AN ABSTRACT OF THE THESIS OF

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Title: Influence of Veneer Roughness, Lathe Check, and Annual Ring Characteristics on Glue-bond Performance of Douglas-fir Plywood

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Current lathe technology, smaller diameter logs, smaller core diameters, and the sale of higher grade veneer for use in engineered wood products are all factors contributing to plywood manufacturers using rougher veneer with different lathe check characteristics. When rough veneer is encountered, plywood manufacturers typically increase the adhesive spread rate in an attempt to achieve sufficient bonds between veneer surfaces. However, the effectiveness of this practice has not been clearly established. Little is known about how veneer roughness and lathe check characteristics interact to determine glue-bond quality or how lathe checks propagate under load while contributing to glue-bond failure. It was hypothesized that veneer roughness, lathe check, and annual ring characteristics interact to determine plywood glue-bond quality (i.e., wood failure percentage and load at failure). This study investigated the influence of veneer roughness, lathe check, and annual ring characteristics on Douglas-fir (*Pseudotsuga menziesii*) plywood glue-bond performance. The study also investigated the differences in glue-bond quality when

samples were tested in a dry and wet (PS 1 boil method) state and prepared such that lathe checks were pulled open or closed.

To evaluate differences in test conditions on standard glue-bond samples, 120 blanks were cut from a Douglas-fir plywood panel and kerfed accordingly to produce 60 open and 60 closed specimens. Out of these specimens, half of the open samples and half of the closed samples were tested in a wet condition and the other half in a dry condition. On each sample, ultimate failure load and percent wood failure were recorded.

A two-way analysis of variance (ANOVA) test performed on the load at failure results indicated that each factor (wet or dry conditioning and open or closed lathe checks) had a statistically significant influence in load at failure, as did the interactions of factors. Further analysis of the interactions using multiple range testing indicated a statistically significant difference between all four groups (dry open, dry closed, wet open, and wet closed). In terms of load at failure, dry closed exhibited the highest average load value, followed by dry open, wet closed, and wet open, respectively. A two-way ANOVA test indicated that each factor (i.e., wet or dry conditioning and open or closed lathe checks) did not have any statistically significant influence on percent wood failure nor did the interactions. In addition, multiple range testing indicated no statistically significant difference between all four groups.

To investigate the influence of veneer characteristics on glue-bond quality, ninety veneer sheets, 12-inches by 12-inches, were separated into three visual roughness categories; smooth, intermediate and rough. Using a laser scatter/optical imaging system, fifteen mathematical roughness measurements were determined for five randomly selected 1-inch by 1-inch areas per sheet. The scanned veneers were placed as center plies in 3-ply, 3-layer plywood panels and pressed using typical mill lay-up procedures. Glue-bond specimens were prepared and tested in accordance to PS 1-95 to evaluate adhesive bonding of the 1-inch^2 areas scanned for roughness. Prior to testing, both sample edges were scanned using a flatbed scanner. During testing, digital video cameras recorded crack propagation and failure on both edges of the 1-inch^2 test area. Ultimate failure loads and percent wood failures were recorded. Lathe check and annual ring characteristics were measured and mode of failure was determined.

Results from an ANOVA test showed that there was a statistically significant difference (p-value < 0.0001) for average load at failure between visual roughness categories. Two sample t-tests indicated a statistically significant difference between average load at failure between smooth and intermediate (p-value < 0.0001), smooth and rough (p-value <0.0001), and intermediate and rough (p-value = 0.043). Analysis of multiple range tests indicated a statistically significant difference for load at failure between smooth and intermediate, and smooth and rough, but found no significant difference between load at failure for intermediate and rough. Intermediate samples had the highest average load, followed by the rough and smooth, respectively, indicating that visual veneer roughness may not be a primary factor in determination of load at failure.

Results from an ANOVA test showed that there was a significant statistical difference (p-value < 0.0001) for average percent wood failure between visual roughness categories. Multiple range tests indicated a statistically significant difference between all three visual roughness groups for average percent wood failure. In addition, two sample t-tests showed a statistically significant difference for average percent wood failure between smooth and intermediate (p-value < 0.0001), smooth and rough (p-value <0.0001), and intermediate and rough (p-value $= 0.01$). Smooth samples had the highest average percent wood failure, followed by intermediate and rough, respectively.

Using stepwise and all possible combination best-fit regression techniques, load at failure was found to decrease as lathe check frequency increased. In addition, load at failure was influenced by the number of growth rings per inch, percent latewood in the test area, earlywood/latewood ratio, distance of second lathe check to the saw kerf, and two distinct mathematical veneer roughness measures. Stepwise and best-fit regression analysis showed that percent wood failure was influenced mainly by mathematical veneer roughness measures, but was also affected by the number of growth rings per inch, percent latewood in the test area, and percent latewood at the tight-side glue-line.

Specimen failure typically occurred by lathe checks propagating in a tangential-radial mode, radial-tangential mode or by glue-line failure attributed to peeling forces and/or severe surface roughness at the glue-line. In addition, both mathematical veneer roughness measures and veneer characteristics of latewood angle, percent latewood, lathe check frequency, growth rings per inch, number of latewood bands, average lathe check depth, and earlywood/latewood width ratio were found to influence elastic properties of glue-bond samples. These results suggest that plywood manufacturers can improve glue-bond quality by monitoring and adjusting for the key veneer characteristics of roughness, lathe check occurrence, and annual ring orientation that were found significant in the study. In particular, by reducing the frequency of lathe checks, higher loads at failure can be obtained and by reducing veneer roughness, percent wood failure can be increased.

Influence of Veneer Roughness, Lathe Check, and Annual Ring Characteristics on Glue-bond Performance of Douglas-fir Plywood

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David B. DeVallance, Author

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This work is dedicated to my father and mother, Gary and Patty DeVallance, who blessed me with their kindness and caring, making me the person I am today. Even though my father has passed from this Earth, he lives within my heart as the best friend and inspiration a son could have ever wished for.

Influence of Veneer Roughness, Lathe Check, and Annual Ring Characteristics on Glue-bond Performance of Douglas-fir Plywood

1. INTRODUCTION

Softwood plywood represents the original type of structural panel used as roof decking, floor decking, and wall sheathing. The emergence of competing structural-use panels, mainly oriented strandboard (OSB), has forced the plywood industry to minimize production costs while maintaining the structural integrity of their panels. Never has this been more apparent than in today's structural panel production trends. Since the year 2000, North American OSB production has surpassed that of plywood (58).

It is important to study veneer roughness and its effect on glue-bond quality for two main reasons: the overall level of roughness is increasing and it is generally agreed that roughness leads to lower glue-bond quality. One reason for the decrease in veneer quality is that smaller diameter logs are being peeled and much more juvenile wood is being utilized. Second, new products, such as laminated veneer lumber (LVL), are utilizing higher-grade veneers, leaving rougher veneers for use in plywood panels. Rougher veneer and veneer with more severe and frequent lathe checks may result in a higher incidence of delamination, a major issue in plywood integrity once it is installed in the field. To avoid delamination when using rougher veneer, plywood manufacturers typically increase the adhesive spread rate. Although increasing the adhesive spread rate is a common practice, questions exist about how lathe checks and veneer roughness affect the load at failure and percent wood failure of plywood glue-bond specimens. This lack of information means that little is known about the effectiveness of increasing adhesive spread rate as a means of improving the ability of the final product to withstand delamination.

2. OBJECTIVES AND HYPOTHESES

2.1 Research Objectives

The objectives of this research were to:

1. Determine which lathe check characteristics affect glue-bond quality and the manner by which lathe checks propagate to cause failure of softwood plywood glue-bond specimens when placed under stress.

2. Determine how veneer roughness, in combination with lathe check and annual ring information, can be used to predict plywood glue-bond quality (i.e., percent wood failure and load at failure).

2.2 Hypotheses

Two primary hypotheses were tested in this research.

1. Veneer roughness, lathe checks, and annual ring characteristics will interact in determining plywood glue-bond test specimen quality (i.e., percentage of wood failure and load at failure).

As veneer roughness increases, the surface area the adhesive must cover increases. Also, rougher veneer will result in reduced surface-to-surface contact between adjacent veneers. Therefore, when adhesive is applied at the same rate as in smooth veneer, the bond will be inadequate and failure will most likely occur at rough veneer locations. It is evident from prior research (59,60) that glue-bond specimens tend to fail at the loose side (i.e., veneer face where lathe checks are present) of the core veneer. This indicates that lathe checks play some role in determining glue-bond quality. Lathe checks present an inherent flaw in the specimen and cause specimens to fracture in wood adherends (i.e., veneer) as flaws propagate until failure. As the frequency of lathe checks increases, so does the tendency for them to propagate toward each other or toward the glue-line (depending on annual ring orientation). This results in a higher percentage of wood failure at a lower ultimate load. Research has indicated that frequency, rather than depth, of lathe checks affects the quality of a plywood glue-bond (41,49). Growth rate of wood also affects the type of lathe checks present in veneer (4,41,50,62).

2. Lathe checks will propagate in the TR mode (i.e., normal to the tangential direction and in the radial direction) when glue-bond specimens are placed under stress. Lathe check crack tip location characteristics, such as position in earlywood or latewood, angle with respect to annual ring, angle with respect to glue-line, and distance from saw kerf, will determine which individual cracks propagate and the extent to which they propagate.

The energy needed to propagate a crack depends on the angle at which the crack tip of the check is located with respect to an annual ring. In veneer peeling, the check may begin at an angle away from the pure TR (tangential-radial) direction. Research indicates that an angled crack (in respect to TR orientation) with the tip located in earlywood will propagate through the middle lamellas and cell walls before reaching a pure TR direction once a latewood ring is encountered (78). TR cracks propagate through the middle lamella only. Therefore, crack tips oriented in the TR direction will propagate under a lower stress. In addition, due to the manner in which saw kerfs are cut into a glue-bond specimen to test each glue-line, higher stresses are likely to occur nearer the saw kerf locations.

3. LITERATURE REVIEW

To investigate the role lathe checks and roughness play in determining plywood glue-bond quality, lathe check formation, previous research regarding their affect on glue-bond quality, and general wood fracture mechanics were explored. Furthermore, fracture of adhesive bonded wood joints, phenol formaldehyde toughness, and spread rates were evaluated. In order to evaluate interactions between lathe checks, annual ring orientation, and veneer roughness in the study, an understanding of their effects on glue-bond quality was essential. Finally, in order to measure both veneer roughness and lathe check propagation, optical scanning techniques are of importance and were investigated. Veneer roughness measurement and related scanning techniques were outlined in detail by Neese (59), and therefore, are only summarized in this literature review.

3.1 Veneer Quality

Veneer quality is an essential key to producing quality plywood panels. Veneer quality in plywood manufacturing is generally assessed by veneer thickness variation, surface roughness, and lathe check depth and frequency. High quality veneer is consistently smooth, uniform in thickness, and relatively tight (i.e., free from deep lathe checks) (25). Modifications in lathe settings make a significant difference in the quality of veneer produced (25). Lathe check depth and frequency have been long time indicators of veneer quality (15). Some researchers feel that shallow lathe checks at a higher frequency (i.e., checks per inch), as opposed to less frequent, deeper lathe checks, indicate a good surface quality (55). When appearance of plywood is a key attribute, as in face veneers, this may be the case. Deep lathe checks in face veneers may lead to surface checking and are pronounced once a finish is applied (25). At least 0.030 inches of solid wood is needed in face veneers for adequate sanding (33). If lathe checks are too deep, they become exposed once a plywood panel is sanded. Deep lathe checks can result in veneer not laying flat and a reduction in flexibility, making the veneer sheets more prone to breaking when handled during manufacturing (33).

Differences in log's wood properties have shown significant relationships to lathe check formation when peeled into veneer. In particular, tree growth rate and log conditioning have been shown to affect veneer quality. Compression and tension perpendicular to the grain along with rolling shear strength properties of wood determine the type of failure that occurs during the peeling process and influences lathe check severity and surface roughness (55). Veneer quality factors of interest during this study were lathe checks, veneer surface roughness, and annual ring characteristics (i.e., growth rings per inch and earlywood/latewood characteristics).

3.2 Lathe Checks

When manufacturing veneer, lathe checks are important characteristics that contribute to veneer quality. In almost all cases, lathe checks are present in veneer to certain degrees. In order to evaluate the effects of lathe checks on plywood glue-bond quality, lathe check characteristics had to be identified and measured. Fundamental background knowledge on lathe checks was key to understanding their formation, effect on glue-bond quality, and best methods to control their formation during peeling.

3.2.1 Lathe Check Development

U.S. Voluntary Product Standard PS 1-95 (83) defines checks in general as "a lengthwise separation of wood fibers, usually extending across the rings of annual growth." Lathe checks are a result of the machining process used to produce veneer. When present, lathe checks create more surface area, thus resulting in over-penetration and adhesive dry-out at the glue-line. Furthermore, lathe checks exhibit areas of weakness.

Peeled veneer exhibits two distinct surfaces, one being a tight side and the other a loose side. The tight side is located against the pressure bar during the peeling process. The loose side is in contact with the lathe's knife and typically develops lathe checks (5,17,21,72). The loose side can develop various amounts of roughness in combination with lathe checks. Figure 3.1 depicts lathe check formation during rotary peeling. A lathe check forms when tension forces of the lathe's knife pulls the veneer away from the peeler block and flattens the veneer from its natural curvature (21).

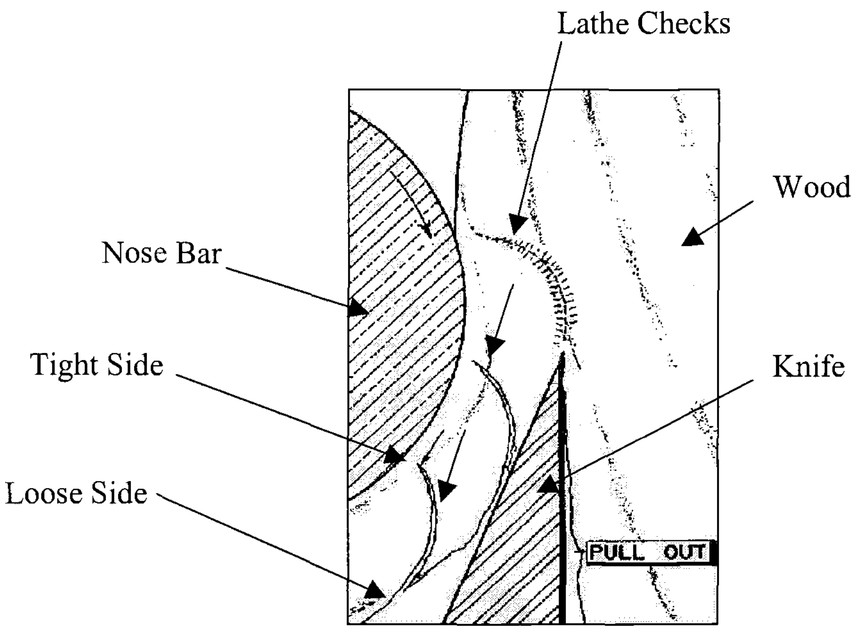


Figure 3.1. Lathe check formation during veneer production (13).

In conifer species, checks initially form in a fairly straight line, then are directed toward a normal angle with respect to the cutting plane. This pattern is associated with a change in the magnitude of the components of force, which results in the maximum tensile stress. This tensile stress at the edge of the knife is not always perpendicular to the cutting plane. Evidence of this is shown by lathe checks starting at an angle to the cutting plane and following a curved path and finally approaching a direction perpendicular to the grain (47). In other words, the lathe check forms as it propagates in a curved path that reaches a TR mode. Checks have also been found to stop near the interface of latewood and earlywood material (43, 16).

To minimize lathe checks, the best means of producing veneer is by peeling away material by forces that cause wood failure in tension perpendicular to grain ahead of the knife (55). Veneer formed by this peeling process tend to exhibit a lesser amount of lathe checks and superior surface quality (55) than found in veneer formed by splitting. More severe lathe checks and rougher surfaces are created when veneer forms by splitting and bending forces that causes the wood to fail in compression perpendicular to the grain or in rolling shear (55). Failure by splitting and bending occurs when the wood has a higher tensile perpendicular to the grain capacity than the tensile force exerted on the veneer by the knife (55).

Lathe checks vary depending on lathe cutting speed, sharpness and angle of the knife, amount of pressure on the nose bar or pressure bar, growth rate of the peeler block, and whether or not the peeler block is heated to the proper temperature.

3.2.2 Effect of Lathe Checks on Plywood Glue-bond Quality

The focus in this study was to determine what role lathe checks play in determining both percentage wood failure and load at failure in traditional plywood glue-bond specimens. Some past studies give insight into how lathe checks affect glue-bond quality but not which characteristics will influence the adequacy of the glue-bond.

Past research investigated effects of veneer lathe checks in determining percent wood failure and load at failure of glue-bond specimens. In early work performed on southern pine plywood, Koch (41) found that veneer peeled cold and loose (i.e., peeled cold with a roller nose bar) yielded a higher percentage of wood failure near the glue-line than veneer peeled hot and tight (i.e., peeled hot with a fixed nose bar). Furthermore, lathe check frequency showed a significant negative relationship to wood failure. Koch (41) observed that greater lathe checks per inch resulted in lower percent wood failure, but no association was found between lathe check depth and wood failure percentage (41). The lathe check frequency influence on the percentage of wood failure was also shown in other research. Some studies indicated that veneer with frequent lathe checks resulted in high wood failure, but the lathe checks may have caused the specimens to have higher wood failure (50). It was noted that the specimens resulted in low shear strength and may in fact not be satisfactory for some structural applications (50). Also, frequent, low angled, lathe checks, combined with earlywood at the glue-line, appeared to contribute more to failure patterns than deep checks oriented perpendicular to the glue-line (48). Kaneda et al. (37) reported that a higher frequency of lathe checks resulted in lower bonding strength in shear samples pulled "closed" and "open" (see section 3.9.2). Further research by Koch (44) suggested that plywood with tight peeled veneer delaminates at a slower rate than plywood with loose peeled veneer for a given high specific gravity of wood. However, later research did not support this relationship (45).

A linear negative relationship between lathe check depth and lathe check frequency was found by Koch (41). However, others have noted that a greater frequency of lathe checks is not associated with the shallowest lathe checks (16, 62), meaning that frequent lathe checks are not necessarily shallow, and can have a high degree of depth. Other studies also showed that a high frequency of checks produce relatively shallow checks and that less frequent checks are characteristically deeper (55).

In a study performed on Douglas-fir and hemlock glue-bond specimens in the pull "closed" condition (see section 3.9.2), Leney and Moir (48) found check depth had no apparent relationship to the failure patterns. However, Leney and Moir (48) did find that lathe check angle to the applied load was significant in attributing to the failure pattern. If check angle is low enough, relative to the glue line, shear movement along lathe checks is part of the weakness in failure patterns. If the angle becomes more than 45^0 to the glue line plane, failure is in a tension mode. Tension failure results in connection of a lathe check with another at the glue-line boundary (i.e., interface), with the cycle repeating itself the entire specimen length. If the remainder of the check approached a perpendicular direction, in relationship to the glue line, it was usually omitted from the failure pattern (48).

3.2.3 Controlling Lathe Check Formation During Peeling

Generally, industry recognizes loose veneer as detrimental in producing quality plywood. Veneer that possesses deep lathe checks, in respect to the thickness of the veneer, is said to be loose (25, 26). Tight veneer consists of shallow, frequent lathe checks. Usually, more attention is paid to reducing the depth of lathe checks rather than the frequency. Four main causes were found to result in veneer being too loose. These causes are insufficient nose bar pressure and/or horizontal or vertical gap setting too wide, logs too cold at the time of peeling, logs too dry during peeling, and knife bevel angle too large (26, 26). Other factors affecting veneer quality are cutting speed and clearance angle.

The lathe's knife acts as a wedge that causes cleavage to occur ahead of the cutting edge. It also results in rapidly increasing bending moments in the veneer sheet causing lathe checks to form when the transverse strength of the wood is exceeded (63). As previously stated, better quality veneer is produced when wood ahead of the knife is peeled by producing tensile forces higher than the tension perpendicular to grain strength of the wood (55). In many instances, wood has a high enough tension perpendicular to grain strength to withstand the tensile forces produced by the knife and failure occurs in compression perpendicular to grain or in rolling shear, thus resulting in lower quality veneer (55). One way to ensure that tension forces exerted by the knife exceed that of wood's tensile strength perpendicular to the grain is by adding nose bar pressure or compression forces to the wood surface ahead of the knife (55). By using pressure, tensile forces subjected upon the wood are greatly increased (55). The magnitude of compression applied to the veneer surface is considered the most important factor that affects veneer peel quality (63). Pressure can be applied ahead of the knife by use of nose bar pressure (i.e., roller bar) or changing lead, gap and exit gap. Figure 3.2, illustrates the location of the roller bar, lead (L), gap (G), and exit gap (E).

By increasing nosebar pressure, a reduced severity in lathe check depth occurs (35, 84), along with an increase in veneer tensile strength (84). Indications are that use of a nose bar or other means to apply horizontal pressure gives support to veneer when the distance between the knife and the edge of the nose bar is less than the veneer thickness (26).

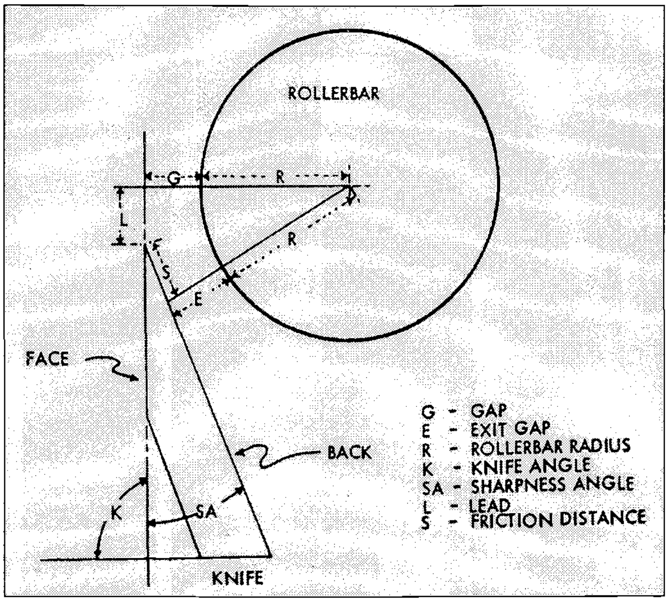


Figure 3.2. Rollerbar, lead, gap and exit gap locations in a lathe setup (15).

In yellow birch veneer, tensile strength was found to improve when the veneer was peeled with nose bar pressure up to 21% (ratio of lead gap opening to thickness). Above 21% pressure, veneer tensile strength then started to decrease (26). Above 21% pressure it was speculated that veneer is permanently damaged, but below 21% pressure, deformation is within the elastic zone of the yellow birch (26). Another study indicated that up to a certain point, by adjusting the lead and exit gap lathe settings to increase pressure reduced lathe check depth in redwood veneer (15) and also showed a tendency to produce more frequent, shallow lathe checks. Again, too much pressure caused lathe check depth to increase. Poor veneer quality is attributed to excessively high or low settings in the gap and lead (15). It was determined by setting exit gap and gap equal to each other the best quality veneer was produced (15). In that particular study, it was concluded that lathe check frequency was not of significant importance as a veneer quality factor when determining optimal compression settings because of its high variability (15).

The optimal level of compression depends greatly on many factors including wood species, temperature of the log, zones in wood from sapwood to core, log moisture content, and angle of the knife bevel (63). Too little compression can result in deep lathe checks and rougher veneer surfaces, while too much compression can produce difficulties in veneer drying (15). Horizontal pressure ranging from 5% to 20% of the nominal veneer thickness can be typically found in industrial peeling operations (63). In many instances, higher horizontal pressures are needed for thicker veneers and lower pressure for thinner veneers (51), and in general, the thinner the veneer, the better the resulting peel quality (63).

