CORRELATION OF WAFERBOARD INTERNAL BOND AND WOOD FAILURE AS MEASURED BY IMAGE ANALYSIS[1]

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ABSTRACT

Waferboard panels were fabricated using light-colored *Populus tremuloides* wood flakes and dark-colored liquid or powdered phenol-formaldehyde adhesive. Internal bond (IB) specimens were prepared and tested according to the normal standards. Image analysis techniques were applied to measure the wood failure (WF) values occurring at the surface of the failed IB specimens. Wood failure values were successfully determined when liquid or powdered adhesive was used at a loading of 6% but not at lower adhesive loadings of 2% and 4%. For the adhesives used, the powdered adhesive produced greater WF values than did the liquid adhesive, for a given IB strength. A stronger correlation between WF values and IB strengths was found for the specimens produced using the powdered adhesive than for those specimens produced using the liquid adhesive.

Keywords: Internal bond, wood failure, image analysis, waferboard.

INTRODUCTION

The proportion of the surface of a glued wood bond exhibiting wood failure (WF) after testing to destruction has long been used as one of the parameters to measure the quality of glued wood bonds. Greater WF values generally indicate a higher quality bond than do lower WF values. High WF values show that both the wood-glue bond and the glueline itself have proven to be stronger than the wood substrate being glued together, and thus failure has occurred through the wood substrate. The proportion of WF found after testing plywood tension shear specimens is one of the parameters that must be determined according to Canadian standards governing Douglas-fir plywood (CSA O121-M *Canadian Standards Association* 1978). Values are specified for the average WF required and the minimum percentage of test pieces that must show a specified WF level. Plywood tension shear specimens are usually subjected to an accelerated aging treatment prior to testing and evaluation of WF. High WF values resulting after such a treatment are assumed indicative of high bond durabilities when the glueline is exposed to exterior conditions.

Practical problems associated with the visual determination of WF in plywood tension shear specimens have included the slow nature of the work, the tedium involved, and the subjectivity of the estimations. Differences may occur in the WF values estimated by different individuals for the same specimen or by the same individual for the same specimen at different times (Miller et al. 1973). Image analysis techniques have been applied to the determination of WF in plywood tension shear specimens (Miller et al. 1973; McMillin 1982, 1984). Images were captured with a video camera and converted to a digital form. Threshold values were then applied to the captured black and white images in order to distinguish between those gray shades in the image corresponding to the lighter-colored wood and those gray shades corresponding to the darker-colored glue. Good agreement was found between the WF values determined by experienced op-

[1] The use of company names or products does not constitute endorsement by the author.

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erators and by the image analysis systems used.

In the past, WF evaluations have not been performed for waferboard test specimens. The main reason for this lack of information concerning waferboard when compared to plywood lies in some of the fundamental differences in the nature of the fabrication of the different panel types. A plywood panel is produced with a definite, predetermined number of gluelines, each of which normally contains a continuous spread of liquid adhesive. While wood and processing variables may affect the quality of the glueline resulting after hot-pressing, it is usually considered that during hot-pressing all wood at the surface of the glueline has come into contact with the adhesive. Thus, upon failure of a tension shear specimen, if failure occurs through the glue rather than through the wood, the failed surface will present the color of the cured adhesive (dark brown in the case of a phenolic adhesive). If failure occurs through the wood rather than through the glue, the failed surface will present the color of the wood (usually lighter than that of the glue). In the case of waferboard, the adhesive is not applied as a continuous sheet but as discrete droplets (liquid) or particles (powder). While some flow and coalescence of these droplets or particles occur during hot-pressing, this flow does not always occur to the extent that a continuous glueline results. The extent of continuity of the glueline will depend among other factors on the size of the droplets or particles and the total adhesive loading. When an IB specimen is later stressed to failure perpendicular to the plane of the board, it cannot be determined with absolute confidence whether an area of wood surface exhibiting no glue on the failure surface is a result of failure occurring in a wood flake rather than at the glueline or whether the portion of the wood flake under observation was simply not brought into contact with the adhesive during hot-pressing.

It would be valuable to be able to determine the extent of WF in some waferboard IB specimens after testing so as to provide additional information about the nature of the bond formation having taken place in certain waferboard bonding situations. It is recognized, however, that the conditions required to produce WF of the type that can be visually determined with some degree of confidence may be quite different from those conditions normally encountered in waferboard fabrication.

In this study, waferboard panels were fabricated using presorted flakes (to remove dark-colored flakes) and powdered and liquid phenolic adhesives incorporating a black dye in an attempt to increase the contrast between wood and glue. Adhesive loadings and pressing times were varied in a deliberate attempt to produce waferboard panels that would exhibit a range of IB strengths. The objective of this study was to determine if WF in waferboard IB specimens could be detected and quantified using an image analysis system.

