# TESTING GLUELINE CONTINUITY IN STANDARD-SIZE HARDWOOD BLANKS BY MECHANICAL METHODS

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ABSTRACT

Glueline continuity is very critical in standard-size hardwood blanks because the blanks are cut up into small furniture parts, and a small gap in the glueline of a blank may extend across the whole part—or a gap may appear as a crack in the final product. Strength is not a critical factor. The objective of this study was to determine if a gap in a glueline can be detected by mechanical means. Furniture manufacturers want to be sure that any blank that they buy will have continuous gluelines. Every blank should be nondestructively tested, and all blanks with a defective glueline should be rejected from the shipment.

Black cherry, red oak, and yellow-poplar standard-size blanks 24 inches wide and 0.75 inches thick were manufactured. Some blanks were crosscut into strips two inches along the grain. The other blanks were cut 24 inches long. Foil defect strips were placed in the middle glueline of some panels to create a gap, thus achieving a range of effective gluelines of 60, 75, 90, and 100%. Static bending perpendicular to the grain, tension perpendicular to the grain, and torsion tests were developed for testing these specimens. Five parameters—modulus of rupture and modulus of elasticity in bending, tensile strength, torsional shear strength, and modulus of rigidity—were measured to determine their sensitivity for detecting defective gluelines.

Based on the results of this study, tensile strength perpendicular to the grain is the most satisfactory parameter for detecting defective gluelines. Its combination of high sensitivity and low variability would result in the smallest amount of destruction of good panels, while failing a larger number of defective panels. It was found that mechanical methods are not appropriate for determining glueline continuity since none of the parameters studied is sufficiently sensitive to detect defects of 10% or less.

*Keywords:* Mechanical tests, static bending perpendicular to the grain, tension perpendicular to the grain, torsion, plate twist, glueline continuity, standard-size blanks, hardwoods, red oak, black cherry, yellow-poplar.

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## INTRODUCTION

In the eastern United States hardwood forest, growth exceeds harvest. Unfortunately, the majority of this excess is in low-quality and/or small diameter trees. Most of this material is used for pallets or pulp and very little for high-valued furniture parts (Reynolds and Gatchell 1979).

Small clear cuttings can be recovered from this material and glued into larger pieces. One concern in doing this is that, as with checks and cracks in fine hardwood lumber, gaps in the glueline are unacceptable. The objective of this study was to determine which, if any, strength or stiffness parameter can be used to detect a gap in a glueline. It was not the intent of this study to determine the mechanical properties (stiffness and strength values) for hardwood gluelines.

The USDA Forest Service has developed a process called System 6 that utilizes low grade bolts from 8 to 12 inches in diameter and 6 feet long to produce standard-size hardwood blanks (Reynolds et al. 1983). Standard-size blanks are defined as pieces of solid wood, from edge-glued construction, of a predetermined size and quality (Araman et al. 1982). From these standard sizes, manufacturers can cut pieces for their own unique furniture and cabinet parts.

In System 6, the bolts are sawn into two 3-sided cants, which are resawn into boards. The boards are kiln-dried to 6% moisture content and then cross-cut to remove defects such as knots, checks, and bow. The cuttings are ripped into widths ranging from 1.5 to 3 inches. The final cuttings are segregated by length and edge glued into standard-size blanks.

Presently, most furniture and cabinet manufacturers utilize high grade lumber in their rough mills to make solid wood parts (Reynolds and Gatchell 1979). These manufacturers could profitably use standard-size blanks as a raw material. Eight manufacturers have successfully used white oak, red oak, and black cherry blanks in trial runs (Araman et al. 1982).

The main concern in purchasing these mass-produced blanks is the integrity of the gluelines between the individual cuttings. Glueline defects may be caused by lack of glue, precuring of glue, inaccurate machining, or other factors. Glueline continuity within the blanks is more important than glueline strength. First, the furniture and cabinet parts cut from the blanks are usually not greatly stressed. Second, in cutting small furniture parts from these blanks, a gap, if present, may extend across the part, resulting in two pieces of a part instead of a usable part. Third, after undergoing moisture content change between the machining and the showroom floor, a gap in the glueline may show up as a crack in the finish, resulting in the whole furniture piece being rejected. Thus, a test method must be developed in order to determine the glueline integrity of standard-size blanks.