Clearance angle also affects the quality of veneer produced. The clearance angle represents the angle of the face of the knife and is illustrated in Figure 3.3. Changes in clearance angle can significantly affect both lathe check depth and frequency (62). A clearance angle of 0^0 maximizes check frequency, while small positive clearance angles (as shown in Figure 3.3) that produce veneer with more uniform quality are preferred to negative angles that reduce quality (62). In another study, neither veneer smoothness or tightness (i.e., lathe check depth) showed any significant trend with change in knife angle (84). The most significant effect of changing knife angle was veneer thickness variability.

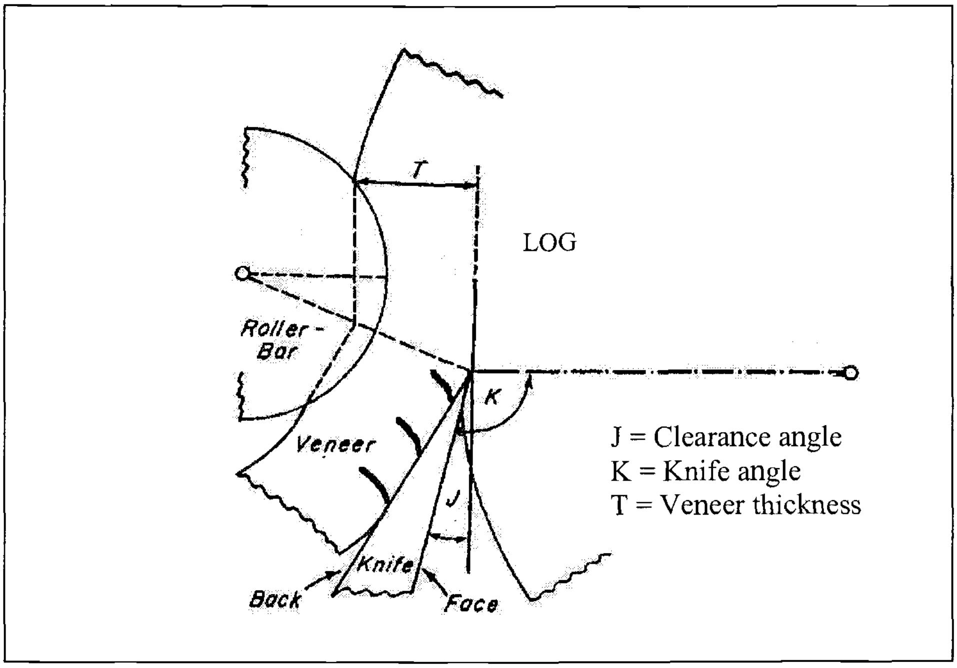


Figure 3.3. Clearance angle and knife angle locations in a lathe setup (62).

Lathe cutting speed (feet of veneer produced per minute) is another variable that affects veneer quality. An increase in cutting speed results in weaker veneer with deeper lathe checks (9, 66). An increase in speed causes reductions in nose bar pressure and can result in more severe lathe check formation (9). Also, cutting speed increases the amount of parallel and perpendicular forces on the knife and the bar (66). These increases in forces placed on the knife result in greater wear on the lathe.

Block temperature at the time of peeling veneer significantly affects both check index (measure of check depth and width) and frequency. Cold-loose peeled veneer (i.e., peeled cold with a roller nose bar) exhibits a higher check index and frequency of lathe checks than does veneer peeled hot-tight (i.e., peeled hot with a fixed nose bar) (43). Other studies indicated that higher peeling temperatures reduced the severity of lathe check depth (14,35). Most wood species are said to produce the best veneer quality when log temperatures are between 100 ^{0}F to 160 ^{0}F (63). In fine grain and coarse grain Douglas-fir peeler blocks heated to a temperature of 140 ^{0}F, tight veneer can be produced at various amounts of nose-bar pressure (14).

3.3 Veneer Surface Roughness

Veneer roughness is another key component in this study in terms of veneer quality. Roughness affects the adhesion of one veneer to another. In order to understand the performance of plywood glue-bonds, veneer roughness had to be determined and classified. Veneer roughness can be categorized in terms of both macro (i.e., visually viewable) and micro (i.e., microscopic scale) roughness. Since the intention of this work is to allow plywood manufacturers to easily evaluate veneer roughness, macro roughness will be measured in this study. Macro veneer roughness results mostly from mechanical processing, but to a lesser degree from anatomical wood features.

3.3.1 Veneer Roughness Defined

In general, roughness is defined as “the irregularities in the texture which results from the inherent action of the production process” (75) and “are considered to include transverse feed marks and other irregularities within the limits of the roughness sampling length” (2).

In general, veneer roughness can be defined by the following equation:

Roughness = True surface area / Apparent surface area

True surface area includes the total surface area with all irregularities and the apparent surface area is the surface projected to the plane of the peel (46,52). Rough veneer has been categorized as contributing to poor quality glue bonds (21,30). Veneer roughness results in elevations on the loose side of the veneer combined with depressions on the tight side. Excessive roughness in Douglas-fir heartwood and sapwood can be attributed to such factors as cross grain, eccentricity of annual rings, varying densities of earlywood and latewood, and veneer peeling techniques. In order to evaluate roughness in core veneers, it is important to determine cross sectional area and length of depressions and elevations (30).

3.3.2 Causes of Veneer Roughness

Both macro and micro veneer roughness can be found in peeled veneer (21,52,73,74). When peeling softwood veneer, the lathe's knife tears through the longitudinal tracheids of the log and results in cavities (i.e., voids) and torn surface wood fibers. The level of micro veneer roughness typically depends on cell dimensions and orientation. When cut at the same angle, earlywood and latewood cells show distinct differences in the size of cavities produced. Due to the inherently larger cell lumens, earlywood cells will have deeper cavities than latewood cells. Furthermore, due to variation in cell wall thickness, earlywood exhibits a greater tendency to tear from the surface when machined than does latewood (49,72).

Considerable damage to the surface of veneer can be caused by tearing of wood cells. The amount of tearing also helps determine the micro roughness of the veneer (47). Cells in front of the cutting edge are under a reduced amount of tension perpendicular to the grain forces relative to the cells at the cutting edge and instead of failing, they resist severing. This results in cells becoming compressed and can produce rough and wooly surfaces (47). Also, cell orientation to the knife's edge can affect anatomical roughness. If trees grow in a less than optimum condition (e.g., grown on steep slopes), changes in the cell's orientation can occur (59). These growth patterns can lead to spiral grain, interlocking grain, wild grain, and compression wood (34,49,64). When cut, these growth patterns can lead to deep cavities and fuzzy grain.

Mechanical processing, primarily at a macro level, affects the roughness of peeled veneer. Anatomical factors that affect the mechanical processing include tree growth rate, annual ring symmetry, and size and frequency of knots (59). In processing, variables such as knife sharpness, knife angle, feed rate, and final veneer thickness may also affect the veneer roughness (26,27,40,47,49). Variation in wood density can have a great influence on the veneer surface (21,26,40,47,49). As varying densities are encountered in the log while peeling veneer, vibrational forces occur and can result in rough veneer being produced (20,21,22,30,47). Due to the effect of density, ring symmetry is important in determining veneer roughness. A log containing eccentric growth rings will cause the lathe's knife to encounter more erratic changes in density than if the rings are perfectly symmetric (59). For example, while peeling a log, the lathe's knife may encounter three or four sets of earlywood and latewood bands, and an increase in surface roughness may occur.

3.3.3 Effects of Veneer Roughness

Veneer surface roughness may affect moisture balance in the glue-line by increasing the moisture absorption due to its greater surface area. Also, frequency and depth of lathe checks may increase glue penetration during hot pressing; therefore, both over penetration and dry-out can be amplified by rough veneer (23,24). Rough veneer may also reduce the contact between veneers and, in combination with lathe checks, leave gaps in the glue-line that may affect the toughness of the adhesive bond.

Rough veneer is difficult to glue because it lacks intimate contact between veneers, promoting conditions that result in dry-out and over penetration. Possessing peaks and valleys on the surface, rough veneer results in only the peaks making intimate contact with each other when the cross bands are rotated at 90^0 (59). When pressed under typical conditions, these peaks constitute the main points of bonding. If pressure is increased, it is possible to press nearly the entire surfaces of adjacent veneers into intimate contact. However, this would require thicker veneers to be produced to compensate for compression losses in the veneer due to the higher pressure.

An increase in the surface area resulting from rough veneer would require a higher spread rate to cover the increased surface area caused by voids and pockets. If the same amount of adhesive is used as for smooth veneer, the adhesive can lay within the voids and cavities and not be transferred to the surfaces of the veneer that will come into contact during pressing. As a result, the areas that are in contact will likely exhibit dry-out prior to pressing. Also, in the case of lathe checks, dry-out may occur more frequently due to over penetration into the cracks.

Some research shows that rough veneer significantly reduces wood failure in plywood glue-bond specimens (20,23,24,59,60). Research on veneer roughness by Neese et al. (60) showed that glue-bond samples tended to fail at either the loose or loose/back (i.e., combination of loose side veneer and back veneer) locations. In that study, 70% of the specimens failed at these locations, no matter what roughness category was involved. This may suggest that lathe checks in the veneer's loose side may be the initial zones of weakness and interact with veneer roughness in determining glue-bond performance. They also found that when percent wood failure was regressed against the average lathe check depth and frequency (which included loose-side roughness), the coefficient of determination (R^2) increased significantly versus that found when using only roughness measurements (60).

3.3.4 Mathematical Veneer Roughness Measures

Many different mathematical measures can be used to express surface roughness. For the purpose of this study, internationally recognized, two-dimensional surface roughness measurements were determined. In particular, center-line average, root-mean square, range, skewness, kurtosis, high 3rd, and low 3rd measures that are based on height and depth (i.e., amplitude) of asperities were calculated. Other measures based on spatial characteristics and combining both spatial and amplitude information can be used. Neese (59) summarized these measures and discussed the limitations of two-dimensional measures.

Perhaps the most commonly used roughness measure in the United States is center-line average (CLA or Ra). CLA is defined as "the arithmetic average of the absolute values of measured profile height deviations taken within a sampling length and measured from the graphical center line" (2,57,75). In general, it measures the average mean deviation from the center-line. Root-mean square average (RMS or R_q), a roughness measure somewhat related to CLA, was also used in this study. RMS is the root-mean-square deviation from the center-line (2). An advantage of using RMS over CLA is that if a center-line shift occurs, CLA may remain unchanged, while the shift would be reflected by a change in the RMS value (59).

Range represents the maximum peak-to-valley height (i.e., the vertical distance between the highest peak and lowest valley) and is more sensitive to extreme values amplitude changes along the area measured (2). Average range was the mean of all 33 range values found for the 33 scan lines. Skewness and kurtosis characterize surface roughness based on amplitude distribution (59). Skewness measures profile symmetry in respect to the center-line, while kurtosis gives a quantitative measure of profile randomness (2,6). Skewness values are equal to zero when symmetric profiles, containing equal numbers of peaks and valleys, are measured (59). Kurtosis values equal to three have a completely random surface (2). Values of kurtosis less than three indicate surfaces with few narrow peaks or valleys, while values higher than three are representative of more pointed peaks and valleys (59).

High 3rd value represents the mean of the third highest amplitude from the normalized mean line for each scan line. High 3rd maximum is the greatest high 3rd value of all 33 scan lines. Low 3rd represents the mean of the data points within each scan line with the third lowest amplitude from the normalized mean line. Low 3rd minimum was the smallest low 3rd value of all 33 scan lines.

3.4 Growth Rate and Annual Ring Orientation

With the availability of older slow growth logs diminishing, many plywood manufacturers are utilizing faster growth logs and peeling veneer closer to the core. The use of plantation trees and smaller diameter logs continues to dominate the industry. The advent of the spindleless lathe allows manufacturers to peel more veneer material near the log's core. In terms of log diameter, veneer roughness and lathe check depth is minimized at 10 and 12 inches diameter, while lathe check frequency and veneer thickness reached a maximum point (62). In general, it has been found that peel quality is reduced as you go from the log's sapwood to core material, due to factors such as lower specific gravity, highest growth rate, cutting speed, and highest angle of attack at the core material (62). When peeled into veneer, logs with slow uniform growth rate (i.e., balanced earlywood and latewood zones) exhibit shallow, numerous lathe checks (62).

Growth rate has a major affect in Douglas-fir veneer, which possesses considerable density differences between earlywood and latewood material (50). Research into the occurrence of shelling, the separation of earlywood and latewood that sometimes occurs in peeling veneer has been performed. Shelling occurred most frequently in veneer from fast grown material where earlywood was on the veneer surface and latewood present at a 7^0 angle (50). Douglas-fir veneer peeled from fast-grown logs resulted in occurrences of shelling, while in slow-grown veneer shelling was not present (50).

It has been noted that the best veneer was produced when peeling logs with growth rings orientated at 0^0 to the knife, while veneer quality decreased progressively as growth ring angle varied in either the plus or minus directions (15). Past research indicated that coarse grain, higher specific gravity veneer tends to check more significantly (i.e., more frequent lathe checks) than does fine grain, lower specific gravity veneer (4, 41). Lathe check depth was significantly less for faster grown material (16). Others have found that veneer peeled from lower density wood results in shallower lathe checks than veneer peeled from trees of a higher density (41). Smaller diameter logs are said to produce poor quality veneer because large tangential stresses are developed as the veneer sheet is bent (9). With slower grown trees, there are more growth rings per inch. When two or more latewood bands are present in veneer, lathe checks tend to stop at the first latewood band in from the knife (50). This occurrence produced shallower lathe checks. When fast-grown logs were peeled, deeper lathe checking resulted (50, 62). In terms of wood failure, when earlywood was present at the surface of the veneer, deep wood failure (i.e., away from the glue-line) occurred in plywood glue-bond specimens (50). When latewood was located at the surface, failure typically occurred at the glue-line where the latewood was present (50).

3.5 Fracture of Solid Wood

3.5.1 Microscopic Fracture in Wood

In softwoods, long slender cells called longitudinal tracheids comprise approximately 90% of the volume and provide the majority of wood's strength. Longitudinal tracheids are oriented parallel to the length of a tree and are several hundred times longer than they are in diameter. These cells are formed by microfibrils laid in layers to make up the cell wall. Chainlike molecules of cellulose, surrounded by hemicellulose, form larger microfibrils. A complete cell is commonly referred to as a wood fiber.

Within a microfibril, the cellulose molecules lay in two types of patterns. Where they lay in a parallel manner, the zone is referred to as the crystalline region. Amorphous regions are located within the microfibril where cellulose has no apparent arrangement. The structure of wood cells is divided into several layers. Individual wood cells are joined together in the compound middle lamella. The cell wall is usually comprised of three layers around the cell lumen (i.e., cell opening where water and nutrients move through the cell) denoted as the S1, S2, and S3 layers, with the S1 layer being outermost followed by the S2 and S3 layers, respectively. The S2 layer is the thickest and contains the greatest amount of cellulose. Cellulose microfibrils in the S2 layer are helically wound in a "Z" orientation, providing much of the wood strength.

Wood fractures molecularly in the amorphous, water accessible regions located in the cell wall, not in the crystalline regions (67). Those cell wall regions are also the most susceptible areas to changes in moisture content, temperature, and chemical interactions. Research shows three types of general fractures occur on a microscopic level in wood: transwall, intrawall, and intercellular (68). Under the transwall system, cracks may be parallel or transverse (perpendicular) to the longitudinal cell axis. Transwall fractures occur either longitudinally or transversely through the entire wood cell. Transwall fractures are common in thin-walled earlywood cells of softwood tracheids, hardwood vessel elements, and parenchyma cells. Longitudinal transwall fractures are uncommon in thick-walled latewood cells because of their high tensile strength parallel to the cell axis (68).

The second type of fracture, intrawall, occurs when a crack travels within the cell wall while leaving the cell lumen intact. This fracture initiates in the discontinuities between layers of the secondary cell wall (i.e., S1, S2, and S3 layers) (68). These discontinuities result from transition in microfibril orientation between layers within the cell wall. It has been shown that these cracks typically initiate at the S1-S2 interface in solid wood (53).

The third type of fracture, intercellular, occurs as cracks initiate and travel in the compound middle lamella (material joining individual cells together). This results in fracturing individual cells apart.

3.5.2 Macroscopic Fracture in Wood

On a macroscopic scale, the types of fracture vary with density of the wood substance through which the crack propagates. Three types of stress fields in wood are defined at the crack tip opening: opening mode (I), forward shear (II), and transverse shear (III). Wood exhibits distinct properties in each of its three principal orthogonal directions: longitudinal (L), radial (R), and tangential (T). A crack may lie in one of these three planes and propagate in one of two directions in each plane, resulting in six crack propagation systems: RL, TL, RT, TR, LR, LT (80,81). The first letter denotes the axis perpendicular to the crack plane, while the second letter denotes the direction of crack propagation. The TL and RL orientations will likely predominate because of wood's low strength and stiffness perpendicular to the grain (81).

3.5.3 Crack Propagation in Wood in the TR & RT Direction

In this study, macroscopic fracture was investigated. Research suggests that when veneer is peeled and lathe checks are produced, the cracks (lathe checks) typically propagate toward a pure TR direction (i.e., normal to the tangential direction and propagating in the radial direction)(7). In that study, it was determined that all lathe checks present in a glue-bond specimen propagate toward a TR direction. The researchers also felt that it was likely possible that the most critical or controlling lathe check propagates in a TR direction, while remaining checks, propagating in other directions, influence the failure pattern of glue-bond specimens. Of particular interest were cracks propagating in the RT direction (i.e., normal to the radial direction and propagating in the tangential direction). When cracks are propagated in an RT direction, stresses in tension that act parallel to wood's radial orientation cause cell wall fractures that exhibit step-like rough surfaces (18). RT crack propagation tends to occur within thin-cell walled earlywood because strength under this condition is controlled by cell wall thickness (18). When a crack is aligned at a 45^0 angle from the RT path, three distinct stages occur. First, the crack follows a direction perpendicular to loading and ruptures cells and middle lamella material. As a crack approaches an earlywood/latewood boundary, it causes pure cell wall rupture within the earlywood and then rupture of the middle lamella in the latewood layer (18). This step-wise pattern is exhibited during formation of some lathe checks. It also provides insight into how a lathe check oriented at a 45^0 angle to a latewood band may propagate.

Cracks oriented in the TR plane either exhibit a flat or slightly step-wise fractured surface when propagated (70,77,78). Such crack propagation begins at the crack tip (29). It is reported that TR cracks grow in an unstable fashion and tend to deviate from their original plane during growth. When growing, TR cracks advance in the radial direction and pass through sequential layers of latewood and earlywood. Cracks often exhibit a "stick slip" means of propagation, as they frequently change directions while extending through the growth rings (77). "Stick slip" refers to the process of primary (i.e., initial) crack arrest in the earlywood, followed by a new (i.e., secondary) crack forming in the latewood just ahead of the crack tip. Bridging material between the primary and secondary crack fails, resulting in one crack.

TR cracks growing through earlywood and latewood layers typically propagate by separation of the middle lamella. In doing so, no tearing of the cell wall occurs. Since the cell walls are not torn, there is low crack propagation resistance for TR cracks (78). Tracheids, being well aligned in rows in the radial direction, allow for crack propagation in the middle lamella to have an almost straight path through both the earlywood and latewood layers. Even with this alignment, however, studies have shown that TR cracks change directions and form along new planes as they pass between earlywood and latewood layers. When cracks begin in earlywood layers, the growth rate decreases, and may stop if not loaded further. When further load is applied, cracks will propagate through the denser latewood layer in an unstable fashion and may again stop in the earlywood if the loading is not increased (78). This process will repeat again as new growth rings are encountered.

Research suggests that as cracks travel in the earlywood region near latewood, the latewood is heavily stressed. This stress can result in secondary cracks in the latewood. As loading increases, high stresses lead to secondary cracks extending and bridging material failing, resulting in a single connected crack (76). Large stiffness variations in growth rings are linked to high stress seen in latewood during secondary crack formation (78).

Plywood lathe checks do not always form in a purely radial direction. When cracks are introduced at an angle (inclined crack) with respect to the radial direction, they tend to deviate toward pure radial growth (7). Thuvander and Berglund (78) report that formation of a secondary crack in the latewood layer, ahead of an inclined crack, causes changes in direction toward a pure TR mode for continued crack growth after propagation through a latewood layer (31,76). The angle of the inclined crack is maintained until the first latewood layer is reached, and typically is a combined separation of the middle lamella and the cell wall. As the crack approaches a latewood layer, it is arrested, and further loading results in secondary crack formation in the latewood in a pure radial orientation. The crack direction then becomes pure radial when the primary crack is stopped in the earlywood, and the secondary crack propagates in a pure TR mode (78). This type of crack deflection is caused by differences in fracture toughness between an inclined crack and a pure radial crack (3).

3.6 Adhesive Wood Joints

3.6.1 Fracture of Adhesive Wood Joints

Proper adhesive wood joints are intended to cause failure in the wood material rather than the adhesive. Therefore, the adhesive must exhibit a high degree of toughness to achieve this. In general, fracture of wood adhesive joints starts with crack initiation at a discontinuity where displacement of the adherends creates the greatest stress concentration and where either the adherend or adhesive is the weakest. Examples of geometric discontinuities in adhesive-bonded veneers can be found at voids in the adhesive layer or voids in the veneer (e.g., rough veneer pockets and lathe checks). An example of a material discontinuity is two different types of wood species with different densities and species dependent properties (68). Due to the inherent variability of wood, some material discontinuity is expected, even when using the same species as adherends. Other material discontinuities include the interface between adherend and adhesive of differing moduli, widely different densities of earlywood and latewood bands, and the transition zone between the low fibril angle S1 and high fibril angle S2 layers in the cell wall. In the case of plywood, individual veneer ply orientation between adjacent layers also represents a material discontinuity.

Research indicates using an adhesive that can penetrate the cell wall results in higher fracture strength in the vicinity of the S2-S3 layers interphase (68).

3.6.2 Crack Propagation in Adhesive Bonded Wood Material

For this study, lathe check presence represents an apparent discontinuity in the adhesive wood joint. Cracks propagate in wood adhesive bonded material in various ways once initiated. The crack can propagate and cause unstable failure, it can propagate in moderate increments of growth with arrest points (stable/unstable), or it can fracture by continuous tearing in small increments. The ideal fracture mechanism in wood adhesive joints requires high crack initiation energy and stable crack growth. For complete failure, an ideal joint requires a great amount of energy (i.e., a strong/stable crack growth). Adhesive bonded wood material exhibits all of these behaviors. If the adhesive is improperly formulated, applied, or cured, the adhesion strength may be lower than the cohesive strength of the wood. When this occurs, the crack will exhibit low initiation energy and will grow in a stable manner in the weaker adhesive layer or joint interface. The crack initiation and arrest energies will be, for all practical purposes, equal. The crack will not deviate from the plane of the wood surface and will produce shallow wood failure (68).

Stable/unstable (i.e., “stick slip”) crack growth occurs when an adhesive is properly cured and applied and the grain direction of the wood is directed toward the bondline. Because weak planes are oriented toward bondlines and adhesives are stronger than wood, a crack is forced to propagate toward the bondline. The crack will travel in the wood near the interface and, in some instances, cross the bondline with moderately high crack initiation energy. As the wood joint is loaded, some energy will be stored in elastic deformation of the wood and adhesive, and some in plastic deformation and microcracking in wood surrounding the crack tip. The crack will likely stop in the wood adherend with lower density. When stored energy reaches a critical level, rapid crack propagation occurs. The failure will likely be shallow in the wood adherend, but may be deeper in lower density wood (68).

Strong/stable crack growth occurs with a tough adhesive that establishes good adhesion to the wood adherends. Furthermore, the wood adherends' surfaces have to be sound and the grain angle of the wood parallel or away from the bondline. Under these conditions, the crack will deviate into the wood, rather than toward the wood/adhesive interface. When this occurs, wood strength determines the fracture toughness of adhesively bonded wood composites. The fracture plane likely will follow the grain angle of the wood and produce a deep wood failure. The crack advances by transwall cracking of the thin-walled cells and intrawall or diagonal transwall cracking of the thick-walled cells. This type of fracture mechanism is the desired mode when producing a wood adhesive joint (68).