METHODS

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 flakes were hand-sorted to remove any dark-colored flakes. The flakes were conditioned to a moisture content of 4% prior to blending with adhesive. Two adhesives were used: a powdered adhesive prepared in the laboratory and a commercial liquid adhesive. The powdered adhesive was prepared according to previously described procedures (Ellis 1993). Chlorazol black (1% based on adhesive solids) was blended into the adhesive in the liquid stage prior to freeze-drying. After drying, the powdered adhesive was ground and sieved to pass a 200-mesh (75-μm) screen. The liquid adhesive used was Cascophen LP02 (Borden Co. Ltd.). Chlorazol black (1% based on adhesive solids) was mixed into the liquid adhesive prior to blending with the flakes. The adhesive was applied to the flakes at loadings of 2, 4, and 6% solids based on the dry weight of the flakes without the addition of wax. Flakes were hand-felted into a mat measuring 25 cm × 25 cm. The mats were pressed at 200 C for 4.0, 5.5, or 7.0 minutes to a thickness of 12.7 mm. The

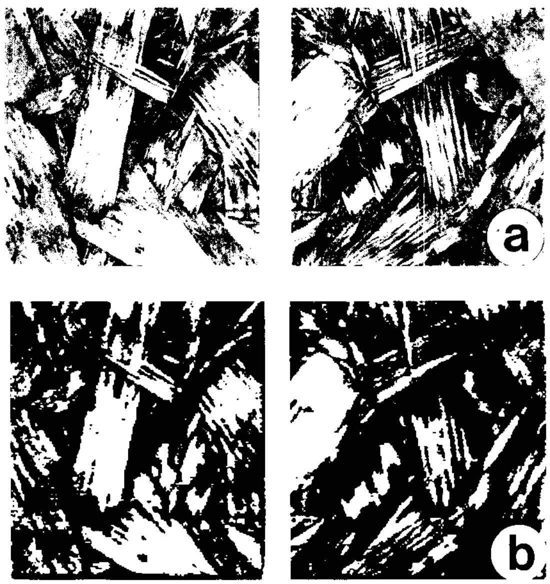

FIG. 1. Matched pair of an internal bond specimen, prepared using 6% powdered adhesive, after testing; (a) black and white photograph; (b) image regenerated using threshold gray shade value of 138.

time from initial pressure on the flake mat to the target thickness was 30 seconds, the press was held at the stops for a varying time depending on the total pressing time, 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 650 kg/m^3 at 12% moisture content. Two panels were produced for each adhesive loading/pressing time combination studied. One commercial waferboard panel was also studied. Nine IB specimens measuring 50 mm × 50 mm were cut from the center of each panel, conditioned to a moisture content of approximately 9% and tested according to ASTM D1037-87 (ASTM 1989).

The image analysis system used consisted of a Javelin® JE3462HR color video camera, a TARGA+® 16/32 frame grabber, a Javelin® CVM13A color monitor, and IBM® 486-compatible microcomputer, and Java® image analysis software. Images of the matched pairs from each IB specimen after testing were captured with the video camera, stored on the computer's hard drive, and analyzed using the image analysis software. A variety of lighting conditions was evaluated to produce the greatest contrast between the dark glue and the light wood. Using the image analysis software, a threshold gray level value was determined below which gray values represented glue failure and above which gray values represented WF. This threshold value was held constant for all the determinations. The percentage WF for each IB specimen was determined as the average value of the percentage of pixels in each of the paired images having gray level values above the threshold value.

RESULTS AND DISCUSSION

Figure 1a illustrates an IB specimen, produced using 6% powdered adhesive, after testing. The light-colored wood is clearly contrasted with the dark-colored blue. Figure 1b illustrates the image produced after capturing the image in Fig. 1a using the video camera and applying a threshold gray shade value of 138. All those pixels in the image of the squares having a gray shade of less than 138 are depicted as black, and all those pixels having a gray shade of 138 or greater are depicted as white. There is a very good visual correlation between the black areas depicted in the thresholded image and the areas of glue failure in the original image.