Again, the objective of this study was to determine which strength or stiffness parameter could be used to detect gaps in the gluelines. The goal of this research project was to develop a machine that would mechanically stress a standard-size blank, evaluate the appropriate parameter, and determine if there was a gap in any of the blank's gluelines. Other aspects of this research are reported by Hesterman (1986).

It was hypothesized that when the blanks were proofloaded, the good blanks would not be damaged, but the defective ones would either fail or have a low value for the given parameter. The selection efficiency and tolerance of the nondestructive test are important considerations (Dean and Kaiserlik 1984). The selection efficiency is defined as the percent of the acceptable pieces passed by a test (Miller 1964). Maximizing this value results in fewer acceptable blanks being destroyed or rejected by the test. The tolerance is the percent of pieces passed by a test that are below standard. Minimizing this value results in fewer defective blanks passed by the test. In other words, the test method and proofload selected must be nondestructive to the good blanks but should reject and may possibly be destructive to the defective blanks.

## PARAMETERS TESTED

The parameters selected for evaluation were chosen on the basis of their ability to satisfy the following criteria:

1. subject the specimen to a constant stress,
2. stress the maximum volume of fiber,
3. stress the maximum possible number of gluelines, and
4. be adaptable to in-line testing.

Three types of tests were used to check the continuity of the gluelines: static bending perpendicular to the grain, tension perpendicular to the grain, and torsional shear by the plate twist method. With these tests, five parameters were investigated in an attempt to quantify glueline continuity: modulus of rupture (MOR) perpendicular to the grain, modulus of elasticity (MOE) perpendicular to the grain, tensile strength perpendicular to the grain, torsional shear strength, and modulus of rigidity (G).

The MOR perpendicular to the grain is a measure of the static bending strength in this direction. Little research has been performed using the MOR perpendicular to the grain. In a study of larch and Scotch pine, Osvenskii and Akopyan (1976) determined that wood is stronger when bent normal to the radial (LR) rather than the tangential (LT) plane. They also determined that the MOR perpendicular to the grain is greater when the convexity of the rings in flat sawn boards is toward the applied load.

The MOE has been used as the nondestructive parameter for estimating the MOR. The $r$-square values for predicting MOR from MOE range from 0.16 to 0.86 (El-Osta et al. 1979; Dean and Kaiserlik 1984; Dean and Kass 1983; Johnson 1977; Koch 1983; Walters and Reiss 1977). Osvenskii and Akopyan (1976) determined that the modulus of elasticity perpendicular to the grain is greater when the convexity of the annual rings is toward the applied load.

Tensile strength perpendicular to the grain is the most variable structural property (Barrett 1974; USDA For. Prod. Lab. 1974; Wangaard 1950). The strength in this direction is very low because the radial and tangential planes act as natural cleavage planes due to checks and check propagation (Barrett 1974; Schniewind and Lyon 1973). Softwoods are stronger in tension in the tangential direction, while hardwoods are stronger in the radial direction. This may be because the large rays in hardwoods add more strength in the radial direction (Gamov 1975; Schniewind and Lyon 1973).

The torsional shear strength of a panel is its strength in shear through the thickness when subjected to a twisting moment. Specimens subjected to torsion are in a state of pure shear stress (Timoshenko 1958; Timoshenko and Woinowsky-

Krieger 1959). The modulus of rigidity is the elastic modulus for shear. The torsional shear test subjects the panel to a constant shear force in the plane of the panel (Bodig and Jayne 1982). The shear modulus measures the elasticity within the plane of the panel. Assumptions regarding forces normal to the plane of the panel become invalid, and error is introduced when the length to depth ratio is outside the range of 25 to 40 (Bodig and Jayne 1982).

The effects of size and the rate of loading are important considerations for determining the ease of adaptability to in-line testing. Since the tests are perpendicular to the grain, the panel length will be the width dimension during the tests. The panel lengths will not be uniform so there could be a beam width size effect. Also, necessity dictates faster loading times for in-line testing.

According to Bohannon (1966), the MOR parallel to the grain in Douglas-fir beams increases with increased depth or span. Osvenskii and Akopyan (1976) found that MOR perpendicular to the grain increases with decreased depth or span. McNatt (1984) indicated that the MOR and MOE of wood-base panels as determined by two point load tests are little affected by panel size. Sliker (1975) found that the MOE decreased with increasing stress level when loaded perpendicular to the grain.