When a crack initiates in the center of an adhesive layer of an isotropic material adherend, it tends to propagate through the center of the adhesive layer. This is not the case in wood, an anisotropic material. The tendency in wood adhesive bonded joints is for the crack to travel in the wood near the joint. First, the crack will propagate toward one or another adherend, if it has a lower modulus than the adhesive, which is the case in most thermosetting adhesives. Second, inequality between the modulus of the two wood adherends induces unequal shear stress around the crack tip in the adhesive and directs the tip toward one of the adherends. Once the crack enters the wood, it travels along the weak RL (radial-longitudinal) and TL (tangential-longitudinal) planes. If the fiber direction of both adherends is orientated toward the bondline, the crack will be forced to remain close to the adhesive layer and travel along the weaker adherend. In cases where one wood adherend has earlywood at the interface and the other adherend has latewood at the interface, it is not uncommon for the crack to travel along the denser latewood adherend. Because adhesive penetrates earlywood better, the resulting bond with earlywood adherends will be more efficient and the crack will tend to grow along the latewood adhesive interface (68).

3.6.3 Measurement of Fracture Energy in Wood Joints

Fractures begin as a flaw or crack in a material. In adhesively joined wood, this initial flaw could be a discontinuity that is a void or change in material properties around the joint. Also, an adhesive may contain air bubbles that cause voids in the adhesive layer. Fracture occurs when the stress at a crack or discontinuity reaches the ultimate strength of the adhesive, the adherend, or the interface. Typically, in describing the critical stress, the critical stress intensity factor (K_{1c}) of a wood adhesive joint is difficult to define because of the dissimilar materials present in the joint. Therefore, the sensitivity of adhesive joints to stress and discontinuities is measured in terms of energy required to initiate the crack or energy released in forming a new crack surface (68). The critical intensity factor and critical strain energy are related in the following equation (68):

$G_c = K_c^2/E\,(1 - v^2)$ where: G_c = critical strain energy

E = tensile modulus of the adherends

v = Poisson's ratio of the adherends

K_c = critical intensity factor

In this study, the adherends will be Douglas-fir veneer; therefore, in a deterministic approach the tensile modulus and Poisson's ratio will be considered equivalent for each adherend. This being the case, the critical stress intensity factor (K_{1C}) is defined in general by the following equation (8):

$$K_{1c} = \sigma_f (\pi a)^{1/2}$$

where: σ_f = fracture stress, a = ½ crack length

The formula for determining K_{1c} had been calculated various ways (1,65,70,79). One similarity in these calculations is inclusion of crack length in the formula. In terms of the plywood glue-bond test, this would be the length of the lathe check that ultimately causes specimen failure.

3.7 Adhesive System

3.7.1 Phenol Formaldehyde Adhesive Toughness

Without sufficiently strong adhesives for bonding wood members together, the structural wood composite lumber and panel industries would not exist. The function of an adequate adhesive used for joining wood materials is to provide sufficient strength to cause fracture within the wood adherends. The most prevalent adhesives used in structural wood composites are thermosetting adhesives, which require heat for curing. The main adhesive system for structural plywood is phenol formaldehyde, so its fracture toughness is important. Phenol formaldehyde adhesive, when cured, is waterproof. Curing of phenol formaldehyde adhesives normally occurs above 220 ^{0}F (5).

Fracture toughness (crack initiation energy) of wood can range from 50 to 1000 J/m^2, while the fracture toughness for thermosetting adhesives can range from 100 to 300 J/m^2 (38). It is reported that the fracture toughness of wood bonded with thermosetting adhesives has a fracture toughness of approximately 100 to 300 J/m^2, but much higher toughness can be achieved if plasicizers and fillers are added to the adhesives. High Mode I fracture toughness for wood adhesive joints is attributed to a reduction in microcracking of wood around the crack tip and adhesive plastic deformation. A flexible adhesive layer distributes concentrated stress on a wood joint over a large area and lowers the level of peak stress. This is most evident in thick adhesive layers, which may inhibit microcracking in the adjacent wood cells. Reduction of microcracking is evident in a lower percentage of wood failure in a tested specimen (68). Because of the geometry of the plywood glue-bond specimen, fracture of the adhesive layer is most likely a combination of Mode I splitting and Mode II forward shear direction. Research does give some insight into the plastic deformation characteristics of phenol formaldehyde adhesives (66).

During wood adhesive joint preparation, wood picks up moisture from the adhesive and expands the wood material. As the adhesive bond cures, the wood has a tendency to shrink and cause cracking in the adhesive layer. Phenol formaldehyde shows a higher degree of plasticity and directionality, both of which suggest an adhesive layer that is strong and tough. When cured, an adhesive joint with phenol formaldehyde does not crack as a result of shrinking stresses, and therefore, has been shown to arrest crack growth (66). Discontinuities (i.e., cracks) will likely not develop in a phenol formaldehyde adhesive layer when veneers are manufactured into panels.

3.7.2 Adhesive Spread Rate

Faust and Borders (24) performed research on glue application rates to control glue-bond strength. They looked at a variable application rate strategy (VARS) to determine the amount of adhesive to use in manufacturing southern pine plywood while taking into account moisture content, veneer temperature, veneer roughness, and assembly time (23,24). The results of their second study (24) indicated that VARS resulted in a higher average wood failure percentage than the constant application rate (CAR), while consuming 13.1 percent less adhesive. They found significant two and three-way interactions between the main effects; therefore, differences in the main effects were somewhat misleading (24). As a result, it was not possible to conclude what effect an increase in glue spread had on glue-bond performance, based on veneer roughness only.

3.8 Optical Scanning Techniques

An optical scanning system can be used to evaluate lathe check characteristics and monitor lathe check propagation. Thuvander et al. (77) described an electronic speckle photography (ESP) method used to measure crack tip strain fields in wood. In their studies, a CCD-video camera, connected to a frame grabber, collected images of a random pattern present on the wood. The pattern can be produced on the surface of the wood by illuminating an object with a laser, painting the surface with a retro-reflective paint, or attaching carbon particles (e.g., photocopy toner). Also, in some instances, the surface of the object itself is sufficient. Motion estimation is important in image analysis and the techniques are classified into three groups: pixel-recursive techniques, character tracking, and block matching (77). In their particular study, they used block-matching techniques because of the high resolution and noise tolerance.

Other researchers have also used video cameras in order to quantify progressive movement of crack propagation (10,11,72). In those studies, images were obtained at intermediate steps prior to crack propagation until total failure. For cases where failure typically occurs quickly when the critical stress is reached, it is necessary to employ a high speed-framing camera, or a video camera, to observe the failure. In a study by Grady and Sun (32), a high speed FASTAX framing camera captured 1,600 frames per second as a graphite/epoxy laminate was subjected to impact loading. Other methods of measuring crack propagation include the use of scanning electron microscopes (SEM) (1, 82), but that method is not practical for the plywood glue-bond tests.

3.9 Glue-bond Testing Techniques

3.9.1 Test Methods Under Industry Product Standards

U.S. Voluntary Product Standard PS 1-95, Section 6.0 (83) outlines procedures for preparation and testing of plywood glue-bond specimens. PS 1 provides various methods dependent upon the intended use and exposure rating of panels being tested. In this study, exterior type adhesive was used. Section 6.1.5 of PS 1-95 (83) indicates that both vacuum-pressure tests and boiling tests are performed on manufactured plywood with exterior glue. In general under PS 1-95, the pass/fail glue-bond quality criterion for exterior panels is an average 85% wood failure on the samples tested. There is no provision for a minimum strength requirement. Other standards such as European Standard EN 314-2 (19) and Japanese Agricultural Standard SIS-8 (35), use both wood failure and strength requirements in judging glue-bond performance.

Glue-bond specimens are prepared to test 1-inch square areas in each glue-line present in a panel. Figure 3.4 provides an illustration of the 3-ply, 3-layer plywood glue-bond specimens prepared in this study. Saw kerfs are made to extend approximately two-thirds through the center ply.

PS 1 outlines two different procedures for sample conditioning. Samples are tested after being subjected to a vacuum pressure cycle and after a boiling test cycle. However, dry samples have also been tested in the past. Past research shows that dry and 24-hour cold soak tests result in higher percent wood failure than vacuum pressure, boil-dry, ice-boil, and cycle cold soak tests (12). Also, dry samples resulted in the highest load at failure between test methods (12).

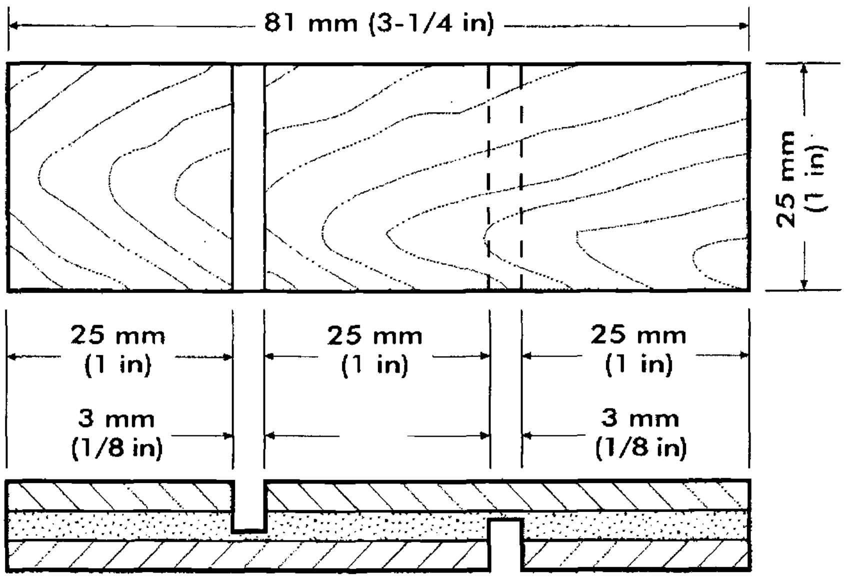


Figure 3.4. Bond durability specimen as outlined in PS 1 (82).

Dry condition samples are tested in a dried state with no cyclic or boiling conditioning. Wet samples are conditioned in accordance with boil test procedures outlined in PS 1 (83) by boiling them in water for 4 hours. Following this, the samples are dried for 20 hours in an oven at 145 ^{0}F, boiled again for 4 hours, cooled in water, and tested wet. In accordance with PS 1, specimens are tested in a machine that applies tensile loading at a maximum rate of 16 inches per minute and grips the specimen so no slippage occurs.

3.9.2 Pulled "Open" versus Pulled "Closed" Test Methods

One variable that PS 1 does not address is lathe check orientation in the test area. Samples can be prepared such that lathe checks located in the test veneer are either pulled open or closed during testing. Differences exist in standard industry practice involving specimen kerfing. Figure 3.5 illustrates the different kerfing method for performing either "open" or "closed" testing. Studies comparing "open" versus "closed" methods indicate a greater amount of wood failure was observed when the lathe checks were pulled "open" in wet shear specimens than when they were pulled "closed" (41). In the case of wet-shear strength, specimens pulled "open" exhibited 25 to 39 percent more strength than those pulled "closed" (41,42). Other research, however, indicates that specimens tested "closed" result in a higher strength than when pulled "open" (37,61).

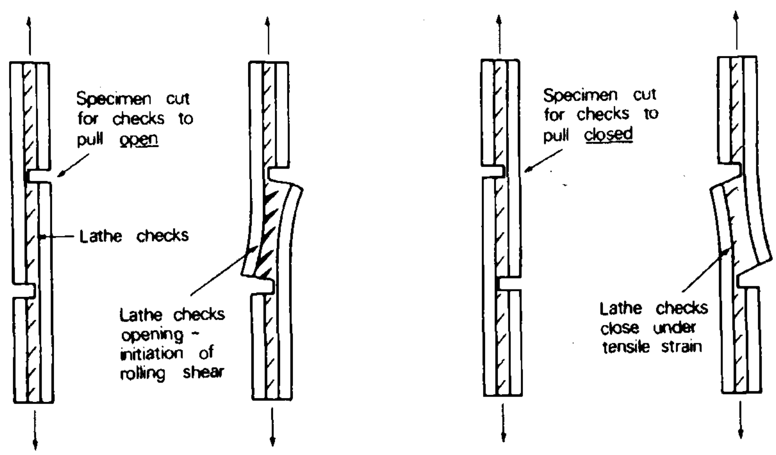


Figure 3.5. "Open" versus "closed" sample kerfing methods (72).

3.9.3 Evaluation of Saw Kerfed Glue-bond Specimen Test

It has long been industry practice to determine glue-bond adequacy by using saw-kerf samples as outlined in Figure 3.4. In fact, standards in the United States, Europe and Japan currently use saw kerfed specimens to determine glue-bond quality. Under the European and Japanese standards, both glue-bond strength and wood failure results are evaluated. Under PS 1, only percent wood failure is examined for construction and industrial plywood glue-bond testing. Excessive lathe checking has been shown to result in weakened veneer, so some feel that a strength test is required (12). If wood failure is used as the criteria, adhesive bonds should have strength equal to or greater than the strength of the veneer (85). A sample may have a very high strength and fail at the glue-line, while another sample may have very low strength and have a high percent wood failure due to failure within a veneer weakened with many lathe checks (85). Once failure is initiated in the wood, it will tend to follow the wood material and result in high percent wood failure but may occur at a low load (85). The question becomes which sample is better, the one with high strength and lower percent wood failure, or the one with low strength and high percent wood failure?

Past studies concluded that saw-kerfed plywood glue-bond samples did not provide an absolute measure of glue-bond strength, but only offer comparisons (85). These tests tend to create excessive stress in the wood material rather than at the glue-line, while in many in-service conditions, stresses are concentrated at glue-lines (54). One study performed by Yavorsky et al. (85), investigated variables affecting results when using saw-kerfed specimens and how stresses are concentrated in the samples. They found that plywood glue-bond specimens have built in moments and that slight mis-machining can significantly change the types of stresses placed on the samples. They indicated that variation in test values result from: eccentricity of specimens, depth of notch or groove (i.e., saw kerf), slope of grain in the veneer, and lathe check orientation (85). At the saw kerf, there are tearing or tensile stresses normal to the glue-line and a slight amount of shear stress. The rest of the sample is subjected to tensile and compressive stress, while the plane of the adhesive joint is free from shear stress (85).

They also found a large component of shear stress, not at the glue-line, but rather in the plane of the core veneer under stress (85). Low shear modulus across the grain in wood resulted in a large shear strain component. Any variation in wood shear modulus because of anatomy and lathe check presence exerts a definite affect on shear strain (85). Stress concentrations at the saw kerfs were shown to form initial cracks at these locations at low loads, while the center test region remained crack free until higher loads were applied (85). Since wood has a relatively low tension perpendicular to grain strength, failure initiates at the saw kerfs due to tensile or tearing (i.e., peeling) forces. In addition, the amount of bending at the notches is controlled by the elasticity of the face and back veneers (85). In 1955, Yavorsky et al. (85) identified a need for a better method to test glue-bond quality that places shear stress at the glue-line. To date, no other acceptable test methods for determining plywood glue-bond quality has been developed and/or used by industry.

4. PRELIMINARY STUDY

4.1 Preliminary Procedures

Prior to the primary study, a preliminary study was performed to determine:

1) Suitable optical imaging techniques for measurement of lathe check characteristics and monitoring of lathe check propagation during testing.
2) Whether glue-bond specimens should be pulled in tension to cause lathe checks to open or close (i.e., "open" method vs. "closed" method).
3) Whether glue-bond specimens should be tested in a dry condition or wet (boiled) condition (83).
4) Differences in lathe check propagation between "open" and "closed" specimens.
5) Provide insight into which lathe check characteristics appear to be important to glue-bond failure, thus requiring measurement in the primary study (e.g., depth, frequency, area, crack tip angle in respect to the annual ring, crack tip angle in respect to the glue-line, etc.).

4.1.1 Preliminary Study Samples

A plywood panel was purchased from a local lumber supplier. All specimens were prepared from the same panel in order to produce samples with similar characteristics. For purposes of developing a suitable optical imaging system, 3-ply, 3-layer plywood samples of Douglas-fir plywood were processed into standard bond durability specimens. The sample size was large enough to ensure development of an adequate optical imaging system. For purposes of determining whether to test primary study samples using "open" or "closed" methods and a dry or wet conditioning, 120 blanks were cut from a Douglas-fir plywood panel and kerfed accordingly to produce n=60 open and n=60 closed specimens.

4.1.2 Glue-bond Testing Device

A testing device was needed to apply a tensile load to the plywood glue-bond specimens and provide sufficient gripping of the specimen so no slippage occurs. A TECO-Mater Shear Testing Machine, as shown in Figure 4.1, was modified from its original state to allow for visual monitoring of both test area edges. Also, modifications were made to better control the speed of testing and to add both a pressure transducer and pressure gauge to measure load. An LVDT was mounted to measure head movement during testing.

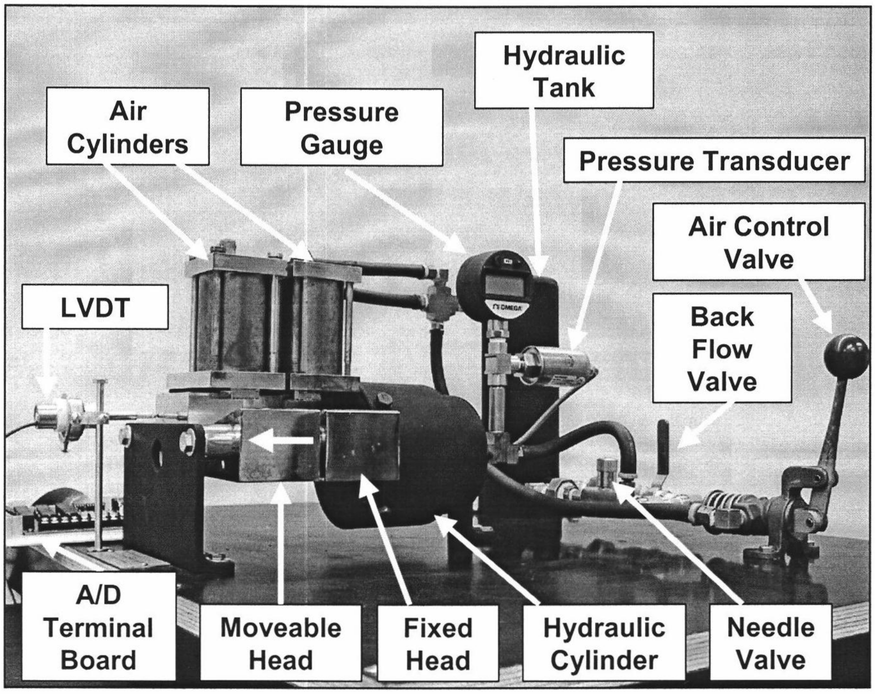


Figure 4.1. Modified TECO-Mater glue-bond test machine.

4.1.3 Optical Imaging Technique Development

For initial determination of whether or not lathe checks can be monitored while under stress, a Pulnix TM-7CN black and white camera was mounted to collect images of the test area. The TECO-Mater Shear Testing Machine was used to pull the samples in tension while one edge was monitored. The camera was connected to a PC via a Targa frame-grabber to collect images of the cross-section surface between the saw kefs at the rate of 30 frames per minute. An incandescent light source was used to illuminate the edge surface. The camera captured an area of 512 by 512 pixels, thus resulting in a resolution of 0.002 inch per pixel. Using proprietary software developed at Oregon State University, the images were analyzed to determine the system's capability of capturing enough frames to monitor the lathe checks as they were placed under stress. After viewing the captured images, it was evident that this system did not adequately capture enough frames during the final failure phase to determine how failure occurred, so a digital video camera system was employed.

The digital video camera system consisted of two Sony digital video cameras (Model #: DCR-TRV27 and DCR-TRV20) as shown in Figure 4.2. One camera was mounted in the front and one in the back of the test machine. While the specimens were being tested, the cameras recorded video of both edges to digital videotapes.

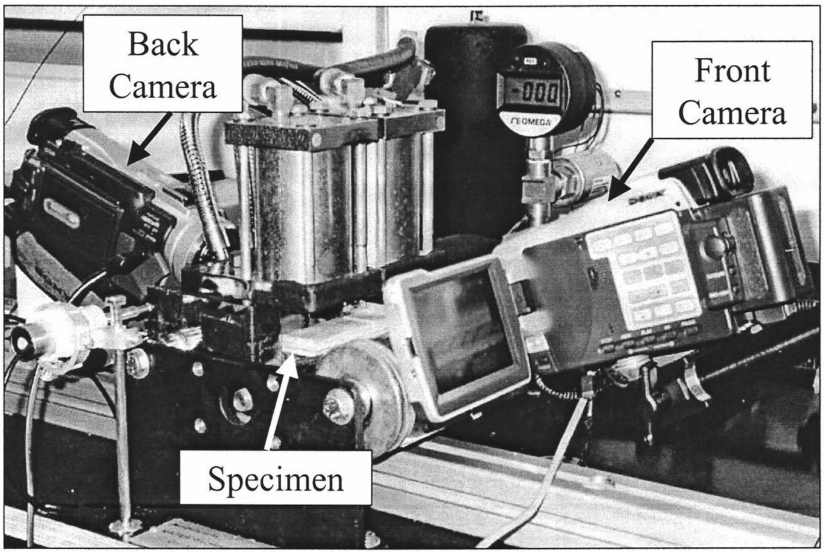
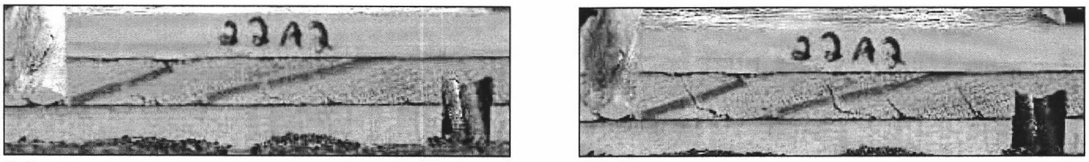


Figure 4.2. Digital video camera system setup.

The resulting videos were downloaded to a computer and Jet Audio software (capable of outputting four frames per second) was used to play, freeze, and capture images. Examples of images that the final digital video camera system can produce of the test area are illustrated in Figure 4.3. The resulting spatial resolution was 0.005 inches per pixel. The resolution was less than the first system, but the ability to capture images faster was greatly increased.



(a) (b)

Figure 4.3. Examples of optical imaging system output; (a) "open" specimen before loading, (b) specimen during loading showing lathe checks opening.

The optical system monitored the cracks throughout the testing. The critical factor was developing a system capable of capturing images fast enough when the lathe checks reached their critical stress intensity and propagated to failure, which primarily occurred in the last one second of the test. This was important for determining the sequence in which individual checks propagated and how failures occurred. The final system was capable of capturing lathe check crack propagation modes and allowed for determining various lathe check characteristics.

4.1.4 Open vs. Closed and Wet vs. Dry Test Preparation

Open and closed tests in both wet and dry conditions were performed to determine differences in load and percent wood failure between methods. Also, general information was obtained in regard to how lathe checks propagate under each system. Out of 120 specimens (60 open, 60 closed), half of the open samples and half of the closed samples were tested in a wet condition and the other half in a dry condition. This resulted in 30 specimens per test condition combination. Once the specimens were prepared, they were tested in a modified TECO-Mater test machine as shown in Figure 4.1.

Using the digital video camera system, lathe checks were monitored while a constant load was applied to the specimens. The rate of loading was 0.01 inches per minute. Upon completion of testing, the digital videos were downloaded to a computer for viewing. Ultimate load was recorded for each specimen, and percent wood failure readings were provided by two different accredited certification agencies. In order to test for differences in percent wood failure readings by a single person, at one agency, one individual read the percent wood failure two times on the same samples. The readings were performed months apart and without the individual's knowledge that they were the same samples previously read.

