NEW METHOD FOR RAPID TESTING OF BOND STRENGTH FOR WOOD ADHESIVES

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Introduction

In developing new adhesives for wood bonding, the testing of bond performance can often be a limiting factor in the development process. Evaluating the bond performance of an adhesive that can be prepared in less than a day often takes several days using standard performance tests. This testing slows the development process and may cause a company to abandon a commercially viable product due to development costs or to offer a product commercially that has not been fully developed. Furthermore, some of the standard tests provide only qualitative data on a pass/fail basis, making it difficult to determine whether changes resulted in better or worse performance. This has led to an interest in developing a faster quantitative screening test for wood bonding.

Most wood adhesives use pressure and heat to form a strong bond. Humphrey has developed the Automated Bond Evaluation System (ABES) for determining the rate of strength development of wood adhesives as they cure (1). This equipment allows for accurate control of bonding pressure, platen temperature, and bonding dwell time and good alignment of the lap shear samples. Given the speed with which samples can be prepared using the ABES, which also provides highly controlled times, temperatures, and pressures, this study was aimed at investigating the use of this equipment for the rapid preparation of heat-cured bonded wood lap shear specimens. The samples could then be removed from the ABES while still intact, equilibrated in a controlled environment, and finally tested dry or wet using a standard tensile testing machine, which is designed to provide absolute strength values. The results involved not only the use of this method for development of new soy flour adhesives but also a comparison of other adhesives to the results from the standard plywood tests ANSI/HPVA HP-1-2004 4-6 (hereafter referred to as HP-1) (2) for interior or decorative plywood and Voluntary Product Standard PS 1-95 6.1.5.1 and .2 (hereafter referred to as PS 1-95) for exterior plywood (3).

Experimental

The wood veneers (eastern white pine, hard maple) were supplied by States Industries (Eugene, Oregon) and stored at 22°C and 50% relative humidity. For the ABES bonding, specimens were prepared 0.8 mm thick and 20 by 117 mm using a die cutter supplied by Adhesive Evaluation Systems (Corvallis, Oregon) and were pressed using 0.89 MPa for 2 min at 120–150°C, depending upon the adhesive. The HP-1 and PS 1-95 tests were done using specimens as outlined in the test protocol. Commercial wood adhesives were supplied by Dynea (Springfield, Oregon). We prepared the experimental adhesives, but the specific formulations are not described here. The ABES unit was manufactured by Adhesive Evaluation Systems (Corvallis, Oregon). Samples were allowed to set for at least 2 days at 22°C and 50% relative humidity prior to testing. If specimens were water soaked, they were placed in water for 4 h and tested while still wet. Strength was measured using an Instron Model 1000 (Norwood, Massachusetts) using a crosshead speed of 10 mm/min.

Results

The natural roughness of wood surfaces, the ability of adhesives to penetrate into wood pores, and the high polarity of wood surfaces allow a wide variety of adhesives to form strong bonds to wood surfaces. Unfortunately, dry wood swells under high moisture conditions and wet wood shrinks under low moisture conditions, but most wood adhesives, especially those for structural applications, do not show much dimensional change at different moisture conditions. This differential strain results in a high interfacial stress concentration in the bondline. Therefore, accelerated wood bond durability tests usually involve water-soak shear tests or cyclic water-soak/heat-drying delamination tests.

Many of the bonding variables were established based upon prior experience. The wood species were sliced eastern white pine veneers (a softwood) and rotary-cut maple veneers (a very strong and difficult-to-bond hardwood). Specimen size was established by the die cutter and ABES equipment dimensions. Pressing temperature was established by standard commercial pressing conditions (150°C for phenol-formaldehyde resin and 120°C for all other adhesives).