Kunesh and Johnson (1974) found that maximum tensile stress parallel to the grain decreases with increasing size. The more fiber being tested, the more likely it is that a weak spot or defect in the wood will be present.

Ehlbech and Colling (1985) reported that small test specimens of beech plywood had much higher maximum shear stresses than larger specimens, but that the shear modulus is unaffected by panel size.

In relating tests results to loading times for particleboard, McNatt (1975) found that for each tenfold increase in time to maximum load: 1) MOR decreased 6%, 2) MOE decreased 5%, 3) tensile strength perpendicular to the face decreased 9%, 4) shear strength decreased 11%, and 5) shear modulus decreased 13%. Liska (1950), working with solid wood, found that MOR decreased with an increase in time but that MOE was unaffected by length of time. Madsen (1975) noted a pronounced decrease in the tensile strength perpendicular to the grain of Douglas-fir with increasing time. Conversely, Strickler and Pellerin (1973) reported that there is no time effect for the tensile strength of Douglas-fir parallel to the grain.

Stranger and Blomquist (1965) stated that the load-carrying capacity of adhesive joints is generally greatest in pure shear, moderate in tension, and low in cleavage. This suggests that torsional shear may be less sensitive than the others for detecting glueline defects. Dibuy (1970) reported that a specimen's shear strength is linearly related to glue bond quality except at the excellent quality level where strength increases greatly. This may suggest that detection of gluelines with large gaps is possible but becomes more unlikely as the gaps become smaller.

## PROCEDURES

Three species were used in this study: black cherry (*Prunus serotina*), red oak (*Quercus rubra*), and yellow-poplar (*Liriodendron tulipifera*). These species provided a wide range of specific gravity (0.47, 0.56, 0.40) (USDA For. Prod. Lab. 1974) and different anatomical arrangements. They are also of major commercial importance in West Virginia.

The lumber for this study was generated in conjunction with other research projects at West Virginia University (WVU). All of the trees had been felled on the WVU Forest and all of the lumber had been dried to approximately 8% in a research kiln at WVU using conventional schedules for each species (Rasmussen 1961).

### *Specimen preparation*

The lumber was converted into small cuttings to be glued into panels. Each board was crosscut first, then ripped into clear straight-grained cuttings ranging between 1.5 and 3.0 inches in width as specified for System 6 panel manufacture (Araman et al. 1982). The cuttings were jointed on both edges and one face and planed to a thickness of ⅞-inch.

For each species, the cuttings were randomly grouped into fifteen piles, each sufficient to make one 24-inch wide panel. Ring curvature within the flat-sawn boards was reversed in adjacent pieces so that warp and differences in the strength and elastic properties would be minimized. The majority of the cuttings were flat-sawn. Quarter-sawn cuttings were interspersed among the flat-sawn cuttings and placed at the panel edges when possible.

Polyvinyl acetate (PVA) adhesive was spread evenly across the jointed edges and allowed to set for about one minute while it became tacky. The panels were then assembled and clamped with standard panel clamps. The panels remained clamped for a minimum of 3 hours and were allowed to condition for at least 24 hours to insure proper adhesive cure. The panels were planed to a final thickness of ¾-inch, and 12 of the panels of each species were cut to 24 inches in length, while the other three were cut to 36 inches in length.

Aluminum foil (0.001-inch thick) was placed in the glueline to create the defects. The adhesive did not adhere to the foil, thereby creating a gap in the glueline. Four glueline continuity levels were used: 100% (controls), 90%, 75%, and 60% of the glueline length.

The thirty-six 24 × 24 panels were used full size in the torsion tests. Again, they were made up of three species, four glueline continuity levels and three replications. During assembly, foil strips the width of the glueline and 2.4, 6.0, or 9.6 inches long were inserted into the middle of the centermost glueline to provide the different glueline gaps.

Each of the nine 24 × 36 panels was crosscut perpendicular to the gluelines to provide eight 2-inch bending specimens and eight 2-inch tension specimens. As previously stated, the width of the specimen does not appreciably influence the results of the tests. The lower glueline quality specimens were ripped along the grain in the center, the fresh edges were prepared for gluing, and foil strips of 0.2, 0.5, or 0.8 inches were inserted into the center of the new glueline. These gave the same percentage defects as for the full panel tests. The specimens were clamped in both longitudinal and transverse directions to insure the best alignment.