4.1.5 Important Lathe Check Characteristics

This part of the preliminary study provided insight into what important lathe check parameters needed to be measured in the primary study. The preliminary testing provided data to give some insight into which lathe check characteristics play an important role in check propagation under each testing scenario (i.e., open vs. closed and dry vs. wet). It was also used to determine differences in lathe check propagation between the test scenarios and investigate the observance of lathe checks opening or closing.

4.2 Preliminary Study Test Results

4.2.1 Open vs. Closed and Wet vs. Dry Test Results

A summary of test results for load at failure and percent wood failure readings of all four groups of samples investigated during the preliminary study are outlined in Table 4.1. Percent wood failure results listed are from the first certification agency that read the samples. Figure 4.4 provides a box and whisker plot of load at failure for the four test cases.

Table 4.1. Preliminary study results summary of load at failure and percent wood failure for wet open, dry open, wet closed, and dry closed samples.

	Open Samples				Closed Samples			
	Wet		Dry		Wet		Dry	
Variable	Load at Failure (lbs.)	Wood Failure (%)	Load at Failure (lbs.)	Wood Failure (%)	Load at Failure (lbs.)	Wood Failure (%)	Load at Failure (lbs.)	Wood Failure (%)
Sample Size	30	30	30	30	30	30	30	30
Average	141.5	85	245.0	88	211.3	87	284.4	91
Variance	401.8	309	1365.7	370	720.0	452	2647.4	381
Standard Deviation	20.0	18	37.0	19	26.8	21	51.5	20
Coefficient of Variation %	14.2	20.7	15.1	21.8	12.7	24.6	18.1	21.5
Minimum	106	45	176	25	169	15	152	15
Maximum	182	100	326	100	271	100	362	100
Range	77	55	149	75	102	85	210	85

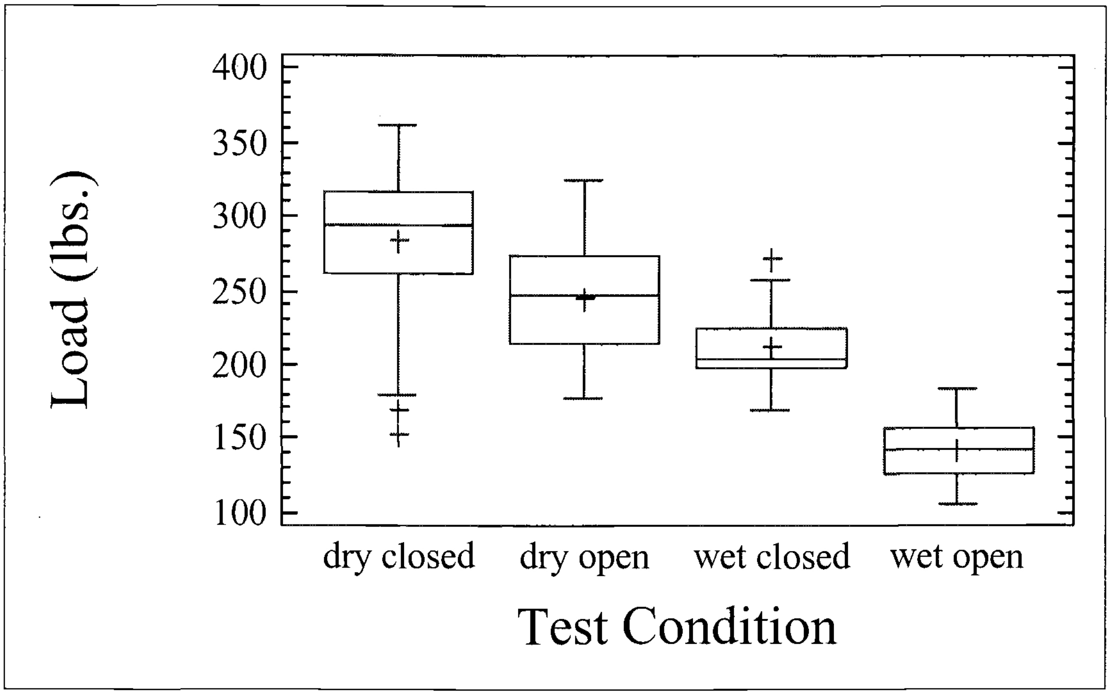


Figure 4.4 Box and whisker plots of load at failure results for dry closed, dry open, wet closed, and wet open samples.

A two-way analysis of variance (ANOVA) test performed on the load at failure results indicated that each factor (i.e., wet or dry conditioning and open or closed lathe checks) had a statistically significant influence in load at failure, as did the interactions of factors (Table 4.2). Further analysis of the interactions using multiple range testing indicated a statistically significant difference between all four groups. In terms of load at failure, dry closed exhibited the highest average load value, followed by dry open, wet closed, and wet open, respectively.

It was clear from the statistical tests that closed samples resulted in a higher average load at failure than open samples and that dry samples exhibited a higher average load at failure than wet samples. With these relationships established, it was determined that testing could be performed for load at failure under any of the individual test conditions, yet it would still be possible to determine whether the same samples tested under a different test condition would result in a higher or lower load at failure. This is important because it allows for testing in a dry state and then relating results back to wet samples that are used under current plywood product standards. Also, PS-1 does not provide any requirements for testing specimens such that lathe checks open or close. This information allows for saw kerfing specimens to open or close lathe checks and then relating the results back to the opposite configuration.

Table 4.2. ANOVA test results for factors of wet vs. dry and open vs. closed on load at failure.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-value
A: Wet/Dry Condition	233854.0	1	233854.0	182.17	0.0000
B: Open/Closed Condition	89314.7	1	89314.7	68.57	0.0000
A*B Interaction	6949.5	1	6949.5	5.41	0.0217
Residual	148914.0	116	1283.7		

Percent wood failure readings were performed by single individuals at two separate certification agencies. Using percent wood failure results from the first certification agency, a two-way ANOVA test indicated that each factor (i.e., wet or dry conditioning and open or closed lathe checks) did not have any statistically significant influence on percent wood failure nor did the interactions (Table 4.3). In addition, multiple range testing indicated no statistically significant difference between all four groups. Reasons for this can be seen in a box and whisker plot of percent wood failure for all four groups as read by the first agency (Figure 4.5). The means are clearly not significantly different, but the variances appear to increase from dry to open and from closed to open. With these relationships established, it is possible to conclude that the same samples tested under a different type of conditioning would result in no statistical difference in percent wood failure. This again is important because it allows for testing in a dry state and feel confident that percent wood failure results would not be statistically different if tested using wet samples as is done under current plywood product standards. In addition, it showed that specimen configuration to open or close lathe checks had no effect on percent wood failure results.

Table 4.3. ANOVA test results for factors of wet vs. dry and open vs. closed on percent wood failure results from the first certification agency.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-value
A: Wet/Dry Condition	440.8	1	440.8	1.17	0.2822
B: Open/Closed Condition	140.8	1	140.8	0.37	0.5426
A*B Interaction	3.3	1	3.3	0.01	0.9253
Residual	43815.0	116	377.7		

Multiple range tests on average percent wood failure readings from the second certification agency showed no statistically significant difference between the groups with the exception of dry closed which was different from all groups except dry open. An explanation for this occurrence could not be positively identified, but was attributed to differences between individual evaluators.

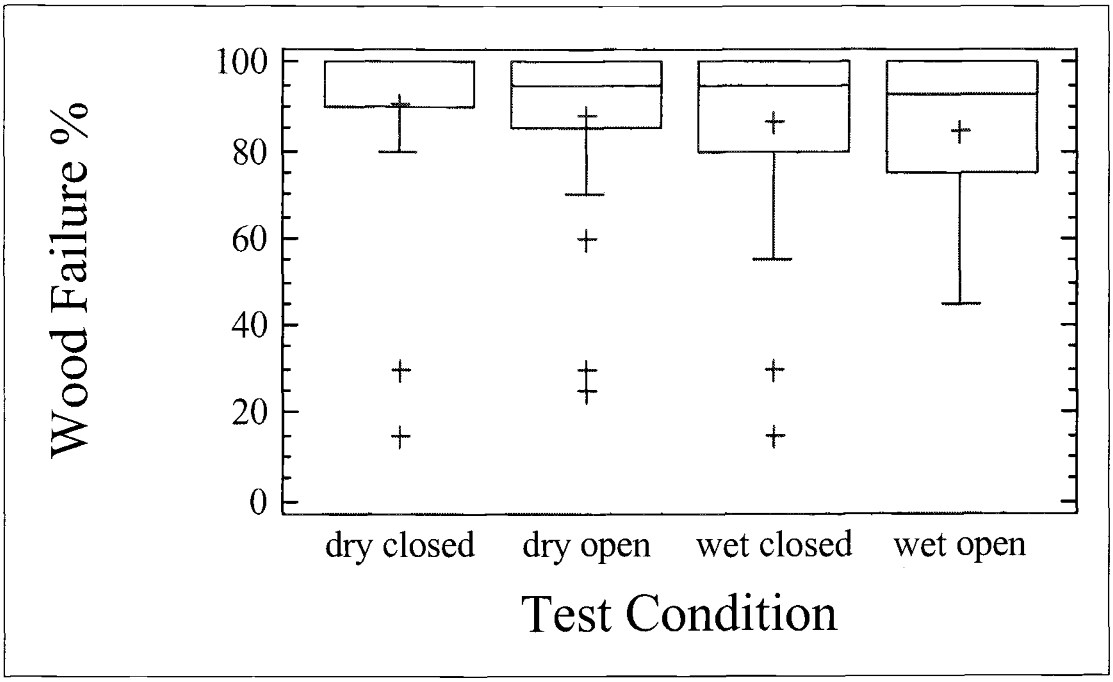


Figure 4.5 Box and whisker plots of percent wood failure results from the first certification agency for dry closed, dry open, wet closed, and wet open samples.

To test the repeatability of percent wood failure readings by a single individual, the samples were read by the same evaluator at the first agency. The readings were performed months apart without the individual's knowledge the samples had been previously read. Results are shown in a box and whisker plot (Figure 4.6). Results of a paired sample t-test showed that there was no statistically significant difference (p-value = 0.3122) between each reading by the same individual. Paired sample t-tests were also performed on readings separated by groups. Again, there was no statistically significant difference found between readings for any of the groups. These results indicate that readings from one individual are repeatable.

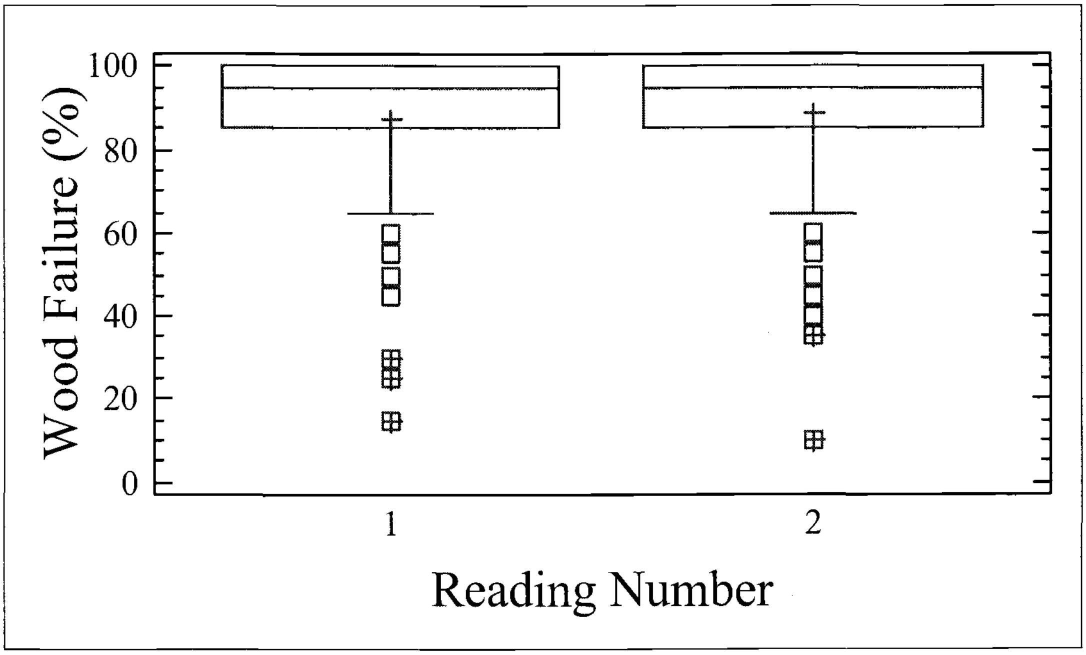


Figure 4.6. Box and whisker plots of percent wood failure readings for preliminary study samples read twice by the same individual.

4.2.2 Important Lathe Check Characteristics Results

Using the preliminary test videos, comparisons of lathe check cracks opening or closing during testing were made. In samples prepared for "open" tests, lathe checks were observed to be opening and propagating, thus causing specimen failure. This occurred in both the wet and dry samples. However, due to wood surface discoloration as a result of boiling the samples for the wet tests, it was much harder to visually identify the lathe checks in the wet samples. This was viewed as being undesirable for the primary tests. In "closed" tests, no checks appeared to open; rather, if they were already closed, they stayed closed and if slightly opened, they closed when the sample was placed under stress. No noticeable crack propagation was observed under the closed system, thus making this mode undesirable for the primary test. In viewing digital video from "open" tests, it appeared that lathe checks near the saw kerf appeared to open and propagate before checks located in the center of the test area. In particular, the lathe check oriented towards and closest to a saw kerf appeared to open and propagate first. From the preliminary study videos, the following lathe check characteristics were established as measurements that needed to be made in the primary study.

- Lathe check frequency (checks per inch)
- Average lathe check depth
- Average lathe check angle in respect to glue-line
- Distance of lathe check crack tip to saw kerf of the closest two lathe checks angled toward the saw kerf
- Actual length of closest two lathe checks angled toward the saw kerf
- Distance of lathe check origin to saw kerf of the closest lathe check angled toward the saw kerf
- Depth of closest lathe check angled toward the saw kerf
- Angle of closest lathe check angled toward the saw kerf

4.2.3 Determination of Primary Study Test Conditions

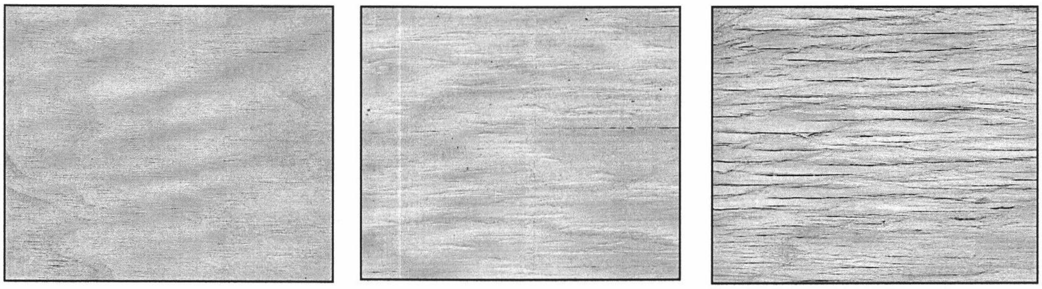
From the preliminary study results, it was determined that dry-open specimens would be used during the primary study. While a relationship was found between ultimate load at failure and the various test conditions, one can determine whether the ultimate load of these specimens tested under another condition would be higher or lower. In terms of percent wood failure, no significant statistical difference was found between any test method, with the exception of one agency's readings for dry closed. It was determined that by testing with open samples, percent wood failure results would not be statistically different when using another method. Also, open tests provided the most useful information on crack propagation as checks visibly opened. When using dry specimens in the open mode, overall image quality was significantly better, as was the ability to locate and measure lathe checks and follow the crack propagation mode.

5. PRIMARY STUDY PROCEDURES

Once the sample conditioning method, testing device, digital video camera system, and important lathe check characteristics were identified and tested in the preliminary study, the primary portion of this study was initiated. In this portion of the study, veneer surface roughness, lathe check, and annual ring characteristics were measured to determine their effects on plywood glue-bond quality. In addition, lathe check crack propagation modes were explored and influences of measured veneer characteristics on the elasticity property of plywood glue-bond specimens determined.

5.1 Veneer Selection

Veneer was selected from three local plywood manufacturers. The veneer used was dried, 1/8-inch rotary peeled Douglas-fir (*Pseudotsuga menziesii*) selected from A, B, C and D-grade sheets. The veneers were divided into three roughness categories of smooth, intermediate or rough, based on visual characteristics of the sheet as defined in PS 1-95 (83). Broken grain and splits were not included in the veneer population. Smooth veneer was free from surface characteristics that would prevent the veneer from being sanded smooth. Rough veneer was defined as veneer exhibiting considerable peaks and valleys that prevent the veneer from being sanded smooth. Veneer of intermediate roughness was defined as veneers exhibiting surface characteristics common to both rough and smooth veneer but not dominated by either characteristic. Each sheet was visually examined under fluorescent lighting conditions to allow for enhanced surface visualization. Figure 5.1 provides a visual representation of the three roughness categories.



Smooth Intermediate Rough

Figure 5.1. Example of veneers in the three visual roughness categories.

Thirty-five veneer sheets, 12-inches by 12-inches, were selected per roughness category and 210 smooth sheets were selected for face and back veneers. Sheets could not be selected with regard to lathe check information; selection was based solely on veneer roughness.

5.2 Sampling Techniques

A rigid 12-inches by 12-inches aluminum template was placed over each sheet of veneer to identify 27 potential samples. Figure 5.2 provides a sketch of the possible 27 samples. Five random numbers (01 to 27) were generated to select five 1-inch by 1-inch samples out of the possible 27. This procedure was repeated once per sheet for all thirty-five sheets in each roughness category. A total of 525 samples that were 1-inch by 1-inch were selected. The samples were conditioned to 5 % moisture content.

Each sample was labeled by full sheet number, grid location, roughness category, and tight or loose side. For example, the tight side of a 1-inch by 1-inch sample from sheet 1 and grid location 10 that exhibited rough surface characteristics was labeled as follows: t1r-10.

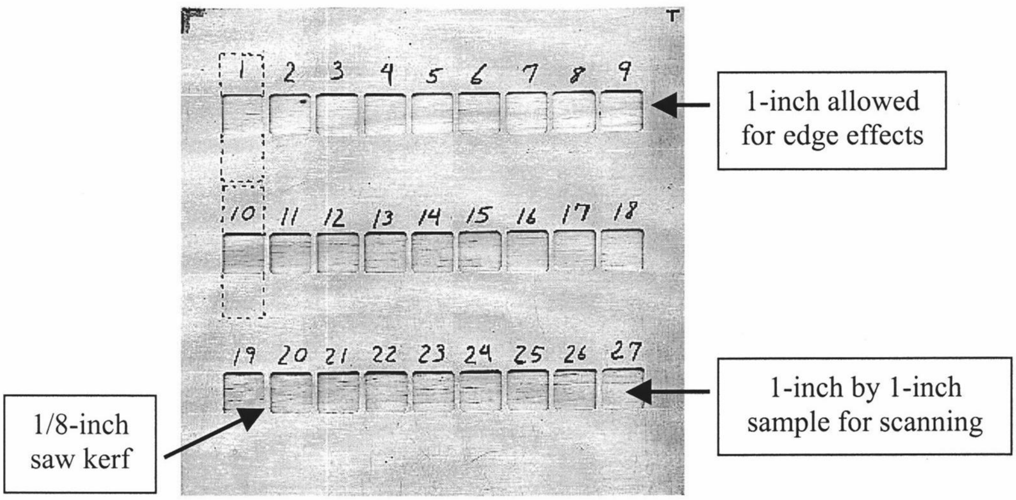


Figure 5.2. Metal template over a veneer sheet showing all possible scanning samples.

5.3 Surface Roughness Scanning

Surface topography was quantified by scanning the randomly selected 1-inch by 1-inch samples in the cross-grain direction on both the tight and loose side using a laser scatter/optical imaging system described by Funck et al. (28) and illustrated in Figure 5.3. The system utilized a 1.0-mW helium neon laser mounted perpendicular to the veneer at a distance of 375 mm. The laser beam passed through a 49-mm polarizing filter and a 100-μm diameter pinhole aperture. This produced a 3-mm diameter laser dot on the veneer surface. A precision X-Y table and an optical bench were used to provide accurate, straight-line movement and proper component alignment, respectively. Scanning was conducted at a constant rate of one inch per minute. Displacement parallel (DP) (distance between scan lines) and displacement lateral (DL) (distance between points along the scan line) were both performed at 0.03-inch intervals. Each side of a 1-inch by 1-inch sample had 33 scan lines with 33 data points per scan line.

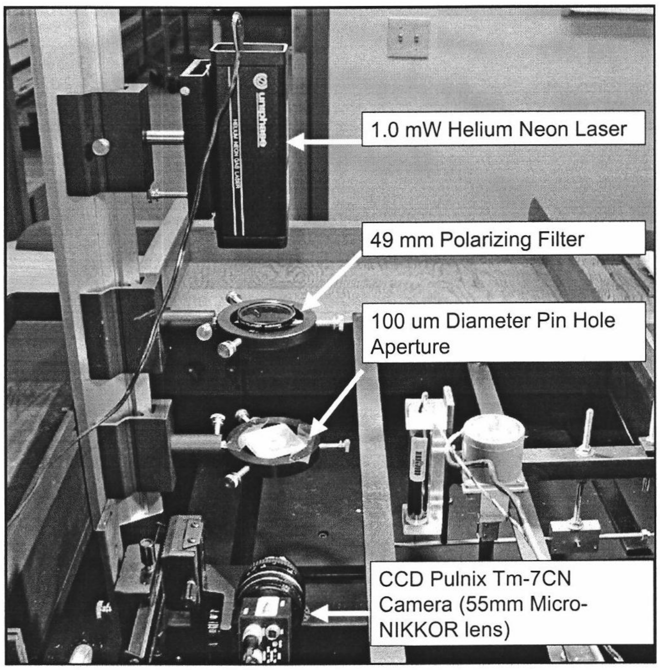


Figure 5.3. Laser scatter/optical imaging system setup.

Scattered laser light reflected back from the veneer surface was captured using an interline transfer CCD Pulnix Tm-7CN video camera equipped with a 55 mm, fl:2.8 Micro-NIKKOR lens mounted at an angle of 19^0 to the veneer surface. The gamma correction was set at 0.45 and the automatic gain control enabled as determined by

Funck et al. (28). A PC equipped with a Targa frame-grabber board and a high performance video display digitized the signals obtained by the video camera system. A gray-scale threshold approach segmented the laser dot from the wood. A 200-pixel square window was placed around the laser-dot to improve processing speed and offset potential low camera angle and short focal distance limitations. Immediately after scanning was completed on an individual sample, it was transferred to a conditioning chamber set at 5 % MC to prevent excessive change in moisture content and minimize any dimensional changes in the sample.

5.4 Mathematical Roughness Measurements

Two-dimensional roughness measurements, as outlined in Section 3.3.4, were used in this study. The following mathematical measures were calculated for both the tight and loose side veneer surfaces:

- Center line average (CLA or R_a)
- CLA maximum minimum
- Root-mean square (RMS or R_q)
- RMS maximum minimum
- Range average
- Range maximum
- Range maximum minimum
- Skewness average (R_s)
- Skewness maximum minimum
- Kurtosis average (R_k)
- Kurtosis maximum minimum
- High 3rd maximum

- High 3^{rd} maximum minimum
- Low 3^{rd} minimum
- Low 3^{rd} maximum minimum

While measuring roughness over the one-inch square area under investigation in this study, 33 individual scan lines were performed. In most cases, average roughness measures were determined by calculating a specific measure for each of the 33 scan lines and then averaging them to obtain a single value for the one-inch square area being measured. Measures reported as maximum-minimum were found by subtracting the lowest scan line value from the highest value. Minimum and maximum values of roughness were determined from the lowest and highest values calculated for the 33 scan lines, respectively.

