 30 seconds, the press was held at the stops for 300 seconds, and there was a 30-second period prior to opening the press during which the pressure was gradually relieved. The panels had a target density of 750 kg/m^3 at 12% moisture content. Three panels were produced using each adhesive, giving a total of 15 panels. Modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) strength, and thickness swelling (TS) were determined according to ASTM D1037-87. From each panel, eight specimens were cut for IB tests, four samples for bending tests, and two samples for TS tests. Two bending samples were tested dry and two after accelerated aging according to the 2-hour boil treatment in Canadian Standard CAN3-0437.1-M85.

Samples for microscopic observation were taken from near the center of each board. Samples were prepared using a modification of an embedding and polishing technique originally devised for viewing paper in cross-section (Gibbon et al. 1989). Samples approximately 3 mm × 7 mm in the plane of the board and 10 mm in the thickness of the board were cut using a small coping-saw. The resin used for the embedding was Spurr's low viscosity epoxy resin. The samples were briefly soaked in acetone to wet them and were then gently aspirated in a mixture of 50% acetone/50% epoxy, then in 10% acetone/90% epoxy, and finally in 100% epoxy. The samples were soaked overnight in 100% epoxy. Empty plastic 35-mm film canisters were used as molds for the resin. Three or four samples were placed at the bottom of each mold, weighted down with a small piece of metal and covered with fresh epoxy. The epoxy was then cured overnight at 70 C. The end surfaces of embedded samples were polished with a series of grinding discs using successively finer abrasive paper (60, 120, 180, 320, and 600 grit). Surfaces were viewed under epi-illumination using a Jenamed 2 fluorescence microscope. An illuminator slide incorporating a 510 dichroic mirror, a BPF 475 excitation filter, and G245 and G247 barrier filters were used. Fujicolor 100 daylight film was used for color photomicrograpy. Approximately 20 samples from boards prepared with each resin were observed before representative photomicrographs were recorded.

RESULTS AND DISCUSSION

It was assumed that the amount of resin retained on the flakes after blending was the same for all resin particle sizes. It is conceivable that very small dry resin particles adhere better to the dry flake surfaces than do larger resin particles, so that as a result the actual retained resin content increases with decreasing resin particle size, even though the same resin quantities are applied. However, this did not appear to be the case within the range of particle sizes used in this study. Examination of any resin remaining in the blender and the extent of the coloration of the resin on the flakes provided no indication of any of the resin fractions being retained on the flakes after blending more so than any of the other fractions.

All board properties investigated showed improved values when smaller resin particle-size fractions were used (Table 1). Dry MOR values were highest for the <45-μm fraction and decreased gradually as resin size increased, until the lowest values were found for the 150–212-μm fraction. There was no significant difference (at the 95% confidence level) between the dry MOE values obtained with the <45-μm and 45–75-μm fractions; but as resin particle size increased further, dry MOE values decreased. Values for bending properties after the 2-hour boiling treatment exhibited the same trend. No significant difference was found between the IB strengths for the boards produced using the <45-μm and 45–75-μm fractions. As resin particle size increased further, IB strengths decreased to a minimum for the 150–212-μm fraction. Thickness swelling values were lowest for the <45-μm fraction and highest for the 150–212-μm fraction. The sensitivity to mois-

TABLE 1. *Properties of waferboard panels.*

Particle size (μm)	MOR (MPa)		MOE (MPa)		IB (MPa)	TS (%)
	Dry	Aged	Dry	Aged		
<45	46.1 A	26.4 A	3,675 A	2,148 A	0.476 A	25.5 A
45–75	42.5 B	19.7 B	3,570 AB	1,800 B	0.467 A	30.0 B
75–106	41.5 B	18.6 BC	3,431 BC	1,662 BC	0.447 B	30.2 B
106–150	37.5 C	16.9 C	3,325 BC	1,588 CD	0.399 C	31.1 B
150–212	33.2 D	12.9 D	3,276 C	1,530 D	0.363 D	35.3 C

For each property tested, means designated with the same letter are not significantly different at the 95% confidence level.

ture in relation to resin particle size was also demonstrated by the percentage retention of MOR and MOE following the 2-hour boiling treatment. Boards produced using the <45-μm fraction retained 57% of the dry MOR and 58% of the dry MOE following boiling. The percentage retention values decreased as resin particle size increased with the 150–212-μm fraction, retaining only 39% of the dry MOR and 47% of the dry MOE following boiling.