### *Testing*

Some preliminary tests were conducted to fine-tune the proposed testing procedures. The 24-inch static bending specimens were placed on supports with a 22-inch span. The load was applied with a 19-inch span, two-point loading head (see Fig. 1). This resulted in 2.5 inches at each end of the specimen that were not

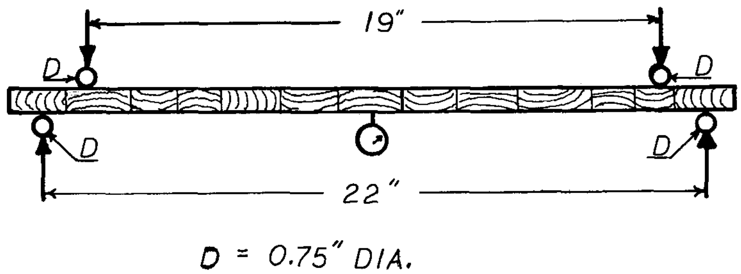


FIG. 1. Test specimen and loading configuration for the static bending perpendicular to the grain tests.

stressed to the same level as the area between the loading points. Increases in the loading head span resulted in shear failures under one of the loading points.

The supports and loading points were 0.75-inch rollers. The loading rate was 0.10 inches per minute as specified by American Society for Testing and Materials (ASTM) Standard D 143 (1981). Deflections were measured with a dial gauge to the nearest 0.001 inch at the specimen midspan on the extreme tension fibers. Readings were taken at intervals of 20 pounds up to 200 pounds, and then the dial gauge was removed to prevent damage at specimen failure.

The tension tests were conducted using wedge-shaped grips to hold the specimen. To prevent the ridges on the grips from damaging the specimen, plywood shims were placed between the specimen and the grips. To prevent slippage between the specimen and the shims, emery paper was glued to the face of the shims (see Fig. 2). Sufficient material had to be placed in the grips to prevent crushing of the specimen, but the desire was to restrict the grips as close to the ends as possible so as to test the maximum possible amount of material. The best compromise was to place 2.0 inches of yellow-poplar or 1.5 inches of black cherry and red oak in the grips. leaving 20 and 21 inches in the testing region. The rate of loading was 0.1 inches per minute in accordance with the ASTM Standard D 143 (1981).

The torsional tests were quite similar to that specified by ASTM Standard D 3044 (1981) for determining the shear modulus of plywood. The standard specifies a length to depth ratio range of 25 to 40. The specimens were 24 inches square and ¾-inch thick giving a ratio of 32.

Metal plates (2.5 × 3 × 0.125 inches) were attached to the corners of the panel

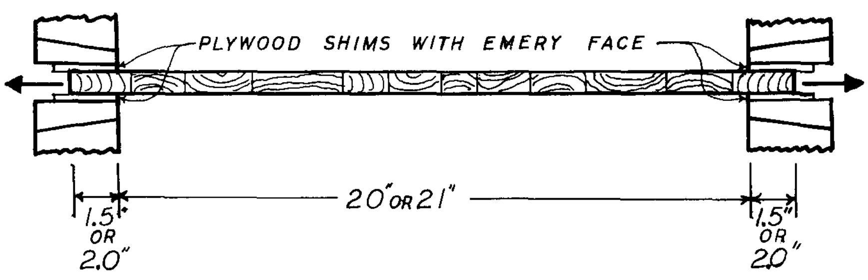


FIG. 2. Test specimen and loading configuration for the tension perpendicular to the grain tests.

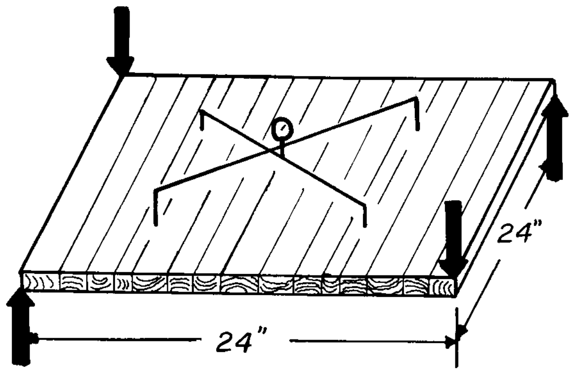


FIG. 3. Test specimen and loading configuration for the torsional shear tests.

so that the $\frac{7}{16}$-inch diameter ball bearings, used to support the ends of one diagonal and apply the load at the ends of the other diagonal, would not harm the corners. The load was applied at the standard rate of 0.3 inches per minute. The deflections were measured by a dial gauge attached to two metal bars whose ends were supported 8.5 inches from each corner on the diagonals (see Fig. 3). Deflection readings were taken every 40 pounds up to 280 pounds; then the gauge apparatus was removed to prevent damage to it at specimen failure.