5.5 Panel Lay-Up: Adhesive Application, Pressing, and Hot-stacking

All panels were laid up at Borden Chemical Inc. in Springfield, Oregon. Thirty-five 12-inch by 12-inch veneer sheets previously selected from each roughness category were located as core material in a 3-ply, 3-layer plywood panel. Both face and back veneers of the panel construction were smooth, touch sanded veneers with their tight sides oriented toward the core veneer.

A phenol formaldehyde adhesive system was applied to the veneer by a laboratory-scale roller glue spreader. Table 5.1 outlines the process variables maintained throughout the panel lay-up based on the adhesive manufacturer's recommendations for the phenol formaldehyde adhesive used.

Table 5.1. Outline of plywood manufacturing process variables.

Station	Process Variable
Adhesive Application	Veneer MC 5% (O.D. basis)
	3351 resin
	Viscosity 16,000 centipoise @ 25 ^{0}C
	Laboratory glue-spreader
	54 lbs./Mft^2 spread rate (double glue-line)
	4 minute stand time after application
Pre-Press	4 minutes
	150 psi
Total Assembly	8 minutes
Hot Press	4 minute press time
	302 ^{0}F temperature
	175 psi pressure
Hot Stacking	24 hour hot stacking time

Each 12-inch by 12-inch sample sheet was positioned between a smooth face and back sheet. Face and back sheets were oriented such that their tight sides were bonded to the scanned veneer. This provided for one glue-bond with tight/tight construction and one glue-bond with tight/loose lay-up. In order to simulate the pressing process of manufacturing facilities, the panels were pressed to pressure rather than a final thickness. All pressing variables were held constant for all the panels produced. Four panels were made in each of the 27 press cycles (the last cycle included 3 extra non-scanned panels produced) in order to produce 105 total panels of 3-ply construction for use in the study. This resulted in a total of 35 panels for each roughness category. The test panels were stacked in a conditioning box set at 90 ^{0}C and 10% relative humidity for a 24-hour post cure period.

5.6 Glue-bond Sample Preparation

Thirty panels from each roughness category were selected for processing into glue-bond specimens, which resulted in a total of 450 glue-bond specimens (150 samples per visual roughness category). The remaining panels were saved in the event any of the processed panels exhibited internal blows. The five randomly scanned 1-inch square areas from each panel were processed into standard bond durability samples as outlined in Figure 3.4. Based on the results of the preliminary study, each sample was kerfed such that lathe checks would "open" when placed under stress and tested in a dry condition. The samples were conditioned at 20^0C and 65% relative humidity in order to assure uniform moisture content throughout the group of specimens.

5.7 Glue-bond Sample Measurements

Since the digital video camera resolution was 0.005-inch per pixel, it was decided to scan the sample edges before testing to achieve a higher resolution. Each sample was scanned using a flatbed scanner at 1,600 pixels per inch resolution (i.e., 0.000625-inch per pixel). This allowed for clearer evaluation of lathe check and annual ring characteristics. Important lathe check characteristics found to be significant in the preliminary study were measured on the scanned images.

In addition, the following annual ring and latewood measurements, some of which are shown in Figure 5.4, were recorded:

- Percentage of latewood in test area
- Number of latewood bands in test area
- Percent of latewood at tight and loose side glue-line interface
- Angle of latewood bands at each saw kerf in respect to glue-line
- Latewood and earlywood width
- Number of growth rings per inch
- Ratio of earlywood width to latewood width (i.e., earlywood width/latewood width)

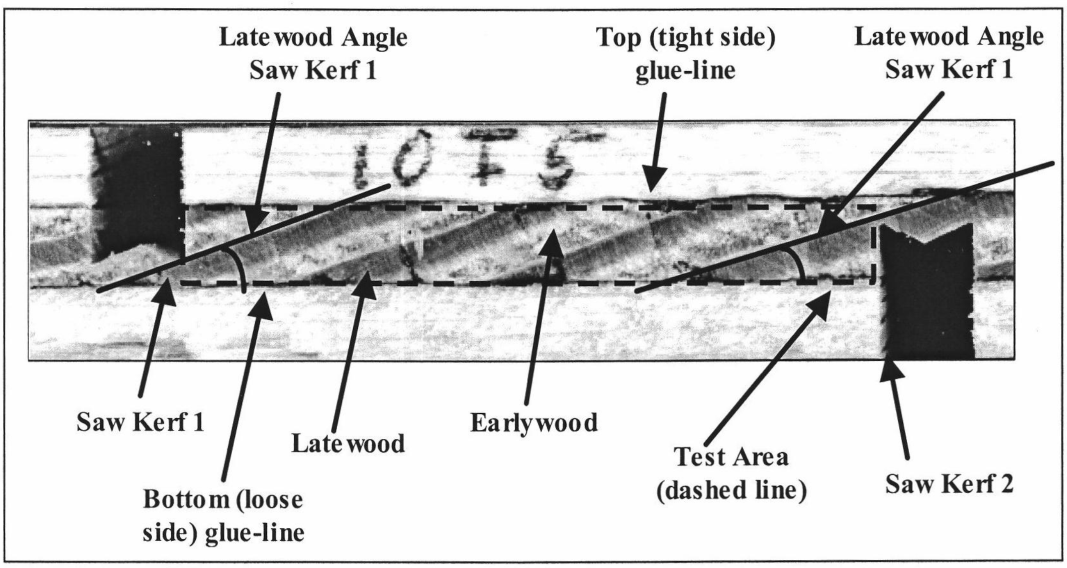


Figure 5.4. Example of latewood measurements recorded from scanned glue-bond samples.

5.8 Glue-bond Sample Tests

Specimens were tested in the same modified TECO-Mater machine used in the preliminary study and shown in Figure 4.1. Digital video cameras (one in front and one in back of the test machine as shown in Figure 4.2) recorded both edges of the glue-bond specimens during testing. Lathe check crack propagation mode was monitored while a constant load was applied to the specimens. The rate of loading was 0.01-inch per minute. The ultimate load at failure was recorded for each sample; load and displacement readings (machine head movement) were also logged. The linear portion of load versus displacement readings was determined for each test and reported as slope in the results and discussion section. Upon completion of testing, the digital videos were downloaded to a computer for analysis of lathe check crack propagation modes. The critical lathe checks causing failure were monitored to determine if TR mode of propagation occurred, or if another mode played a role in the specimen failure pattern. The failed samples were sent to an accredited certification agency for analysis of wood failure percentage.

5.9 Data Analysis Techniques

Multiple linear regression and analysis of variance (ANOVA) were used to test all mathematical and visual roughness measures, lathe check and annual ring characteristics and any interactions between variables as a source of variation for load at failure and percent wood failure. Correlation analysis was used to determine if the mathematical roughness, lathe check and annual ring characteristics were good estimators of plywood bond performance (i.e., percent wood failure and load at failure). Correlations between all characteristics (i.e., roughness, lathe check, and annual ring measures) were determined by correlation matrix methods. In addition, all possible combinations (i.e., best-fit) regression models were generated using SAS, Release Version 8.02, statistical software (69) by running linear regression R-squared and maximum R-square methods to further investigate variable interactions.

6. PRIMARY STUDY RESULTS AND DISCUSSION

6.1 Relationship Between Visual Veneer Roughness Categories and Glue-bond Performance

Because many of the variables measured in this study were correlated, it is important to understand their relationship to the visually segregated veneer roughness categories. Box and whisker plots of individual veneer lathe check and annual ring characteristics measured in the study for each visual roughness category are provided in Appendix A, while box and whisker plots for individual mathematical surface roughness measures are located in Appendix B. Of particular interest in the box and whisker plots of the visual roughness categories were lathe checks per inch and average latewood band angle (absolute) to the glue-line.

Figure 6.1 shows the box and whisker plots for lathe checks per inch in each visual roughness category. From these plots, it is apparent that smooth veneer exhibited a higher average number of lathe checks per inch than did intermediate and rough categories. Results from an ANOVA test showed that there was a significant statistical difference (p-value < 0.0001) for average lathe checks per inch between visual roughness categories. Analysis of multiple range tests indicated a statistically significant difference in average lathe check frequency in smooth veneer as compared to intermediate and rough veneer. There was no statistical difference in average lathe check frequency for intermediate and rough veneer.

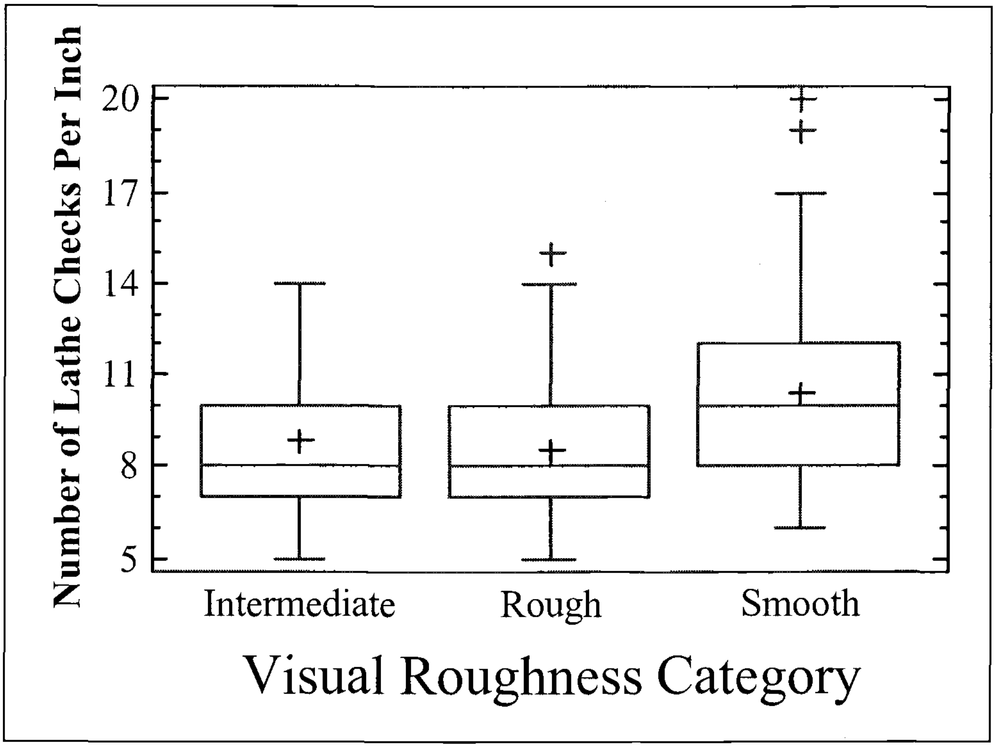


Figure 6.1. Box and whisker plots for lathe check frequency (number of lathe checks per inch) from smooth, intermediate, and rough visual categories.

Figure 6.2 shows the box and whisker plots for average latewood band angle (absolute) to the glue-line for each visual roughness category. From these plots, it is apparent that roughness is related to latewood band angle. Visually rough veneer exhibited a much higher average latewood band angle than did smooth and intermediate categories. Results from an ANOVA test showed that there was a significant statistical difference (p-value < 0.0001) for average latewood band angle (absolute) to the glue-line between visual roughness categories. Analysis of multiple range tests indicated a statistically significant difference between all three visual roughness categories, with smooth visual roughness category samples exhibiting the lowest average latewood angle, followed by intermediate and rough, respectively.

This is consistent with the theory that rougher veneer is peeled when the lathe encounters many sets of earlywood and latewood (as evident by a high latewood band angle) as veneer is produced.

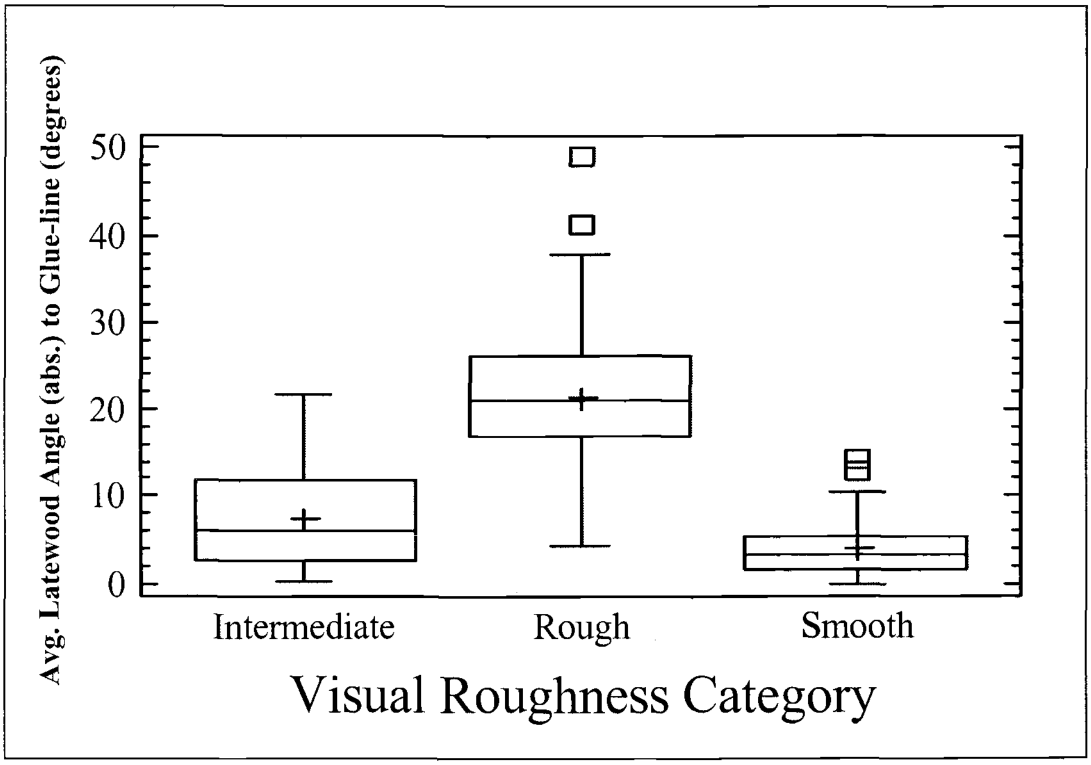


Figure 6.2. Box and whisker plots for average latewood angle (absolute) to the glue-line from smooth, intermediate, and rough visual categories.

Table 6.1 provides load at failure test results for the three visual roughness categories. Results from an ANOVA test showed that there was a statistically significant difference (p-value < 0.0001) for average load at failure between visual roughness categories. Figure 6.3 illustrates these differences. Two sample t-tests indicated a statistically significant difference between average load at failure between smooth and intermediate (p-value < 0.0001), smooth and rough (p-value <0.0001), and intermediate and rough (p-value = 0.043). Analysis of multiple range tests indicated a statistically significant difference for load at failure between smooth and intermediate, and smooth and rough, but found no significant difference between load at failure for intermediate and rough.

The same trend existed when looking at average number of lathe checks per inch between categories, indicating that lathe check frequency plays a role in influencing load at failure. Test results showed that intermediate samples had the highest average load, followed by the rough and smooth, respectively. This indicated that visual levels of veneer roughness might not be the only factor for determining load at failure and that other wood properties such as lathe check and annual ring characteristics most likely influenced the results.

Table 6.1. Load at failure test results for smooth, intermediate, and rough visual roughness categories.

	Load at Failure (lbs)		
Variable	**Smooth**	**Intermediate**	**Rough**
Sample Size	150	150	150
Average	205.2	274.5	262.8
Variance	2989.1	2026.1	2906.3
Standard Deviation	54.7	45.0	53.9
Coefficient of Variation %	26.6	16.4	20.5
Minimum	107	109	121
Maximum	380	384	421
Range	273	275	301

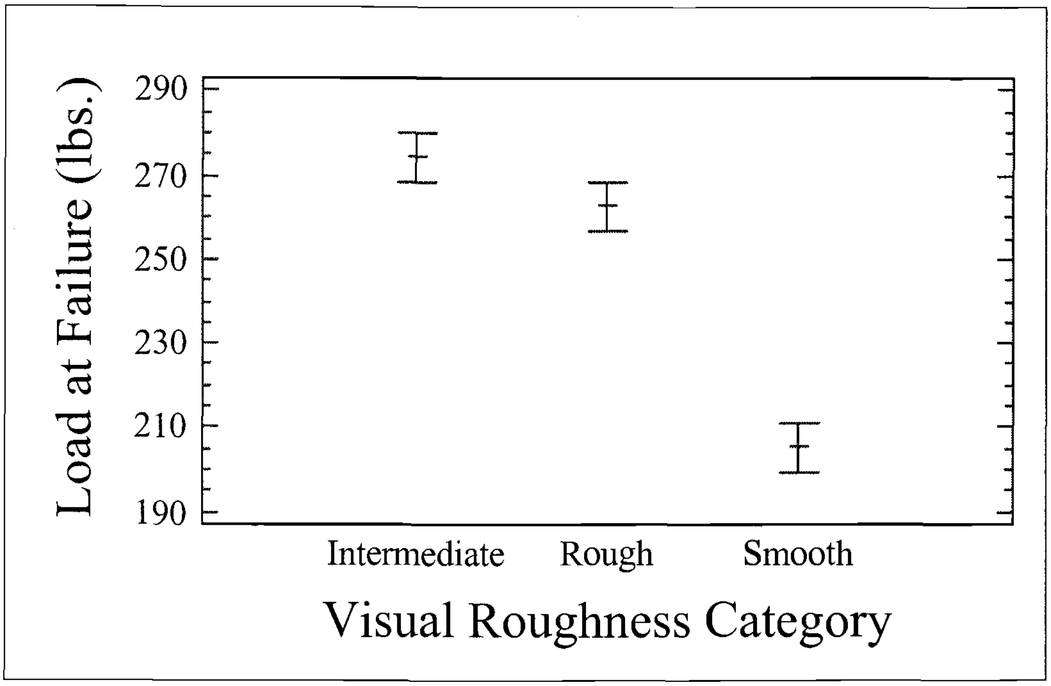


Figure 6.3. 95 percent confidence intervals for average load at failure from smooth, intermediate, and rough visual roughness categories.

Due to the configuration of standard glue-bond samples, in particular placement of saw kerfs, the test sample undergoes peeling stresses, bending stresses and shear stresses. This test configuration results in high bending stress and peeling stress concentrations in the test area adjacent to the saw kerfs. These high stresses tend to cause a ripping at the adhesive layer and force lathe checks to open. Since bending and peeling occur, there are not pure shear forces in the adhesive layer and thus the glue-line alone is not being tested. Therefore, with lathe checks present and opening, the center veneer material becomes more important in determining load at failure. If the stresses in the adhesive layer were purely in shear, visual surface roughness by itself might be the most significant factor in determining load at failure.

Figure 6.4 provides box and whisker plots of load at failure for the three visual roughness categories tested. Because the medians lie close to the box plots' centers, it appears that load at failure results within a roughness category are fairly symmetrical and not particularly skewed. This should be expected since for the most part, veneer within each group was taken from the same raw material supplier and care was taken to select scanning areas that represented that particular roughness category. Also, the spread between groups appears to be equal.

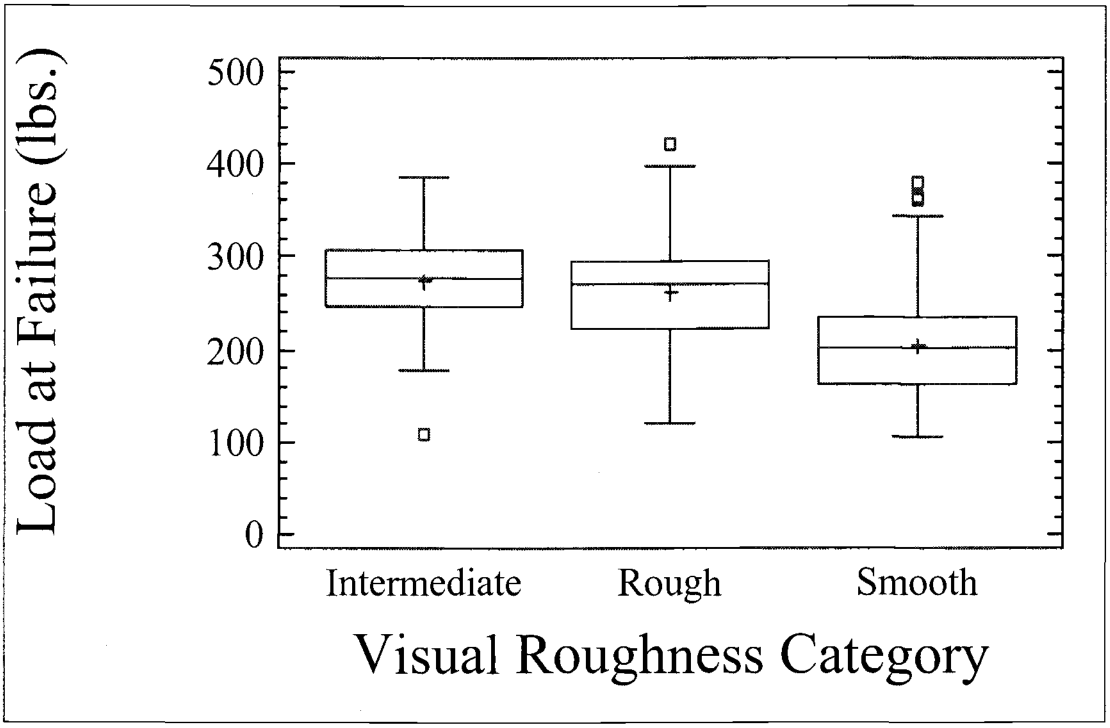


Figure 6.4. Box and whisker plots for load at failure results from smooth, intermediate, and rough visual roughness categories.

Percent wood failure readings were performed by an independent third party panel certification agency. Table 6.2 provides test results for percent wood failure based on the three visual roughness categories.

Table 6.2. Percent wood failure test results for smooth, intermediate, and rough visual roughness categories.

	Percent Wood Failure		
Variable	**Smooth**	**Intermediate**	**Rough**
Sample Size	150	150	150
Average	90	78	72
Variance	192	505	348
Standard Deviation	14	23	19
Coefficient of Variation %	15.3	28.8	26.0
Minimum	20	10	15
Maximum	100	100	100
Range	80	90	85

Results from an ANOVA test showed that there was a statistically significant difference (p-value < 0.0001) for average percent wood failure between visual roughness categories. Multiple range tests indicated a statistically significant difference between all three visual roughness groups for average percent wood failure. In addition, two sample t-tests showed a statistically significant difference for average percent wood failure between smooth and intermediate (p-value < 0.0001), smooth and rough (p-value <0.0001), and intermediate and rough (p-value = 0.01). Test results showed that smooth samples had the highest average percent wood failure, followed by intermediate and rough, respectively. Based on these results, it was found that as visual surface roughness increases, percent wood failure decreases. Figure 6.5 shows the box and whisker plots for percent wood failure readings in each visual roughness category. Intermediate and rough categories exhibited larger ranges, while most smooth category samples achieved wood failure percentages above 90 percent.