Soy studies

The test method was originally developed as a screening tool in making new soy flour adhesives for interior decorative plywood bonding. The standard test protocol, HP-1 (2), requires a considerable amount of veneer, is time consuming, and gives a pass-fail result with considerable variability. A less time-consuming test was needed that would give reproducible and more quantitative results. We had used the ABES for its designed purpose of determining strength development with time at temperature by measuring bond strength immediately after bonding. Could the machine be used to measure bond strength after full cure and water soaking? In some cases, it could, but we found that often the sandpaper grips were insufficient for high strength bonds and did not hold the wet wood samples very well. It was easier to use the ABES for bonding and to store the samples while they cured, water soak them if desired and then test using a standard tensile testing apparatus with jaws that had been modified to hold the thin specimens. We felt that if we wanted to condition the samples for 2 days to ensure equilibrium moisture content, which required removing them from the ABES instrument, then it seemed logical to test the specimens using an instrument developed for tensile evaluation.

Results for the rapid testing method using the ABES/Instron combination were compared with those obtained in the standard HP-1 test for our experimental soy flour adhesives (Figure 1). We found that below a certain shear strength, the adhesives did not pass the standard test; above another shear strength, the adhesives were able to pass the standard test. The shaded area indicates resins that showed marginal success or minimal failure (the values are not given because they seem to be adhesive specific). Furthermore, we were able to quantify improvement in one adhesive over another even for two adhesives that failed the standard HP-1 test. Thus, the new test method served its intended purpose of rapidly indicating if our adhesive was good or needed improvement.

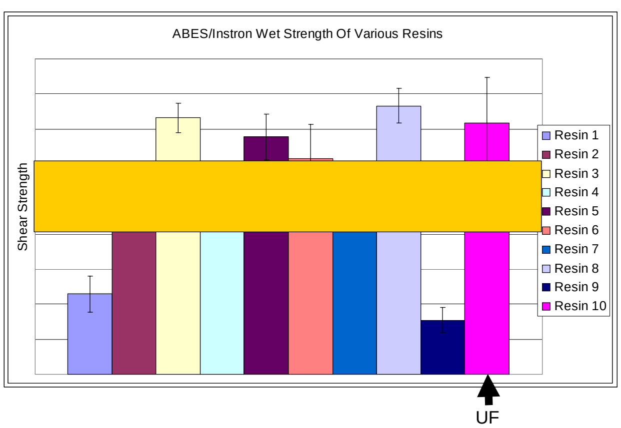

Figure 1. ABES/Instron wet shear data of experimental soy adhesive resins with a UF control resin with the box separating the resins that failed the delamination (below the box) from those that passed (above the box) (*n* = 5).

Comparative tests

An important issue was whether this comparison in performance between the two tests was useful for other wood adhesives and how it compared to other plywood adhesive tests. Thus, the rapid wood lap shear testing method was investigated with four standard wood adhesives: urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF), phenol-formaldehyde (PF), and poly(vinyl acetate) (PVA). Two standard durability tests were selected for comparison: HP-1 for interior or decorative plywood (2) and PS 1-95 for exterior plywood (3).

The rapid test shows that PVA provided high dry strength but little strength under wet conditions (this was a non-cross-linking PVA) on both wood species (Figure 2). The other adhesives lost some strength under wet conditions, with the general order of wet strength being PF > UF > MUF. The ANSI/HPVA three-cycle soak showed no delamination within the maple bonds, but much delamination was observed within the pine bonds (Figure 3). Because maple is normally considered more difficult to bond than pine, the greater delamination with the pine could be indicative of more rapid swelling forces. The PS 1-95 shear data shows respectable strength retention under wet conditions for all adhesives except the PVA adhesive (Figure 4).

Discussion

The standard evaluation of plywood often involves measuring not only the strength of the wood bonds but also the ability of these bonds to withstand the effects of moisture change. For wood bonds, the most severe tests usually involve testing strength for wet specimens or bond delamination after either immersion in boiling water or repetitive cycles of water soaking and drying.

Comparing our rapid wood bond durability test and the plywood delamination test (Figures 2 and 3), tests for the maple do not show the good correlation observed in the soy flour adhesive studies. This may be caused by the UF, MUF, and PF adhesive formulations being more sensitive to other factors, such as penetration into the wood, for the three-cycle test than for our rapid tests. In addition, the delamination test not only has a shear component caused by swelling of the wood, but also has a normal component as the wood tries to warp. On the other hand, the rapid wood bond durability test does provide a reasonable comparison to the plywood wet shear test (comparing Figures 2 and 4). The higher values for the rapid test compared with the standard test is probably due to the rapid test using only two parallel plies rather than that the three plies (with the center being a cross-ply) used for the standard test.