The number of tests conducted in this study were: 72 static bending, 72 tension, and 36 torsional. After each test, a 2 × 2 × 0.75 sample was removed near the point of failure and used to determine moisture content and specific gravity.

*Equations*

The following equations were used to calculate the five parameters from the test data:

$$\mathrm{MOR} = \mathrm{M/S} \tag{1}$$
$$\mathrm{MOE} = (1{,}443\ \mathrm{PL}^3)/(340{,}736\ \mathrm{DI}) \tag{2}$$
$$\mathrm{Tension} = \mathrm{P/A} \tag{3}$$
$$\mathrm{Torsion} = \mathrm{M}(3 + 1.8\mathrm{d/b})/(\mathrm{bd}^2) \tag{4}$$
$$\mathrm{G} = 3\mathrm{u}^2\mathrm{PC}/(2\mathrm{h}^3\mathrm{DC}) \tag{5}$$

where:

M = maximum moment (in. lb),
S = section modulus (in.$^3$),
P = maximum load (lb),
L = span (in.),
I = moment of inertia (in.$^4$),
D = deflection (in.),
A = cross sectional area (in.$^2$),
d = depth (in.),
b = base (in.),
G = modulus of rigidity (psi),
PC = load at each corner (lb),

TABLE 1. *The average values and standard deviations for five parameters and three species: black cherry (BC), red oak (RO), and yellow-poplar (Y-P) having continuous gluelines (controls) (psi).*

| Parameter | Species | Average | SD |
|---|---|---|---|
| MOR | BC | 1,406 | 202 |
| | RO | 1,586 | 330 |
| | YP | 1,295 | 171 |
| MOE | BC | 148,123 | 14,544 |
| | RO | 156,346 | 18,293 |
| | YP | 101,875 | 13,472 |
| TENSION | BC | 886 | 88 |
| | RO | 782 | 160 |
| | YP | 696 | 128 |
| T. SHEAR | BC | 1,318 | 461 |
| | RO | 1,556 | 423 |
| | YP | 1,360 | 528 |
| RIGIDITY | BC | 172,790 | 9,540 |
| | RO | 158,683 | 18,336 |
| | YP | 104,108 | 8,681 |

h = plate thickness (in.),
DC = deflection relative to center (in.),
u = distance from panel center to where deflection was measured (in.).

## DATA ANALYSIS

In order to compare the various test parameters, a unitless quantity called *stress level* was used. For each species, the mean values of each parameter for the control specimens were calculated (see Table 1). The parameter values of each defective glueline specimen was divided by the respective control mean. Defective glueline specimens that failed at locations other than the defective glueline were excluded from this analysis.

The average stress level values were determined for each parameter for each percent effective glueline and for each species (see Table 2). Regression analyses were conducted relating stress level to percent effective glueline. With these analyses, prediction intervals were developed for each percent effective glueline that gave the stress levels at which 95% of the defective panels with that percent effective glueline could be detected (see Table 3).

## RESULTS AND CONCLUSIONS

The results of this study indicate that stiffness parameters (modulus of elasticity and modulus of rigidity) are poor indicators of defective gluelines. Tables 2 and 3 indicate that a defective glueline does not appreciably affect the stiffness of the panel. The average stress level of the panels with 40% of the glueline missing (60% effective) was nearly 1.000, which means that the stiffness parameters were the same as those for the nondefective controls. The 95% prediction level for these panels is higher than the mean values for the controls.