Although it was possible to achieve a successful distinction between WF and glue failure for the waferboard specimens bonded using 6% adhesive (both liquid and solid), it proved more difficult to distinguish between WF and glue failure when lower adhesive loadings were used in the waferboard fabrication. When only 2% or 4% adhesive was applied, the adhesive was spread out over the surface of the flakes to the extent that the color of the adhesive was not intense enough to allow the differences between the wood and the wood coated with adhesive to be detected by the video camera with any great degree of confidence. With the commercial waferboard, the adhesive loading used in its preparation was also insufficient to allow differentiation be-

TABLE 1. *Average internal bond strengths and wood failure values for adhesive/loading/press time combinations.*

Adhesive	Loading (%)	Press time (min)	Internal bond* (MPa)	Wood failure* (%)
Powder	2.0	7.0	0.418	—
	4.0	7.0	0.588	—
	6.0	4.0	0.499 C	20 B
		5.5	0.601 B	20 B
		7.0	0.660 A	26 A
Liquid	2.0	7.0	0.360	—
	4.0	7.0	0.531	—
	6.0	4.0	0.546 B	13 A
		5.5	0.554 B	11 A
		7.0	0.616 A	14 A

* Means designated by the same letter are not significantly different at the 95% confidence level.

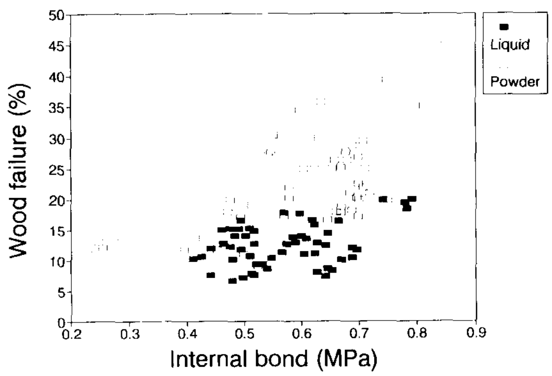

FIG. 2. Wood failure values determined by image analysis as a function of internal bond strength for waferboard specimens bonded using 6% liquid and powdered adhesive.

tween WF and glue failure. In addition, the presence of darker-colored wood flakes and the occasional bark fragment in the commercial panel further complicated this differentiation.

The results of the IB strength tests and the WF value determinations for the different adhesive/pressing time combinations are shown in Table 1. As was expected, longer pressing times led to greater IB strengths. At the two longer pressing times, the powdered adhesive produced greater IB strengths than did the liquid adhesive, and the powdered adhesive produced higher WF values at all three pressing times. The expected increase in IB with higher adhesive loading levels was also observed.

The relationship observed between the IB strengths measured and the WF values determined by the image analysis system for the waferboards fabricated using either 6% powdered or 6% liquid adhesive is shown in Fig. 2. Specimens producing greater IB strengths generally exhibited more WF. For a given IB strength, WF values for the specimens produced using powdered adhesive were greater than for those specimens produced using liquid adhesive. The linear correlation between WF values and IB strengths was greater for the specimens produced using powdered adhesive ($R^2 = 0.385$) than for those specimens produced using liquid adhesive ($R^2 = 0.153$).

There was no attempt to compare the WF values determined by the image analysis system to those determined by a human operator. While determination of WF in plywood tension shear specimens is regularly performed by human operators, the visual determination of WF in waferboard is different for two reasons. First, the area being examined in the waferboard IB specimens is approximately four times greater than the failure area of a typical tension shear specimen. Second, with the plywood tension shear specimen, the longitudinal direction of the wood grain in the WF runs in one of only two directions (either parallel or perpendicular to the long axis of the specimen). In waferboard IB specimens, the longitudinal grain of the WF may run in any direction. The random nature of the orientation of the WF in the waferboard IB specimens makes it more difficult for a human operator to visually quantify the area of WF. Since operators trained in the visual determination of WF were not available, any quantitative visual estimation of WF to compare to the values determined by the image analysis system would have been subjective at best.

The technique described here was successful at determining WF in IB specimens where presorted, light-colored wood flakes and a dark-colored adhesive were used as long as a minimum adhesive level was used in the preparation of the waferboard panel. It is recognized that the 6% resin loading levels at which

WF was detected in this study are much higher than standard industry practice. However, provided that these suitable conditions are used in panel preparations, this technique may prove to be a useful research tool in future studies of the effects of pressing variables on waferboard properties and glueline quality. It is also recognized that the measure of WF expressed here may include areas of flakes that received no resin coverage during the blending step in panel fabrication. This factor would have more of an effect on the ability to determine true wood failure at the lower resin loading levels where complete coverage of the flakes was very likely not achieved. However, at the highest resin loading level used, 6% resin solids, resin coverage of the flakes was complete as indicated by analysis of images of flakes taken after blending, prior to the panel fabrication.

CONCLUSIONS

A measure of wood failure in waferboard internal bond specimens was successfully determined using the image analysis system described but only at adhesive loadings of 6%. Higher wood failure values were associated with greater internal bond strengths. The specimens produced using powdered phenol-formaldehyde adhesive produced greater wood failure values for a given internal bond strength than did those specimens produced using liquid adhesive at the same resin loading level.

ACKNOWLEDGMENTS

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