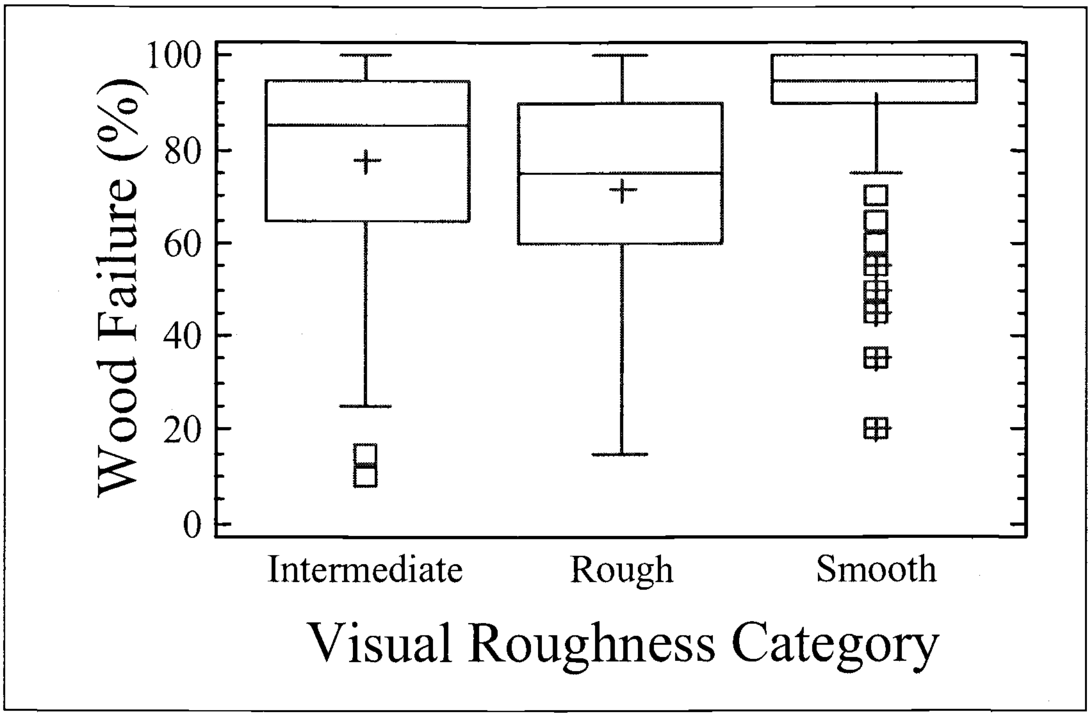


Figure 6.5. Box and whisker plots for percent wood failure readings from smooth, intermediate, and rough visual roughness categories.

6.2 Influence of Veneer Characteristics on Glue-bond Performance

Correlation analysis, stepwise regression, robust regression, and all possible combinations (R-square and maximum R-square) best-fit regression techniques were performed on load at failure and percent wood failure versus all veneer roughness, lathe check, and annual ring measures. Also, regression analysis was used to single out significantly influential characteristics that affect glue-bond quality as tested by current methods (19,36,83). This was done to provide guidance to manufacturers regarding the relationship between veneer quality and glue-bond quality. It also provided information regarding what veneer properties need to be adjusted during the peeling process to achieve better glue-bond performance. Cross correlations (i.e., correlation coefficients and significance level) between all veneer roughness, lathe check, and annual ring measures and all test results were determined and are provided in the Appendix C. It should be noted that some correlations between variables could be coincidental and care should be taken to determine if variables are logically related.

6.2.1 Influences on Load at Failure Performance

Correlation analysis was performed between load at failure results and all veneer roughness, lathe check, and annual ring measures (Appendix C). Table 6.3 shows the coefficients for those characteristics that had a significant individual correlation (at a 0.01 level) with load at failure. In most cases, there were positive correlations between statistically significant characteristics and load at failure. However, lathe check frequency and growth rings per inch were negatively correlated with load at failure. This suggests that as the number of lathe checks present and/or the number of growth rings per inch in veneer increases, the load at failure decreases in glue-bond samples. Another characteristic of interest was latewood angle in respect to the glue-line. Latewood angle and load at failure were positively correlated suggesting that as latewood angle increases, load at failure tends to increase.

Table 6.3. Statistically significant correlation coefficients from individual correlation analysis between load at failure and various characteristics.

Characteristic	Correlation Coefficient	Characteristic	Correlation Coefficient	Characteristic	Correlation Coefficient
Slope (lbs/in)	0.470	Loose CLA Average	0.269	Earlywood Width (in.)	0.240
Check Frequency (checks/inch)	-0.382	Loose RMS Max. Min.	0.268	Tight CLA Max. Min.	0.233
Growth Rings Per Inch	-0.325	Tight High 3rd Max. Min.	0.267	Tight Range Max.	0.220
Loose Range Max.	0.325	Loose High 3rd Max.	0.265	Tight High 3rd Max.	0.211
Loose Range Max. Min.	0.314	Loose Low 3rd Max. Min.	0.261	Tight Range Avg.	0.196
Tight Low 3rd Max. Min.	0.314	Tight Range Max. Min.	0.258	Tight RMS Average	0.185
Loose Range Average	0.303	Loose CLA Max. Min.	0.250	Tight CLA Average	0.179
Loose High 3rd Max. Min.	0.287	Tight Low 3rd Min.	-0.250	Latewood Angle (abs.) in respect to glue-line	0.175
Latewood Width (in.)	0.283	Loose Low 3rd Min.	-0.248	% Latewood - Veneer Loose Side	0.129
Loose RMS Average	0.276	Tight RMS Max. Min.	0.241		

While Table 6.3 lists 29 variables that had significant individual correlations to load at failure, stepwise regression analysis indicated that only seven of those characteristics were statistically significant (at an alpha level = 0.05) in predicting load at failure of glue-bond specimens (Table 6.4). Those characteristics found to be non-significant in predicting load at failure along with their p-values are listed in the Appendix D.

Table 6.4. Significant variables, regression coefficients, and p-values from stepwise regression analysis for predicting load at failure.

Independent Variable	Regression Coefficient	p-value
Constant	304.91	0.000
Lathe Check Frequency (checks/inch)	-9.61	0.000
Growth Rings Per Inch	-2.05	0.000
Percent Latewood in Test Area	1.75	0.000
Tight-side Range Maximum Minimum	1.73	0.000
Distance of 2nd Lathe Check Origin to Saw Kerf	-110.66	0.004
Earlywood/Latewood Width Ratio	7.26	0.005
Tight-side Low 3rd Minimum	0.90	0.024

In this stepwise regression, only 30 percent of the variation (R-squared = 0.30) in load at failure was explained by the linear regression coefficients. Again, of particular interest in this regression were lathe check frequency and growth rings per inch. Stepwise regression shows that a higher frequency of lathe checks in the test veneer lowers load at failure values. In order to further investigate check frequency effects, load at failure results for the samples were separated into specific groups based on the number of lathe checks present. Figure 6.6 provides a main effects plot of mean load at failure within a group containing a specific number of lathe checks. From this plot, it is shown that mean load at failure in glue-bond samples decreased as the frequency of lathe checks increased.

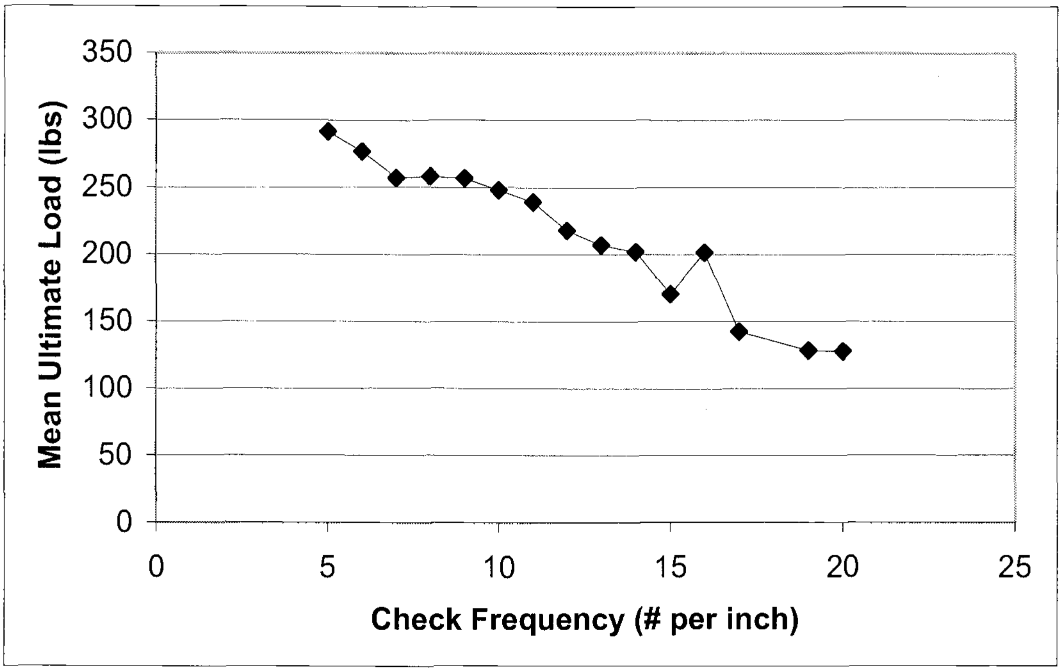


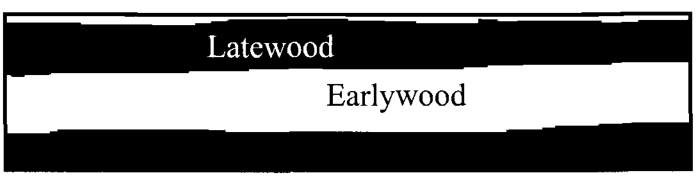
Figure 6.6. Main effects plot on mean load at failure based on lathe check frequency.

All possible combinations best-fit regression results, provided in Appendix E, showed that lathe check frequency was the first variable selected into each model and was present in every model generated. These regressions also provided information that some variables were highly correlated and substituted for each other in different models. For example, lathe check origin distance to the saw kerf of lathe check #1 and #2 substituted for each other and it is clear that those two measures are highly correlated with each other. In addition, it was found that they also had a high negative correlation with lathe check frequency. Logically, as lathe check frequency increased, it would stand to reason that lathe check #1 and #2 origin distance to the saw kerf would decrease. From a manufacturing standpoint, when peeling veneer, the distance of lathe check #2 origin to the saw kerf can only be controlled by changing lathe check frequency.

More growth rings per inch resulted in lower loads at failure in glue-bond specimens. However, this finding may be influenced by rough veneer samples having a significantly lower average growth ring per inch value than the other two roughness categories and rough samples having a high latewood angle. When rough category samples were removed from the analysis, growth rings per inch became non-influential in predicting load at failure and latewood band angle became significant. Again, statistically significant correlations existed between the number of growth rings per inch and many variables. In particular, latewood band angle (absolute) to the glue-line and the number of latewood bands in the test area were correlated with growth rings per inch. In looking at visual roughness categories, rough samples possessed a lower mean growth ring per inch value than the other two categories and had a much higher latewood band angle, as shown in Figure 6.2.

In terms of earlywood and latewood width present in the test area, the higher the ratio of earlywood/latewood band width, the higher load at failure becomes. It may be that the relationship of higher load at failure when earlywood width is greater than latewood width is due to the fact that lathe checks tend to propagate in latewood in an unstable manner, and when loading is stopped, the checks arrest in the earlywood material (78). When further loading is applied, the checks again propagate. This suggests that earlywood material has a higher capacity to resist lathe check propagation. Also, as lathe checks propagate under a "stick slip" method, the checks are arrested in the earlywood material, while secondary cracks form in latewood. A greater amount (i.e., width) of earlywood present between adjacent lathe checks would require higher force to join the checks together and cause failure. In addition, since the latewood fractures in an unstable matter, the thinner the latewood band, the less the amount of force that would be required to propagate a check completely through the material.

Stepwise regression also indicated that as the percent latewood in the test area increased, the load increased. In comparison to earlywood/latewood width ratio, it would stand to reason that as the percent latewood increased, the earlywood/latewood width ratio would decrease and thus, the load at failure would decrease. However, this was not always the case in the study. Depending on the orientation of earlywood and latewood bands in the test area, a sample having an earlywood/latewood width ratio over 1.0 could have a higher percentage of latewood in the test area. Some examples of this would be two latewood bands and only one earlywood band in the test area or two latewood bands and a full earlywood band along with another partial earlywood band. Figure 6.7 illustrates this possibility.



earlywood/latewood width ratio = 1.2, % latewood = 58%

Figure 6.7. Example of an earlywood/latewood width ratio over 1.0 with a higher percent latewood than earlywood in the test area.

It could be that load at failure increased as percent latewood increased because of more latewood near the glue-lines or near the saw kerfs or that latewood material has a higher density and would in turn show better capacity to withstand forces placed on the specimen. The amount of latewood could have also changed the stress concentrations placed on the test area. However, this particular study was not designed to analyze this occurrence. Also, the distance to the saw kerf of the second lathe check origin was found to negatively influence load at failure. As this distance increases, load at failure decreases. Again this may be related to changes in stress concentrations in the sample, but this study was not designed to analyze that issue.

These results suggest that if one is interested in increasing load at failure values for glue-bond specimens, close attention should be paid to reducing the frequency of lathe checks when peeling veneer. This is in contrast to industry practice, where typically, quality veneer is viewed as having frequent, shallow lathe checks rather than a few deep lathe checks. In this study, lathe check depth did not have a significant influence on load at failure in glue-bond specimens. However, from a production standpoint, deep lathe checks can cause some handling issues. Frequent lathe checks were not necessarily associated with shallow lathe checks. While correlation analysis between lathe check frequency and average lathe check depth resulted in a statistically significant (p-value = 0.004) positive correlation coefficient, it was only 0.136.

Since the forces created by the plywood glue-bond specimen geometry resulted in shear forces being placed on the wood material rather than concentrated at the glue-line, an increase in lathe check frequency resulted in less wood material between each check. Because a lower amount of wood needs to be severed to join each crack together and cause failure, a lower force is required. To increase load at failure in glue-bond specimens by reducing the amount of lathe checks present in veneer, the plywood industry needs to rethink the way it views quality veneer. It was evident that lathe check depth played little or no role in influencing load at failure for glue-bonds. Therefore, the veneer peeling process needs to be re-examined so that lathe check frequency is reduced, while ensuring that the resulting check depths are such that handling losses and face checking are minimized.

Roughness measures found to be statistically significant are quite difficult to associate with load at failure. Since the geometry of the specimen does not concentrate shear stresses at the glue-line and places high bending and peeling stresses near the saw kerfs, overall veneer roughness may not be a good predictor of load at failure in the specimens. In order to truly attempt to predict the influence of veneer roughness on load at failure, the entire glue-line would need to have the equivalent amount of shear stress placed over it which was not the case in this study.

However, both roughness measures that were found significant in influencing load at failure were highly correlated with latewood band angle (absolute) to the glue-line. As previously discussed, Figure 6.2 showed that latewood angle was significantly different between the roughness categories. When looking at the all possible combinations best-fit regression equations, latewood angle appears as a variable in the second best-fit equation with seven variables and in the first best-fit equation with eight variables. It was also found that latewood angle substituted for roughness measures in the models with seven variables. In addition, many roughness measures are highly correlated with each other and substituted for each other in the best-fit models, and many of the roughness measures are highly correlated with latewood angle. Therefore, it is apparent that manufacturers need to control latewood angle in order to reduce roughness and manipulate load at failure.

To reduce the influence on the regression equation and coefficients of some outliers that were present in the data within each group, robust regression techniques were performed. Three types of robust regressions were used; Andrews' sine, Tukey's bi-weight, and least absolute deviation (56). Tukey's bi-weight robust regression resulted in the highest R-squared value of 0.96, followed by Andrew's sine at 0.72, and least absolute deviation at 0.49. Then, predicted values produced by each equation were compared to test results for load at failure in order to determine how well the regressions performed. Table 6.5 shows the number of samples out of 450 total that had predicted values that were within +/-10, +/-15, and +/-20 percent of the actual load at failure values for each previously discussed regression technique.

Table 6.5. Total number and percentage of samples predicted within ±10, ±15, and ±20% of the actual load at failure test values using various regression equations.

	Number of Ultimate Load Values Predicted Within Criteria / Percentage out of 450 samples			
Criteria	**Stepwise**	**Least Absolute**	**Andrew's Sine**	**Tukey's Bi-weight**
Within ±10%	174 / 38.7%	194 / 43.1%	227 / 50.4%	247 / 54.9%
Within ±15%	243 / 54.0%	270 / 60.0%	285 / 63.3%	282 / 62.7%
Within ±20%	315 / 70.0%	330 / 73.3%	327 / 72.7%	307 / 68.2%

While the robust regressions with their higher R-squared values accomplished slightly better percentages of predicting load at failure within ±10 and ±15 percent, the stepwise regression equation performed just as well or better when predicting within ±20 percent. Since the robust regression equations took into account and used all 55 measurements recorded from each sample, using them did not improve the predicted values enough to justify making this many measurements on a sheet of veneer when the stepwise regression used only seven measures to predict load at failure.

6.2.2 Influences on Percent Wood Failure Performance

Correlation analysis was performed between percent wood failure readings and all veneer roughness, lathe check, and annual ring measures (Appendix C). Table 6.6 shows the coefficients for those measurements that had a significant correlation (at a 0.01 level) with percent wood failure readings. Both tight and loose side roughness measurements were significantly correlated with percent wood failure. Mathematical veneer roughness measures showed to have the highest correlation with percent wood failure, while many annual ring characteristics and a few lathe check characteristics were significant. This suggest that veneer surface roughness measures primarily influence percent wood failure and interact with annual ring and lathe check measures in determining percent wood failure.

Table 6.6. Statistically significant correlation coefficients from individual correlation analysis between percent wood failure and various characteristics.

Characteristic	Correlation Coefficient	Characteristic	Correlation Coefficient	Characteristic	Correlation Coefficient
Tight Low 3rd Min.	0.457	Tight Range Average	-0.369	Tight Range Max. Min.	-0.280
Slope (lbs/in)	-0.427	Loose CLA Average	-0.360	Earlywood Width (in.)	-0.278
Loose Low 3rd Max. Min.	-0.423	Tight RMS Average	-0.359	Tight RMS Max. Min.	-0.276
Tight Low 3rd Max. Min.	-0.422	Loose Low 3rd Min.	0.357	Tight CLA Max. Min.	-0.274
Loose Range Max.	-0.415	Loose Range Max. Min.	-0.351	Avg. Latewood Angle (absolute) to Glue-line	-0.255
Loose Range Average	-0.411	Tight CLA Average	-0.349	Latewood Angle at Saw Kerf 2	-0.226
Tight High 3rd Max. Min.	-0.389	Loose CLA Max. Min.	-0.331	Avg. Latewood Angle to Glue-line	-0.216
Loose High 3rd Max.	-0.387	Loose RMS Max. Min.	-0.316	Latewood Angle at Saw Kerf 1	-0.194
Loose RMS Average	-0.375	Tight High 3rd Max.	-0.300	Check Frequency (checks/inch)	0.139
Tight Range Max.	-0.375	Growth Rings Per Inch	0.299	Lathe Check #1 Tip Dist. to Saw Kerf 1	-0.128
Loose High 3rd Max. Min.	-0.370	Latewood Width (in.)	-0.290	Lathe Check #2 Origin Dist. To Saw Kerf 1	-0.121

Stepwise regression analysis indicated that six measurements were statistically significant (at an alpha level = 0.05) for predicting percent wood failure. Table 6.7 lists those measurements, regression coefficients and p-values. P-values for those measurements found to be non-significant in predicting percent wood failure are listed in the Appendix D. In this stepwise regression, only 23 percent of the variation

(R-squared = 0.23) in percent wood failure was explained by the linear regression coefficients.

Table 6.7. Significant variables, regression coefficients, and p-values from stepwise regression analysis for predicting percent wood failure.

Independent Variable	Regression Coefficient	p-value
Constant	94.41	0.000
Tight-side Low 3rd minimum	0.891	0.000
Loose-side Low 3rd maximum minimum	-0.728	0.000
Percent Latewood in Test Area	-0.351	0.000
Growth Rings Per Inch	0.397	0.001
Percent Latewood at Tight Side Glue-line	0.116	0.005
Loose-side CLA Average	0.869	0.008

The intent of the prediction equation was to provide a means to successfully predict whether or not use of a particular veneer would result in sufficient percent wood failure. Therefore, the PS 1 standard of 85% wood failure was used as the pass/fail criteria for an individual sample. Even though the R-squared value was low, the stepwise regression equation successfully identified 147 of the 168 samples that failed (i.e., percent wood failure $\leq$ 84%). Table 6.8 shows the actual number of samples found to be below and above the pass/fail criteria of 85% wood failure and the number of samples that were predicted to be below and above.

Table 6.8. Predicted number of samples and percentage of samples that would have been predicted correctly using the stepwise regression prediction equation.

Criteria	Actual Number of Samples	Predicted Number of Samples	Percentage Predicted Correctly
85% and higher	283	127	45%
84% and lower	167	147	88%

Even though the stepwise regression equation would have correctly predicted 88% of the samples that were below the pass/fail criteria, it still incorrectly predicted 156 samples were below 85% wood failure when in actuality they achieved a wood failure percentage of 85% or greater. This being said, it appears that the stepwise regression equation found in this study would not be a viable means to predict whether a sample would pass or fail the 85% criteria limit. However, it does provide insight into which measurements from this study significantly affect percent wood failure.

Various roughness measures, as defined in Section 3.3.4, affected percent wood failure. Two roughness measures (Tight-side low 3rd minimum and Loose-side low 3rd max.min) entered the regression equations first. Tight-side low 3rd minimum was significant in influencing percent wood failure. Values of low 3rd minimum are expressed as negative numbers. Within the visual veneer roughness categories, the smooth category exhibited the least negative mean value of tight-side low 3rd minimum, followed by intermediate and then rough, respectively. In the stepwise regression equation, a less negative measure of tight-side low 3rd minimum increases the percent wood failure. A smoother surface would have a less negative tight-side low 3rd minimum value. Percent wood failure would increase because glue-line contact is more intimate, thus causing the wood to fail in the higher stressed center veneer. Loose-side low 3rd max.min. was also found to be significant. Within a visual roughness category, the mean value for loose-side low 3rd max.min. was lowest for the smooth category, followed by the intermediate and rough categories, respectively. Smoother surfaces have a lower value of low 3rd max.min., and with a negative coefficient in the equation, better glue-line bonding may occur and cause more failure in the center wood material.

On the other hand, loose-side CLA average was found to be significant, but it had a positive coefficient. It would stand to reason that a smoother surface should have a lower CLA average value, so it would be expected that a higher CLA average value would decrease bonding at the glue-line and result in lower percent wood failure. However, this was not the case in this study. A weakness of CLA values is the inability to indicate differences between surfaces with dissimilar peak and valley frequencies (59). A surface with frequent shallow valleys can have an equivalent CLA value to a surface with very few deep valleys (59). Furthermore, it may be that a rougher surface with a higher CLA average would also have a higher value of low 3rd max.min., thus interacting in influencing percent wood failure. In addition, from the best-fit models with four variables, loose-side CLA average and growth rings per inch substituted for each other and are significantly correlated and interact in the stepwise regression equation for predicting percent wood failure.

Again, from correlation analysis and best-fit regression analysis, many roughness measures were highly correlated with each other and substituted for one another in the models. It appears that roughness plays a significant role in influencing percent wood failure and because of the specimen's geometry, interacts with wood properties while doing so. Since the specimen's geometry does not concentrate shear stresses at the glue-line and places high bending and peeling stress near the saw kerfs, overall veneer roughness may by itself not be a good predictor of percent wood failure. Wood properties and annual ring measures may indicate how the samples fail and interact in determining percent wood failure. Also, measures of veneer roughness near the saw kerfs, rather than over the one inch square area, may influence percent wood failure by determining how much force the glue-line can withstand and thus cause increases in stress and failure in the center of the veneer.

Among the significant measures that were related to annual ring measures, higher percentages of latewood in the test area negatively influenced percent wood failure. This effect of percent latewood on wood failure is opposite to what was found for load at failure, where higher percent latewood in the test area increased load at failure. Those higher loads at failure as percent latewood increases, when combined with shear stresses concentrated in the center veneer, increase the capacity of the wood to withstand failure. This can result in higher amounts of glue-line failure, thus having a negative affect on percent wood failure.

On the other hand, growth rings per inch positively affected percent wood failure. Again, once analysis was performed without the rough category veneer (that possessed a significantly lower average number of growth rings per inch), growth rate became non-significant in influencing percent wood failure and latewood angle became significant. This being said, when rough samples were included in the analysis, the effect of growth rings per inch on percent wood failure was opposite to what was found for load at failure. Load at failure decreased as the number of growth rings per inch increased. Again, growth rings per inch and latewood band angle are correlated and visually rougher veneer possessed higher average latewood angles and lower average number of growth rings per inch than the other categories of visual roughness. Also, growth rings per inch was negatively correlated with many roughness measures.