Wood is weak in shear strength and one of the strongest properties of adhesives is shear strength. These facts would suggest that torsion is of little use in detecting defective gluelines. The results of this study corroborate this. No torsion stress

TABLE 2. *The average stress levels for five parameters and three species: black cherry (BC), red oak (RO), and yellow-poplar (YP) having three effective glueline percentages.*

| Parameter Species | % Glue line 90 | 75 | 60 |
|---|---|---|---|
| MOR | | | |
| BC | 1.019 | 0.836 | 0.652 |
| RO | 0.817 | 0.663 | 0.510 |
| YP | 1.184 | 0.945 | 0.705 |
| MOE | | | |
| BC | 0.897 | 0.932 | 0.968 |
| RO | 0.938 | 0.949 | 0.959 |
| YP | 0.938 | 0.935 | 0.931 |
| TENSION | | | |
| BC | 0.702 | 0.616 | 0.530 |
| RO | 0.899 | 0.722 | 0.545 |
| YP | 0.808 | 0.618 | 0.428 |
| T. SHEAR | | | |
| BC | 0.964 | 1.228 | — |
| RO | 0.831 | 0.823 | 0.815 |
| YP | 0.519 | — | 0.819 |
| RIGIDITY | | | |
| BC | 1.084 | 1.105 | — |
| RO | 1.044 | 1.063 | 1.081 |
| YP | 0.984 | — | 1.027 |

level values for black cherry panels with 60% gluelines or yellow-poplar panels with 75% gluelines are given because all of these specimens failed in the wood outside of the defective glueline. The 95% prediction values indicate that the defective panels would have to be stressed to a higher level than the average failure level for the controls in order to detect 95% of the defective panels.

MOR in bending showed some promise as a detector of defective gluelines. The average stress levels ranged from 0.510 to 0.705 for 60% gluelines, 0.663 to 0.945 for 75% gluelines, and 0.817 to 1.184 for 90% gluelines. These values indicate that MOR could be used to detect large glueline defects. However, the variability of this parameter was so great that the stress level needed to detect 95% of the panels with 40% of the glueline missing ranged from 0.743 to 0.937. The remaining 95% prediction levels were about the same as, or greater than, the average failure stress level for the controls.

The tensile strength parameter was the best of the five parameters studied in detecting defective gluelines. The average stress levels were less than 0.60 for the 60% effective gluelines, less than 0.75 for the 75% effective, and less than 0.90 for the 90% effective. The variability was small enough that the panels could be stressed sufficiently to detect 95% of the panels with 75% effective gluelines without too many nondefective panels failing, although to detect 95% of the panels with a 90% effective glueline, a stress level about equal to the average failure level of the controls would be needed.

Tension appears to be the best test method of the three studied for quality

TABLE 3. *The stress levels needed for five parameters and three species: black cherry (BC), red oak (RO), and yellow-poplar (YP) so as to fail 95 percent of the panels with three levels of effective gluelines.*

| Parameter Species | % Glue line 90 | 75 | 60 |
|---|---|---|---|
| MOR | | | |
| BC | 1.256 | 1.059 | 0.884 |
| RO | 1.057 | 0.887 | 0.743 |
| YP | 1.433 | 1.170 | 0.937 |
| MOE | | | |
| BC | 1.079 | 1.104 | 1.145 |
| RO | 1.122 | 1.120 | 1.138 |
| YP | 1.129 | 1.107 | 1.109 |
| TENSION | | | |
| BC | 0.853 | 0.753 | 0.672 |
| RO | 1.039 | 0.858 | 0.687 |
| YP | 0.950 | 0.753 | 0.568 |
| T. SHEAR | | | |
| BC | 1.320 | 1.519 | — |
| RO | 1.134 | 1.099 | 1.119 |
| YP | 0.875 | — | 1.127 |
| RIGIDITY | | | |
| BC | 1.288 | 1.302 | — |
| RO | 1.249 | 1.249 | 1.286 |
| YP | 1.224 | — | 1.236 |

control of the glueline continuity of standard-size blanks. Since the blanks will be cut up into smaller pieces or furniture parts or used where appearance is important, a gap of 10% or less (90% effective or greater) could be critical. A 10% gap would be a 2.4-inch gap in the glueline in a 24-inch panel or a 7.2-inch gap in a 72-inch panel. If the quality control system must detect defects of 10% or less, it appears that none of the mechanical methods studied will suffice.

## SUMMARY

Standard-size blanks are edge-glued hardwood panels manufactured 24 inches wide and to customer specified lengths. They are used in place of in-house cuttings from rough lumber in furniture or cabinet factories. Since they will be cut into small parts or used where appearance is important, total glueline continuity is critical. Standard-size blank manufacturers need an in-line quality control check to determine the continuity of each glueline in each panel. This study looked at three test methods and five parameters to determine if a mechanical test could be used for the quality control check. The results of this study indicate that tension perpendicular to the grain is the best of those methods studied but that mechanical methods are not appropriate.

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