Sample preparation by the embedding and polishing technique followed by observation under the fluorescence microscope proved to be successful in illustrating the distribution of resin along glue-lines and the variation in the amount of resin found in different glue-lines in each waferboard sample. When resins of smaller particle sizes were used, there was a more complete coverage along individual glue-lines and less variation in resin coverage between different glue-lines (Fig. 1a). Observation of glue-lines from waferboard panels produced with larger resin particles showed more discontinuous glue-lines. The resin was concentrated at particular points along the glue-lines, resulting in a scarcity of resin at other points (Fig. 1b, c). There was also greater variability in the amount of resin observed between different glue-lines. As the resin particle size increased, this trend became more apparent.

When the fracture surfaces of tested IB samples were observed, the distribution of resin on the flakes was evident. Quite even and complete resin coverage occurred with the <45-μm fraction (Fig. 2a) as shown by the uniform distribution of red color on the fracture surface. The green color observed towards the upper right portion of the photomicrograph is where wood failure occurred in a flake. The red color of the 150–212-μm resin fraction was clearly seen in distinct aggregations and complete flake coverage was not achieved (Fig. 2b). The green color observed throughout this photomicrograph was not due to wood failure but to absence of adhesive.

From the fluorescence microscope observations, it is apparent that the smaller resin particles produced a more even and complete coverage of flakes than did the larger size particles. This uniform coverage resulted in more continuous and less variable glue-lines between flakes in the pressed panels and manifested itself as an improvement in all panel properties compared to panels produced using larger resin particles.

Although the same quantity of adhesive was present in all of the panels, the resin was more effectively distributed when more smaller particles were spread over the surface of the wood flakes than when there were fewer but larger points of adhesion. Thus it could be expected that the same panel properties achieved with the 150–212-μm fraction could have been achieved with a lower amount of the <45-μm fraction.

The diameter of the largest vessel elements of *Populus tremuloides* is 50–100 μm (Panshin and de Zeeuw 1980). It would appear that the smallest particle-size fraction of resin examined (<45 μm) is not in the range that potential problems suggested by Wilson and Krahmer (1976) occurred whereby the resin particles reside in the cell lumen and do not take part in the adhesion process. The majority of the resin particles in the <45-μm fraction are expected to be just smaller than 45 μm since they were