Manufacturers need to view these measures differently when assessing quality veneer. If they were interested in higher percent wood failure, a lower percent of latewood should be present. To achieve higher loads at failure, veneer with opposite characteristics, higher percent latewood, should be used. While manufacturers cannot control the percent latewood in the test area when peeling, there is a highly significant correlation between percent latewood and earlywood/latewood width ratio (correlation coefficient = -0.738). Therefore, manufacturers can adjust the percent latewood in veneer by peeling logs with a certain earlywood/latewood width ratio. The influence of growth rings per inch on glue-bond quality appears to be related to differences between values in each roughness category and may not be a viable characteristic that influences glue-bond quality.

Percent latewood at the tight side glue-line positively influenced percent wood failure. Why this occurrence took place is not quite clear and will require further investigation. Typically, latewood at the glue-line would decrease the adhesion between veneers. It may be that the denser latewood at the surface changed the way forces were distributed within the specimens and caused increased stresses within the wood rather than at the glue-line. However, this occurrence was not tested in this study.

To reduce the effect of outliers on the regression equation, Andrews' sine, Tukey's bi-weight, and least absolute deviation robust regression analyses were performed. Tukey's bi-weight robust regression resulted in the highest R-squared value of 0.94, followed by Andrew's sine at 0.70, and least absolute deviation at 0.43. In order to determine how well the regressions performed, predicted values from each equation were compared to actual test results for percent wood failure. Table 6.9 shows the number of samples out of 450 total predicted to within ±10, ±15, and ±20 percent of the actual percent wood failure values when using each regression technique. It should be noted that as a general industry rule, wood failure readings performed by an individual are only accurate within ±5 percent.

Table 6.9. Total number and percentage of samples predicted to within ±10, ±15, and ±20% of the actual percent wood failure readings, using various regression equations.

	Number of Wood Failure Values Predicted Within Criteria / Percentage out of 450 samples			
Criteria	**Stepwise**	**Least Absolute**	**Andrew's Sine**	**Tukey's Bi-weight**
Within ±10%	224 / 49.8%	216 / 48.0%	217 / 48.2%	251 / 55.8%
Within ±15%	303 / 67.3%	316 / 70.2%	339 / 75.3%	331 / 73.6%
Within ±20%	359 / 79.8%	374 / 83.1%	377 / 83.8%	373 / 82.9%

The robust regressions with the higher R-squared values accomplished only slightly better prediction percentages. Because the stepwise regression equation performed almost as well or better in many cases, this questions the practical use of the robust regression equations, since all 55 separate veneer characteristics would need to be measured on the veneer. In contrast, the stepwise regression uses only six measures to predict percent wood failure. In terms of predicting percent wood failure values below or above the 85% criteria outlined in PS 1, the robust regressions did a better job of predicting values above 85% than stepwise regression. Nevertheless, the robust regressions still incorrectly over predicted a significant percentage of the samples that were below 85% wood failure to be 85% or greater. However, stepwise regression did a better job in predicting values below the 85% criteria than the robust regressions.

6.3 Lathe Check Crack Propagation and Critical Stress Intensity

In viewing the videos, it was apparent that a significant amount of bending was occurring in the test area near the saw kerfs. This bending would contribute to high peeling and tensile stress at the saw kerfs. Figure 6.8 shows the bending at the saw kerf locations. The configuration of the test specimen does force the lathe checks to open, but not always in a true Mode I (crack opening) fashion. The lathe checks undergo both an opening and sliding mode of crack propagation. This being the case, traditional calculation for the critical stress intensity factor is not appropriate and was not determined in the study. Future work in measuring strain distributions that cause varying amounts of sliding and opening on the lathe checks will need to be explored in order to determine the critical intensity factor when working with this particular specimen geometry.

In general, lathe checks located near saw kerfs opened and propagated first. Due to the specimen's configuration and the concentrated stresses near the saw kerfs, one would have expected this to happen. In particular, the lathe check closest to the saw kerf to which the checks are oriented towards propagated first. This was usually followed by rapid specimen failure.

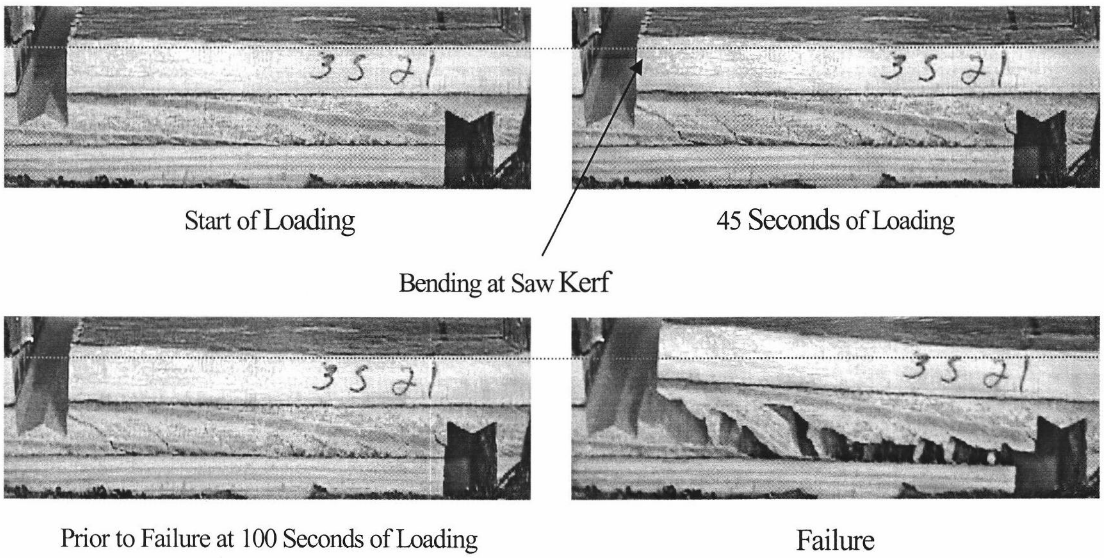


Figure 6.8. Apparent bending action at the test specimen's saw kerf locations.

Analysis was performed to measure the amount of bending taking place at the saw kerfs. Due to the low spatial resolution (0.005 inches per pixel) of the video cameras, slight bending could not be measured. Once the specimen reached near failure conditions, vertical displacement due to bending could be measured, but analysis of bending at the saw kerf could not be performed.

Displacement measurements were recorded based on horizontal head movement of the test machine. Load vs. displacement graphs were generated and the slope of the linear portion was calculated and recorded to better understand the mechanical properties of the glue-bond specimen. Figure 6.9 illustrates a typical load versus displacement graph. In looking at the graph, the proportional limit occurs at a relatively low load. In viewing the video, it appears that lathe checks begin to open at the proportional limit, but due to low camera resolution, this occurrence could not be measured adequately. Also, in many instances there was a noticeable dip or leveling off of the load increase just prior to failure. It appears that the majority of the critical lathe check propagation is taking place during this period. In addition, the curve more closely resembles a typical bending curve more than it does a shear curve, indicating that a considerable amount of bending may be taking place.

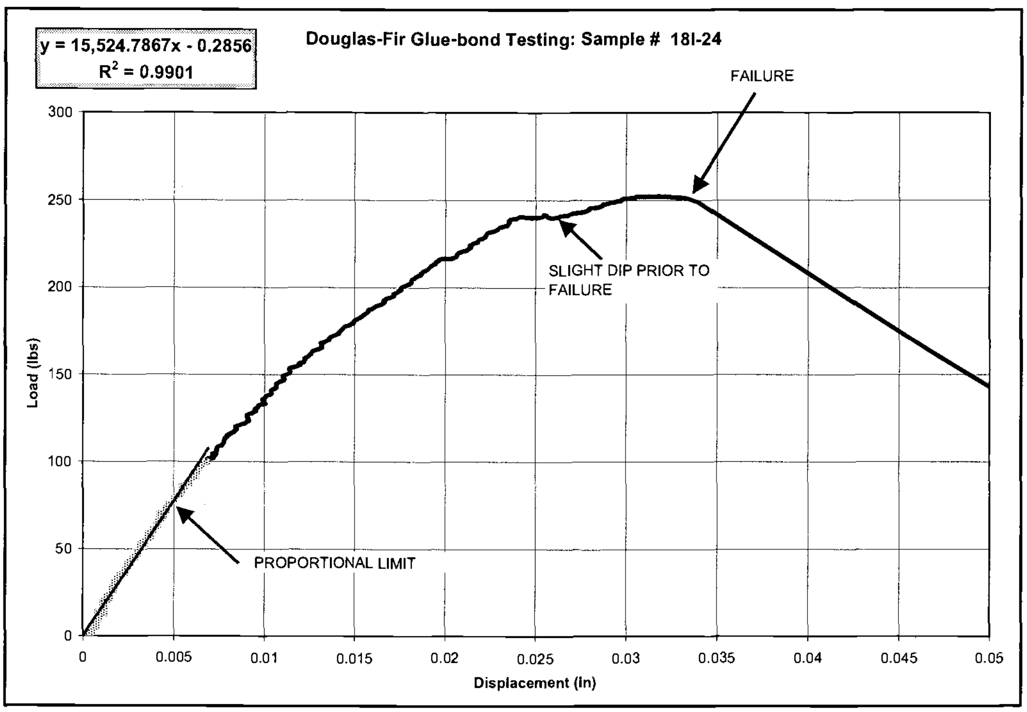


Figure 6.9. Typical load versus displacement (measured from head movement) graph obtained from testing plywood glue-bond samples.

Stepwise regression analysis was performed to investigate which veneer measures affect load vs. displacement properties of typical glue-bond samples. Table 6.10 provides the regression coefficients found to be statistically significant at the 0.05 level. The stepwise regression equation resulted in an R-squared value of 0.66. Looking strictly at latewood and lathe check measurements, the stepwise regression analysis showed that higher average latewood band angle and higher percent latewood results in higher elasticity. Conversely, as lathe check frequency, number of growth rings per inch, average lathe check depth, and earlywood/latewood ratio increases, the elasticity of glue-bond samples decreases.

Table 6.10. Significant variables, regression coefficients, and p-values from stepwise regression analysis for predicting load vs. displacement.

Independent Variable	Coefficient	p-value
Constant	18,520	0.000
Average Latewood Angle (absolute)	169.69	0.000
Percent Latewood in Test Area	125.54	0.000
Tight-side Range Maximum	53.47	0.000
Lathe Check Frequency (checks/inch)	-239.85	0.000
Growth Rings Per Inch	-176.63	0.000
Number of Latewood Bands in Test Area	710.10	0.000
Loose Low 3rd maximum minimum	94.52	0.011
Avg. Lathe Check Depth (in.)	-35,048	0.010
Earlywood/Latewood Width Ratio	-361.00	0.020
Tight High 3rd maximum minimum	104.77	0.021

Therefore, to optimize elasticity properties of glue-bond samples, veneer with high latewood band angles and percent latewood combined with less frequent, shallow lathe checks, larger growth rings, and a low earlywood/latewood ratio would need to be produced. However, it was not determined in this study as to how elasticity of glue-bond samples relates to actual panel in-service performance. In comparing influential measures on load at failure and slope, an increase in percent latewood positively affected both values, while check frequency and growth rings per inch had negative effects. This would be expected as load at failure and slope had a significant positive correlation with each other, as shown in Table 6.3. One annual ring characteristic found to have opposite effects on slope and load at failure was earlywood/latewood width ratio. As earlywood/latewood width ratio increased, elasticity (i.e., slope) decreased, while load at failure was found to increase. In comparison to percent wood failure, percent latewood and growth rings per inch showed an opposite effect on slope than they did for percent wood failure. This again would be expected as percent wood failure and slope had a significant negative correlation with each other as shown in Table 6.6.

In viewing the scanned images of the specimens prior to testing, it was apparent that lathe checks initially formed in a curved path that deflected in a TR direction (i.e., perpendicular to growth rings). The formation of lathe checks toward a TR mode during the process of peeling a log into veneer appeared to occur by a step-wise manner. The stepwise crack formation was evident by frequent changes in the growth plane of a crack as it passed through earlywood and latewood bands.

One of the objectives was to observe whether or not this TR crack growth pattern continued and caused failure of glue-bond specimens placed under stress. Upon viewing the digital video captured during testing, four different specimen failure patterns were observed. While lathe checks oriented in a TR direction appeared to open, they did not always propagate in that direction during failure of the glue-bond sample.

The first mode observed was a combination of TR propagation of the closest lathe check oriented towards the saw kerf and RT (i.e., normal to the radial direction and propagating in the tangential direction) failure of the remaining glue-bond specimen. Figure 6.10 shows that sequence of events to failure.

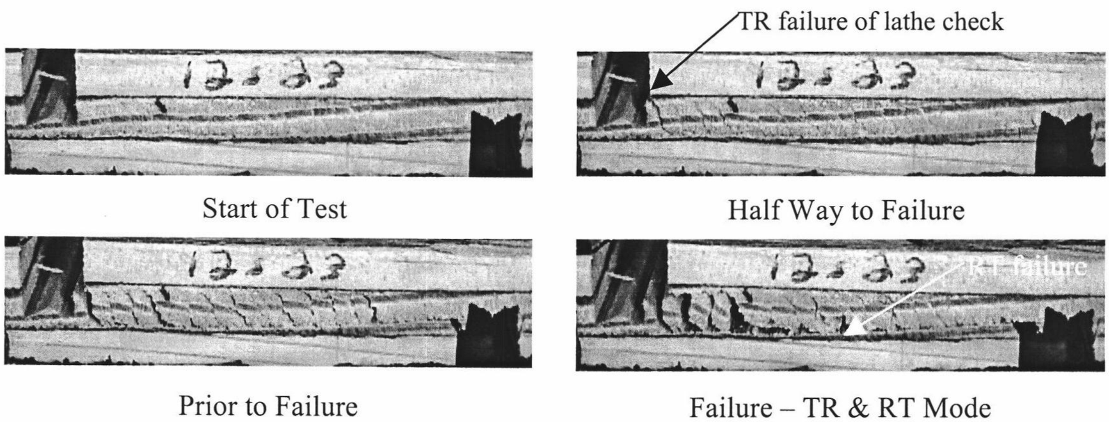


Figure 6.10. TR failure of first lathe check followed by RT failure in the rest of the specimen.

The closest lathe check propagated in a TR mode and terminated as it went to the saw kerf. This TR mode propagation appeared to be due to high bending forces at the saw kerfs. Other lathe checks further away from the saw kerfs were noted to open, but failure occurred as the wood material between lathe checks failed in an RT direction. When this material ruptured, the lathe checks present were connected together and specimen failure occurred. This may also help explain why check frequency tends to lower load at failure, since the "bridging" material between lathe checks is less as the frequency of lathe checks increases. Less distance of wood material between checks would in effect require less force to fracture this bridging material.

In the case where growth rings were oriented parallel with the glue-line, shear stress present in the test veneer near the center was oriented parallel to this bridging material and caused the failure to occur by these means. Past research by Schniewind and Centeno (71) showed that the critical stress intensity factor for wood in the TR and RT orientations were equivalent. Since wood material located away from the saw kerfs has a higher stress in the direction of loading rather than bending, the easiest path for lathe checks to propagate and the wood to fail is the RT direction. When growth rings were at a slight angle with respect to the glue-line, failure also occurred in the material between lathe checks in an RT mode, but the shear forces in the specimen were not parallel to the mode of failure. In many instances, both RT bridging material and TR lathe check propagation failure appeared in a single sample.

The second mode of failure observed was complete RT mode fracture of the wood. Figure 6.11 shows the lathe checks opening and being deflected toward an RT mode. Even the lathe checks near the saw kerf were noted to propagate toward the saw kerf by an RT mode. It was still the case that the closest lathe check oriented toward the saw kerf propagated first, followed by sudden specimen failure in the RT mode. Many of the failures in the RT direction also occurred in earlywood near the earlywood/latewood interface. This occurrence was likely due to the fact that strength in an RT mode is controlled by cell wall thickness, so cracks tend to propagate in the thinner cell wall earlywood (18).

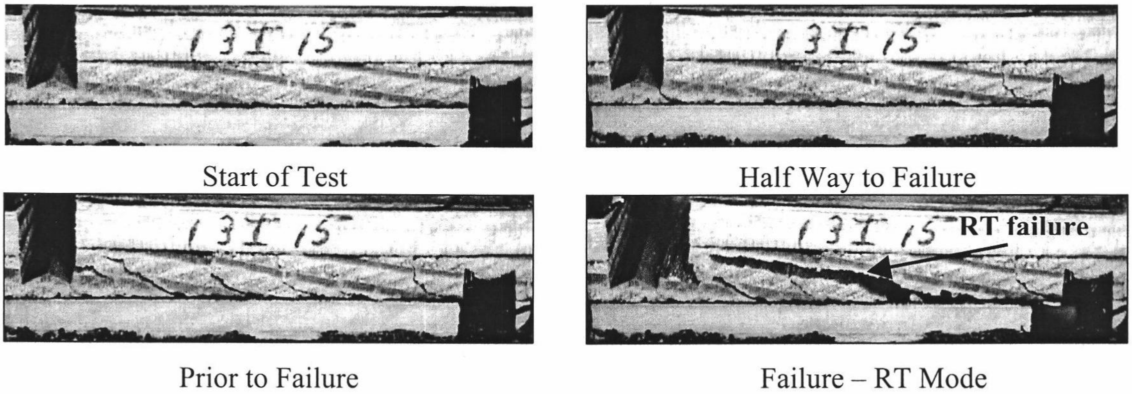


Figure 6.11. RT mode failure of first lathe check followed by sudden complete RT failure of the specimen.

The third type of failure occurred when samples failed near the loose side glue-line; it appeared to do so by peeling forces due to bending of the sample near the saw kerfs. Figure 6.12 shows this type of failure occurring due to the wood material between lathe checks rotating.

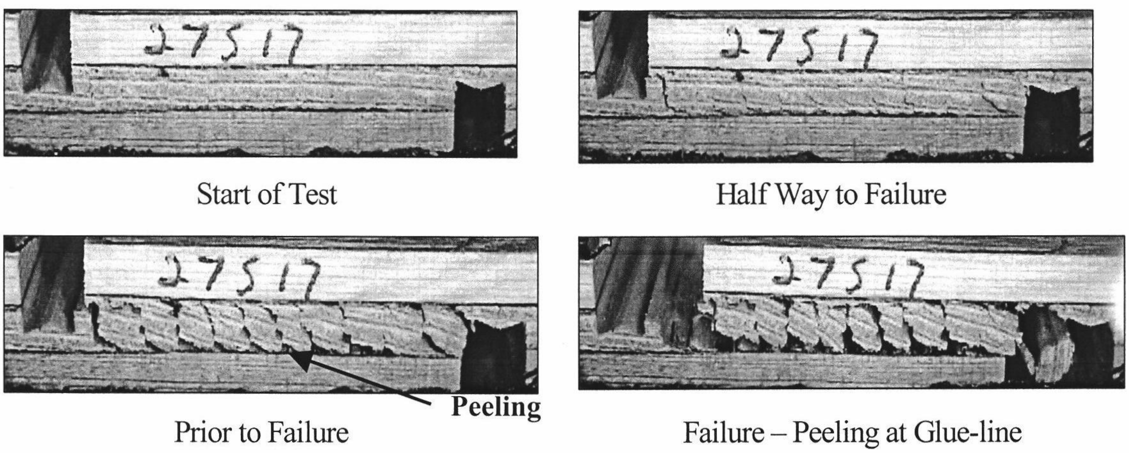


Figure 6.12. Failure in the loose-side glue-line due to bending and peeling forces causing rotation of the wood material between lathe checks.

Bending forces made the wood material between lathe checks rotate upward and peel from the end toward the saw kerf to the next immediate lathe check. In many cases, this peeling also caused RT mode failure of wood material near the glue-line. Frequent lathe checks represent less wood material between lathe checks that require peeling, resulting in a lower load at failure as check frequency increased.

The fourth type of failure pattern observed was at the tight-side and loose-side glue-lines. In Figure 6.13, it can be seen that the lathe checks appear to propagate slightly, followed by rapid specimen failure in the glue-line. In many instances, the failure occurred with a portion of the top and bottom glue-line failing. When failure occurred at the glue-line, it would seem that the strength of the wood material was greater in the TR and RT direction than the strength at the glue-line.

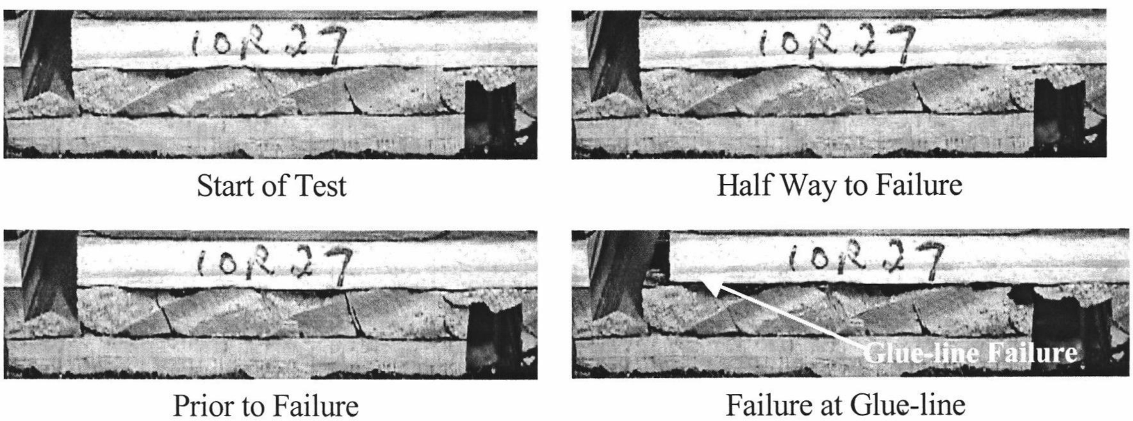


Figure 6.13. Failure at the glue-line due to rougher veneer surface and glue-line strength below that of the wood material.

Of particular interest is the veneer surface roughness near the saw kerfs. If the veneer did not have sufficient bonding at the saw kerf locations and a corresponding strength capacity to force the wood material to fail, glue-line failure would be initiated. This situation occurred at both high and low loads and was most likely dependent upon characteristics of the wood material in the test area.

For crack propagation, further studies investigating stress distribution within each individual specimen and how veneer characteristics affect such distributions are needed to explain the mechanism of failure modes witnessed during this study. Higher resolution cameras would allow more precise measuring of bending displacements taking place at the saw kerfs. Also, use of a strain indicating coating or matrix applied to each face of the specimen's test area would allow for determination of stress distributions.

7. CONCLUSIONS AND FUTURE RESEARCH RECOMMENDATIONS

This study investigated the influence of veneer surface roughness, lathe checks, and annual ring characteristics of Douglas-fir veneer on industry accepted plywood glue-bond performance as indicated by load at failure and percent wood failure. Also, lathe check crack propagation modes were observed for standard glue-bond samples. Visual and optical measurement techniques in a controlled laboratory setting were used to determine veneer roughness and investigate their effect on glue-bond performance. The use of digital video cameras provided information about how lathe checks propagated and how failure occurred when glue-bond specimens were placed under stress. By measuring various lathe check and annual ring characteristics, information about important veneer qualities and their affect on glue-bond performance was determined.

The results of the study indicate that glue-bond quality under the current test methods is influenced by both veneer roughness and wood material properties (i.e., lathe check and annual ring characteristics). Load at failure was mainly influenced by wood material properties, in particular, lathe check frequency, along with some effect due to veneer roughness. Percent wood failure was mainly influenced by veneer roughness, along with interactive effects of annual ring orientation contributing to specimen failure.