Conclusions

The need to efficiently test wood bonds for strength and durability has been met with the development of a rapid wood bond durability test. The use of commercially available equipment that is already in many wood adhesive

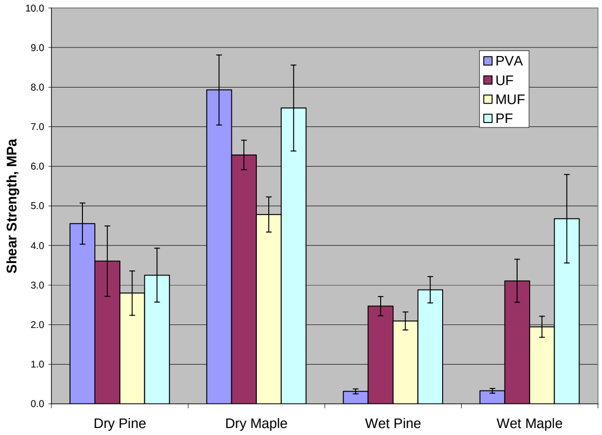

Figure 2. ABES/Instron data for pine and maple lap shear specimens bonded with different adhesives (*n* = 5).

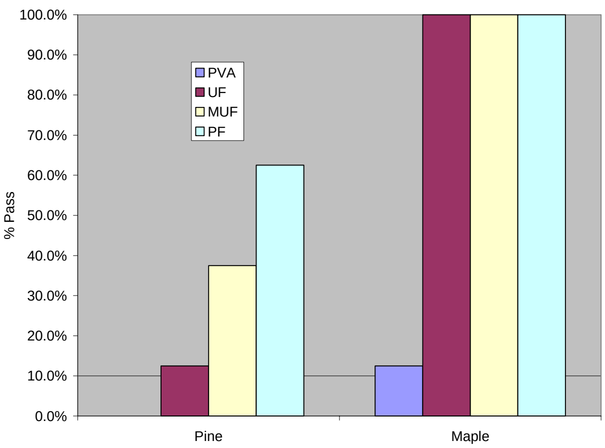

Figure 3. The three-cycle soak/dry tests using pine and maple bonded with PVA, UF, MUF, and MF adhesives determined the percentage of samples that passed the delamination test (*n* = 8).

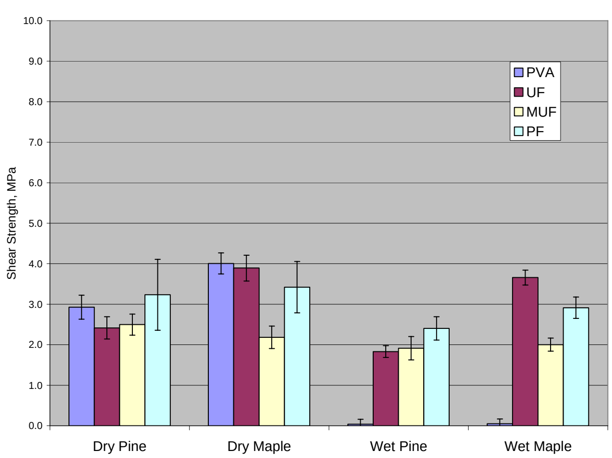

Figure 4. Lap shear tests using PS-1-95 on maple and pine bonded with PVA, UF, MUF, and PF adhesives (*n* = 6).

laboratories makes this a practical process for rapidly screening new types of wood adhesives. The results from this test better correlate to the performance PS 1-95 wet shear tests, whereas its relation to the ANSI/HWPVA test is more dependent upon adhesive formulation. This new test is being further investigated because it will allow the testing of more bonding variables, shows good reproducibility, and is less sensitive to adhesive viscosity and percentage solids than are other tests (data not shown here).

Acknowledgments

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PROCEEDINGS

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