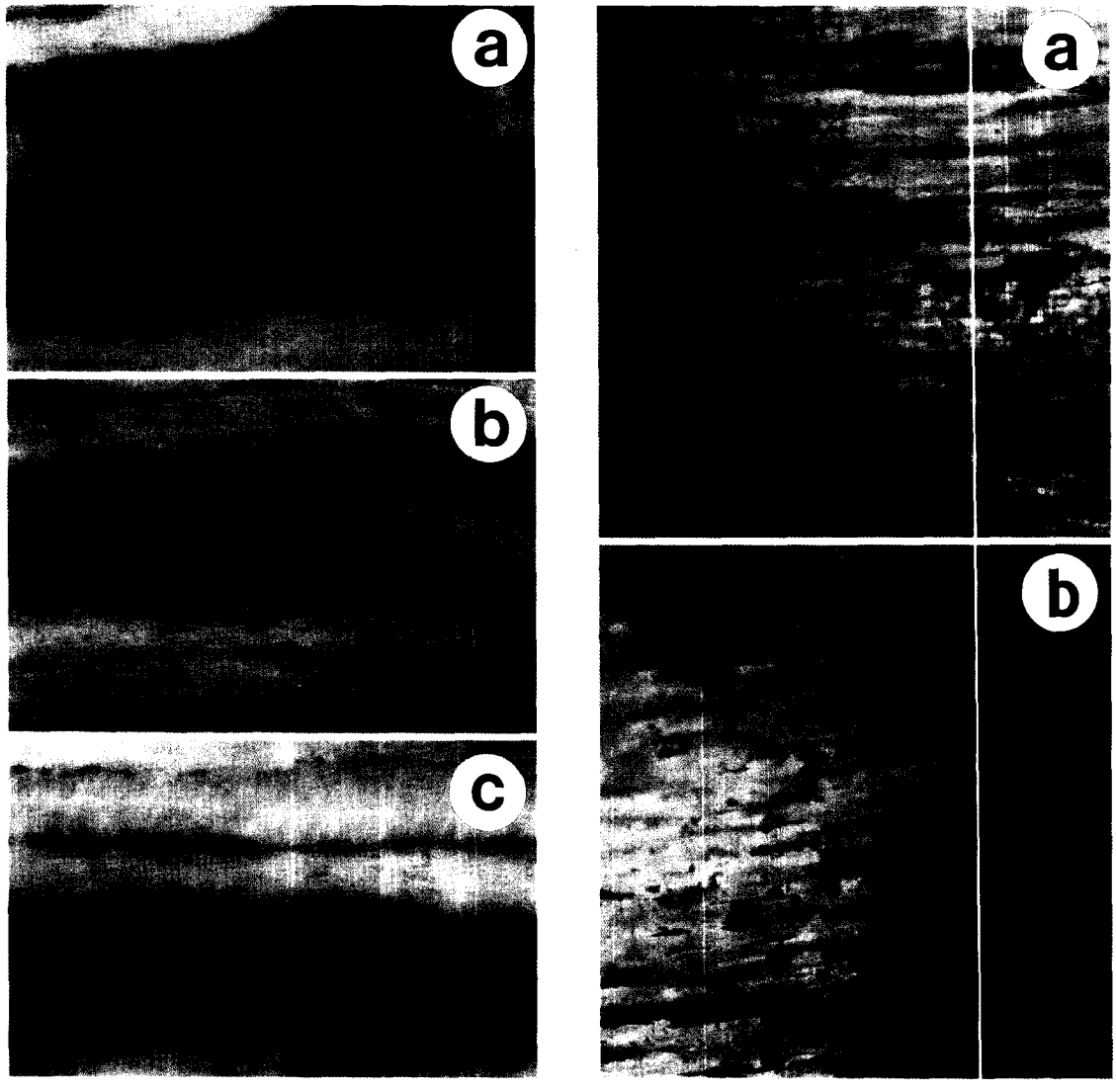

FIG. 1. Fluorescence photomicrographs of glue-lines from waferboard panels prepared using different resin particle-size fractions (a) <45 μm, (b) 75–106 μm, and (c) 150–212 μm (all ×23). The resin appears red and the wood appears green.

FIG. 2. Fluorescence photomicrographs of fracture surfaces of tested IB samples from waferboard panels prepared using different resin particle-size fractions (a) <45 μm and (b) 150–212 μm (both ×23). The resin appears red and the wood appears green.

fractionated using a 325-mesh sieve. It may be the case that if still smaller particle sizes are examined, an optimal point may be determined where panel properties might begin to decrease due to the lower proportion of resin becoming involved in the adhesion process as a direct result of the small particle size. If such a relationship exists, it is conceivable that the optimal size is not constant for all wood species. Hardwoods, in particular ring porous hardwoods with large diameter earlywood vessel elements, would likely require a larger resin particle size than would softwoods where the lumen diameter of the longitudinal tracheids

is less than that of the vessel elements of hardwoods. Coarse texture softwoods that have longitudinal tracheids with large diameters might also show more sensitivity to the adhesive particle size than fine texture softwoods.

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