Smoother visual surface roughness characteristics of veneer were indicative of higher mean percent wood failure. Smooth category veneer provided the highest percent wood failure, followed by intermediate and rough veneer respectively. This indicated that visually rougher veneer resulted in lower percent wood failure. In contrast to using mathematical roughness measures, a higher roughness measure (i.e., indicator of rougher surface) did not always produce lower percent wood failure. This occurrence likely was a result of the mathematical roughness measures taking into account the entire one-inch square area. Analysis of the roughness measures near the saw kerfs may provide better indications of how mathematical surface roughness affects percent wood failure. This specific issue requires further investigation. Load at failure results did not indicate that smoother visual roughness categories resulted in higher strength glue-bonds. Intermediate visual roughness resulted in the highest mean load at failure, followed by rough and smooth categories, respectively. This indicated that visual roughness was not the most influential veneer characteristic in determining load at failure; instead other characteristics also affected the strength of standard plywood glue-bond samples.

Seven veneer characteristics were found to be influential in determining and predicting load at failure. Of these seven, two lathe check and three annual ring characteristics were significant. Lathe check frequency (i.e., number of lathe checks per inch) negatively affected load at failure. As the number of lathe checks increased, the amount of "bridging" material between each check was decreased and less force was required to fracture the material and join the checks together. The distance of the second lathe check in from the saw kerf and oriented toward the saw kerf had a negative affect on load at failure and was correlated and interacted with check frequency.

Traditionally, plywood manufacturers envision quality veneer as being free from deep lathe checks and containing frequent, shallow checks. This study found that lathe check depth did not influence load at failure. Rather, a high frequency of lathe checks was the most significant factor in reducing load at failure. Plywood manufacturers interested in obtaining higher load at failure values will need to reduce the number of lathe checks by manipulating their lathe settings and block conditioning accordingly. However, they will also need to find a good balance between lathe check depth and frequency in order to minimize handling losses. This study did not find any association that suggested that a higher frequency of lathe checks results in veneer with shallower checks. Rather, it was found that as lathe check frequency increased, lathe check depth also increased, but even though the correlation coefficient between the two was statistically significant, it was also fairly small.

A higher number of growth rings per inch resulted in a decrease in load at failure, but this finding may be confounded by a difference in growth rings per inch and each roughness category. Also, increases in both percent latewood in the test area and the ratio of earlywood width/latewood width were found to positively influence load at failure values. An increase in two mathematical veneer roughness measures, tight-side range max.min. and tight-side low 3rd minimum, positively influenced load at failure. Because the test specimen's geometry meant that the shear stress was much more concentrated in the wood material and higher stresses were located near the saw kerfs, mathematical measures of veneer roughness near the saw kerfs may provide a better indication of glue-bond quality than the roughness measures over the entire one-inch square area as investigated in this study.

Six veneer characteristics were found to be influential in determining and predicting percent wood failure. These included three annual ring and three mathematical roughness measures. Higher percentages of latewood in the test area negatively influenced percent wood failure. This is in contrast to load at failure, which increased as percent latewood increased. Percent latewood at the tight-side glue-line and growth rings per inch positively affected percent wood failure. As the number of growth rings per inch increased (i.e., slower grown), the wood failure percentage increased, but again may be confounded by differences in growth rings per inch between categories. Veneer roughness measures of tight-side low 3rd minimum, loose-side low 3rd max.min. and CLA average were highly correlated with percent wood failure. Smoother surfaces have less negative tight-side low 3rd minimum values, and it was found that as tight-side low 3rd minimum became less negative, percent wood failure increased. Smoother surfaces also have a lower loose-side low 3rd max.min. value and results indicated that as loose-side low 3rd max.min. decreased, percent wood failure increased. However, rougher surfaces result in a higher CLA than smoother surfaces, and the study indicated that as the CLA increased, percent wood failure also increases. Due again to the specimen's configuration, these roughness measures may change the stress distribution in the test area and influence how much shear stress is placed on the wood material, thus causing wood failure to occur.

In predicting both load at failure and percent wood failure, the R-squared values for the stepwise regression equations were relatively low. However, while higher R-square values were obtained by using robust regression techniques, the stepwise equations, from a practical standpoint, performed just as well in predicting the test results from the data measured in the study. While the robust regression technique required 55 measures to be made, the stepwise equations only required seven measures to predict load at failure and six to predict percent wood failure.

Four modes of failure in plywood glue-bond specimens were observed to occur. The first was a combination of TR mode crack propagation of the first lathe check oriented toward a saw kerf followed by RT mode failure of the rest of the specimen. The second mode was complete RT mode crack propagation and failure. The third was complete failure by peeling at the glue-line, and the fourth mode was failure at the glue-line with no significant crack propagation A significant amount of bending was observed at each saw kerf. This bending placed tearing or peeling forces and higher stresses at the saw kerf locations, leaving the glue-lines to be relatively shear stress free. The highest amount of shear stress would most likely occur in the center of the wood material in the test area.

It was evident from this study's results that specimen geometry and inherent moments near the saw kerfs had a significant impact on the way stresses were distributed. The study provides insight into what veneer characteristics influence load at failure and percent wood failure. Lathe check and annual ring properties are important because the wood material itself, rather than the glue-line, was under stress due to the specimen geometry concentrating the stress away from the glue-line and creating high peeling stresses at the saw kerfs. Veneer roughness alone did not determine glue-bond quality under traditional plywood test methods, but would most likely influence how the stresses are distributed in the specimen.

This study came to the same conclusion as Kaneda et al. (37), a high frequency of lathe checks results in lower strength. This study showed that as lathe check frequency increased, load at failure decreased. Koch (41) found lathe check frequency to have a negative effect on percent wood failure. This study did not find that lathe check frequency was significant in predicting percent wood failure. Lathe check frequency did, however, have a statistically significant, but relatively weak positive correlation (correlation coefficient = 0.139) to percent wood failure.

Using visual veneer roughness, past research by Neese et al. (60) found a significant difference in average load at failure between smooth and rough, and intermediate and rough, with no difference between smooth and intermediate. This research showed that there was a statistically significant difference in average load at failure between smooth and rough, and intermediate and rough, with no difference between intermediate and rough (based on multiple range test). This indicates that visual roughness alone is not the only factor that influences load at failure, but that lathe check and annual ring characteristics interact and contribute to load at failure of standard glue-bond specimens. In terms of percent wood failure, Neese et al. (60) found a significant difference in average percent wood failure between smooth and intermediate, and smooth and rough, with no difference between intermediate and rough. This research, however, indicated that there was a statistically significant difference in average percent wood failure between all three groups. As a result, it was found that veneer roughness was the primary influence on percent wood failure, while also indicating that annual ring orientation interacted and contributed in determining percent wood failure.

Mathematical veneer roughness measures did not adequately predict percent wood failure. However, this study did indicate that various mathematical veneer roughness measures significantly influenced percent wood failure and that many of the veneer roughness measures are highly correlated with each other. In addition, mathematical veneer roughness measures were highly correlated with average latewood angle (absolute) to the glue-line and as the angle increases, roughness increases.

To better predict glue-bond quality using current test methods, future research that investigates the effects of surface roughness near the saw kerf, and quantifies the stress development in plywood glue-bond specimens, will need to be performed. Future research is needed to determine the effects of surface roughness, lathe check, and annual ring characteristics of veneer on the stress development in a saw-kerfed specimen. Analyses could then be performed to determine how these factors interact and influence specimen failure. However, such research will present a large undertaking and may not result in any practical information for the plywood industry.

The underlying question is clearly whether the test method currently used by industry evaluates glue-bond performance or rather evaluates the performance or strength of the wood. Since the current method places a great deal of stress in the wood material, it may be that the test method has the potential to predict structural performance of plywood once in service. The saw-kerfed method, however, does not provide the means to adequately determine glue-bond performance. The intent of a glue-bond performance test is to determine whether or not sufficient bonding takes place at the glue-line. To do this, stresses must be concentrated at the glue-line, particularly the shear stresses. As evident from this study and past studies, the standard saw kerf specimens used in the plywood industry do not provide for concentrated shear stress at the glue-line. To reliably relate veneer surface roughness to glue-bond quality, a new test method will need to be developed that provides uniform shear stress distribution at the glue-line, while eliminating, or at least reducing to an insignificant amount, the degree of tearing and bending forces on the specimen. Until a new testing method is developed, predicting glue-bond quality using veneer roughness by itself will not be able to be investigated. Furthermore, until a new test method is developed, the true influence of veneer roughness cannot be determined without interactions of wood material properties playing a role in glue-bond quality results. By placing shear stresses solely at the glue-line, a better chance exists to successfully predict both percent wood failure and load at failure based on veneer roughness.

From an industry perspective, PS 1 does not provide requirements for load at failure; rather glue-bond performance is based solely on percent wood failure. From a mathematical roughness standpoint, it may not be appropriate to target a specific value for roughness; rather, this study proved that visually rougher surfaces reduce the percent wood failure in glue-bond specimens. To achieve high glue-bond performance in terms of percent wood failure, veneer with relatively smooth visual surfaces and low percentages of latewood in the veneer should be used.

In contrast, many of the measures that positively affect percent wood failure, negatively affect load at failure. Even though PS 1 does not have load at failure requirements, other standards in Europe and Japan do. Also, since standard plywood glue-bond tests, in essence, measure the strength of the veneer material, a high possibility exists that load at failure has direct implications to in-service strength and performance of plywood. In terms of load at failure, percent latewood in veneer positively affects load at failure. The exact opposite was the case when looking at percent wood failure as an increase in percent latewood reduced percent wood failure. However, the main influential variable influencing load at failure under the current test method is lathe check frequency. As the number of lathe checks per inch increases, load at failure decreases. In addition, as the earlywood/latewood band width ratio increases, load at failure increases. So ideally, veneer with less frequent lathe checks, higher earlywood/latewood width ratio, and a high percentage of latewood in the test area should be peeled to increase load at failure. Roughness measures may be of little importance in standard glue-bond specimens, since much of the stresses are concentrated in the wood rather than at the glue-line, but the surface must be sufficiently bonded to force the applied load into the wood away from the glue-line.

It is evident from this study that industry needs to pay close attention to veneer quality to achieve adequate glue-bond quality. Specifically, veneer roughness and lathe check frequency are key to producing veneer suitable to achieve sufficient bonding between veneers. While peeling logs to a smaller diameter and at very high speeds, lathe settings will need to be manipulated to produce veneer with fewer lathe checks and smoother surfaces, thus resulting in higher load at failure and percent wood failure values. They must take care to balance both load at failure and percent wood failure to achieve sufficient glue-bond performance. Even if a high percent wood failure is achieved, but at a very low load, the impacts on strength capacities of in-service plywood could be jeopardized. In particular, strength properties such as rolling shear (i.e., planar shear) may be significantly reduced if glue-bond specimens show a low load at failure. However, this assumption will require further investigation to examine how standard plywood glue-bond specimens and plywood rolling shear capacity are related.

This study was successful in separating influential veneer characteristics that affect plywood glue-bond performance and indicated that some measures have an opposite effect on load at failure than on percent wood failure. The opportunity exists to further evaluate influential veneer characteristics using another, yet to be developed, test method that provides better evaluation of adhesion at the glue-line. By producing quality veneer with smooth surfaces and few lathe checks, the need for manufacturers to increase glue-spread rate can be minimized and glue-bond quality maintained.

BIBLIOGRAPHY

1. Akande, J.A., and G.H. Kyanka. 1990. Evaluation of tensile fracture in aspen using fractographic and theoretical methods. Wood and Fiber Sci. 22(3):283-297.

2. ANSI. 1986. Surface Texture (Surface Roughness, Waviness, and Lay). American National Standard ANSI/ASME B46.1-1985. The American National Standards Institute, N.Y., N.Y.

3. Ashby, M.F., K.E. Easterling, R. Harrysson and S.K. Maiti. 1985. Proc. R. Soc. London A 398. 261 pp.

4. Batey,T.E. 1955. Minimizing face checking of plywood. Forest Prod. J. 5(5): 277-285.

5. Baldwin, Richard F. 1995. Plywood and Veneer-based Products: Manufacturing Practices. Miller Freeman Books, San Francisco, 338 pp.

6. Bennett, Carl A., and Norman L. Franklin. 1996. Statistical Analysis in Chemistry and the Chemical Industry. John Wiley and Sons, Inc. New York, NY.

7. Boatright, S.W.J. and G.G. Garret. 1983. J. Mater. Sci. 18(1983):21-81.

8. Bodig, J., and B.A. Jayne. 1993. Mechanics of Wood and Wood Composites. Krieger Publishing, Melbourne, FL. 736 pp.

9. Cade, J.C., and E.T. Choong. 1969. Influence of cutting velocity and log diameter on tensile strength of veneer across the grain. Forest Prod. J. 19(7):52-53.

10. Chen, J.T., and W.C. Wang. 1996. Experimental analysis of an arbitrarily inclined semi-infinite crack terminated at the bimaterial interface. Experimental Mechanics. 36(1):7-16.

11. Choi, D., J.L. Thorpe, W.A. Cote Jr., and R.B. Hanna. 1996. Quantification of compression failure propagation in wood using digital image pattern recognition. Forest Prod. J. 46(10):87-93.

12. Chow, S., and W.G. Warren. 1972. Efficiency of plywood bond-quality testing methods. Canadian Forestry Service, Western Forest Products Laboratory, Information Report VP-X-104. 14pp.

13. Collins, E.H. 1960. Lathe check formation in Douglas-fir veneer. Forest Prod. J. 10(3):139-140.

14. Corder, S.E., and G.H. Atherton. 1963. Effect of peeling temperatures on Douglas-fir veneer. Forest Research Laboratory, Oregon State University. 31pp.

15. Cumming, J.D., and B.M. Collett. 1970. Determining lathe settings for optimum veneer quality. Forest Prod. J. 20(11):20-27.

16. Cumming, J.D., C. Fischer, and F.E. Dickinson. 1969. Rotary veneer cutting characteristics of young-growth redwood. Forest Prod. J. 19(11):26-30.

17. Demas, T. 1992. Basic Plywood Processing. American Plywood Association, Form No. Z439B. Tacoma, WA.

18. Dill-Langer, G., S. Lutze, and S. Aicher. 2002. Microfracture in wood monitored by confocal laser scanning microscopy. Wood Science and Technology. 36(2003): 487-499.

19. European Standard EN 314-1&2. 1993. Plywood - Bond quality – Part 1. Test Methods, Part 2, Requirements. European Committee for Standardization., Brussels. 14pp.

20. Faust, T.D., and James T. Rice. 1986. Effects of veneer surface roughness on the gluebond quality of southern pine plywood. Forest Prod. J. 36(4):57-62.

21. Faust, T.D., and James T. Rice. 1986. Characterizing the roughness of southern pine veneer surfaces. Forest Prod. J. 36(11/12):75-81.

22. Faust, T.D. 1987. Real time measurement of veneer surface roughness by image analysis. Forest Prod. J. 37(6):34-40.

23. Faust, T.D., and James T. Rice. 1987. Effects of variable glue application rate strategy on bond quality and resin consumption in the manufacturing of southern pine plywood. Forest Prod. J. 37(7/8):64-70.

24. Faust, T.D., and Bruce E. Borders. 1992. Using variable glue spread rated to control bond quality and reduce glue consumption in pine plywood production. Forest Prod. J. 42(11/12):49-56.

25. Feihl, O., and V Godin. 1962. Peeling defects in veneer. Their causes and control. Dept. of Forestry, Technical Note No. 25. 18pp.

26. Feihl, O., and V Godin. 1970. Peeling defects in veneer. Their causes and control. Dept. of Fisheries and Forestry, Canadian Forest Service. Publication No. 1280. 18pp.

27. Feihl, O., H.G.M. Colbeck, and V. Godin. 1965. The rotary cutting of Douglas-fir. Can. Dep. Forest., Publ. 1004. 31pp.

28. Funck, James W., J.B. Forrer, D.A. Butler, C.C. Brunner, and A.G. Maristany. 1992. Measuring surface roughness on wood: a comparison of laser scatter and stylus tracing approaches. SPIE Vol.1821:173-184.

29. Furukawa, I. 1978. Optical microscopic studies on the longitudinal tensile failure of notched microtome sections. Mokuzai Gakkaishi Journal of the Japan Wood Research Society. 24(9):598-604.

30. George, P., and D.G. Miller. 1970. Detection of roughness in moving Douglas-fir veneer. Forest Prod. J. 20(7):53-59.

31. Gibson, L.J., and M.F. Ashby. 1988. Cellular Solids: Structure and Properties. Pergamon Press, Oxford.

32. Grady, J.E., and C.T. Sun. Dynamic delamination crack propagation in a graphite/epoxy laminate. Composite Materials: Fatigue and Fracture, ASTM STP 907. H.T. Hahn, Ed., American Society for Testing and Materials, Philadelphia, 1986, pp. 5-31.

33. Hailey, J.R.T., and W.V. Hancock. 1973. Methods and techniques for veneer peeling research. Canadian Forestry Service, Western Forest Products Laboratory, Information Report VP-X-107. 21pp.

34. Haygreen, J.G., and J.L. Bowyer. 1989. Forest Products and Wood Science: an Introduction (2nd ed.). Iowa State University Press, Ames, Iowa.

35. Hoadley, R.B. 1963. Influence of certain variables on veneer-cutting behavior. Forest Prod. J. 13(12):538-548.

36. JAS SE-3. 2000. Japanese Agricultural Standard for Plywood. Japanese Plywood Inspection Corporation. Tokyo, Japan. 36pp.

37. Kaneda, H., H. Sasaki, and T. Maku. 1968. Fundamental studies on the mechanical properties of plywood: Influence of the lathe checks of veneer on the strength and elasticity of plywood. Wood Res., Kyoto No. 45:9-22.

38. Kinloch, A.J., and R.J. Young. 1983. Fracture Behavior of Polymers, Applied Science, London, England.

39. Kivimaa, E. 1965. Investigating rotary veneer cutting with the aid of a tension test. Forest Prod. J. 6(7):251-255.

40. Knospe, L. 1964. The influence of cutting process in slicing and peeling on the quality of veneers. U.S. Forest Serv., Forest Prod. Lab., Madison, WI. Transl. 607. 10pp.

41. Koch, P. 1965. Effects of seven variables on properties of southern pine plywood: Part I, maximizing wood failure. Forest Prod. J. 15(9):335-361.

42. Koch, P. 1965. Effects of seven variables on properties of southern pine plywood: Part II, maximizing wet shear strength. Forest Prod. J. 15(11):463-465.

43. Koch, P. 1965. Effects of seven variables on properties of southern pine plywood: Part IV, minimizing face checking. Forest Prod. J. 15(12):495-499.

44. Koch, P. 1967. Minimizing and predicting delamination of southern plywood on exterior exposure. Forest Prod. J. 17(2):41-47.

45. Koch, P. 1970. Delamination of southern pine plywood during three years of exterior exposure. Forest Prod. J. 20(11):29-31.

46. Koch, P.E. 1972. Utilization of the Southern Pines: Vol. II. U.S. Department of Agriculture-Forest Service, Washington D.C.

47. Leney, Lawrence. 1960. A photographic study of veneer formation. Forest Prod. J. 10(3):133-139.

48. Leney, Lawrence, and R.H. Moir. 1968. Veneer characteristics as related to failure in plywood tension-shear specimens. Forest Prod. J. 18(4):33-39.

49. Lutz, J.F. 1956. Effect of wood-structure orientation on smoothness of knife-cut veneers. Forest Prod. J. 6(11):464-468.

50. Lutz, J.F. 1964. How growth rate affects properties of softwood veneer. Forest Prod. J. 14(3):97-102.

51. Lutz, J.F., and R.A. Patzer. 1966. Effects of horizontal roller-bar openings on quality of rotary-cut southern pine and yellow poplar veneer. Forest Prod. J. 16(10):15-25.

52. Marian, J.E., D.A. Stumbo, and C.W. Maxey. 1958. Surface texture of wood as related to glue-joint strength. Forest Prod. J. 8(12):345-351.

53. Mark, R.E., 1981. Adhesion in Cellulosic and Wood-Based Composites. Plenum Press, New York, New York.

54. Marra, A.A. 1955. A new method for testing wood adhesives: I. The specimen. Forest Prod. J. 5(5):301-305.

55. McMillan, C.W. 1958. The relation of mechanical properties of wood and nosebar pressure in the production of veneer. Forest Prod. J. 8(1):23-32.

56. Montgomery, D.C, E.A. Peck, and G.G. Vining. 2001. Introduction to Linear Regression Analysis. 3rd ed. Wiley, New York, NY. 641pp.

57. Mummery, Leigh. 1990. Surface Texture Analysis Handbook. Schnurr Druck: Hommelwerke GmbH, West Germany, 106pp.

58. Musilino, R. September 2001. Personal communication with TECO Corporation, Madison, Wisconsin.

59. Neese, J.L. 1997. Characterizing Veneer Roughness and Glue-bond Performance in Douglas-fir Plywood. M.S. thesis, Oregon State University, Corvallis, OR.

60. Neese, J.L., J.E. Reeb, and J.W. Funck. 1999. Relating Traditional Surface Roughness Measures to Glue-bond Quality in Plywood. Submitted to Forest Prod. J.

61. Palka, L.C. 1966. Factors affecting the strength properties of Douglas-fir plywood normal to the glueline. Forest Prod. J. 16(3):44-52.

62. Palka, L.C., and B. Holmes. 1973. Effect of log diameter and clearance angle on the peel quality of 0.125-inch-thick Douglas-fir veneer. Forest Prod. J. 23(7):33-41.

63. Palka, L.C. 1974. Veneer cutting review – factors affecting and models describing the process. Canadian Forestry Service, Western Forest Products Laboratory, Information Report VP-X-135. 54pp.

64. Panshin, A.J., and, Carl de Zeeuw. 1980. Textbook of Wood Technology: Structure, Identification, Properties, and Uses of Commercial Woods of the United States and Canada (4th ed.). McGraw-Hill, Inc., New York.

65. Pellicane, P.J., J. Bidig, and J.R. Goodman. 1982. Simulation of the tensile strength-fracture toughness relationship. Wood Science. 14(4):168-177.

66. Peters, C.C., A.F. Mergen, and H.R. Panzer. 1969. Effect of cutting speed during thick slicing of wood. Forest Prod. J. 19(11):37-42.

67. Porter, A.W. 1964. On the Mechanics of Fracture in Wood. Forest Prod. J. 14(8): 325-331.

68. River, B.H., 1994. Fracture of Adhesive-Bonded Wood Joints. Pizza, A., Mittal, K.L., eds. Handbook of Adhesive Technology. New York: Marcel Dekker, Inc.; 1994. Chapter 9.

69. SAS Statistical Software, Release 8.02. Copyright 1999-2001. SAS Institute Inc. Cary, NC.

70. Schniewind, A.P., and R.A. Pozniak. 1971. On the fracture toughness of Douglas-fir wood. Engineering Fracture Mechanics. Vol. 1971(2):223-233.

71. Schniewind, A.P., and J.C. Centeno. 1973. Fracture toughness and duration of load factor I. Six principle systems of crack propagation and the duration factor for cracks propagating parallel to grain. Wood and Fiber. 5(2):152-159.

72. Sellers, T. 1985. Plywood and Adhesive Technology. Marcel Dekker, N.Y. 661pp.

73. Stumbo, D.A. 1960. Surface texture measurements for quality and production control. Forest Prod. J. 10(2):122-124.

74. Stumbo, D.A. 1963. Surface texture measurements methods. Forest Prod. J. 13(7):299-304.

75. Thomas, G.G. 1974. Surface Texture: Chapter 8 in Engineering Metrology. John Wiley and Sons, New York, NY.

76. Thuvander, F., L.O. Jernkvist, and J. Gunners. 2000. Influence of repetitive stiffness variation on crack growth behaviour in wood. J. Mater. Sci. 35(2000):6259-6266.

77. Thuvander, F., M. Sjodahl, and L.A. Berglund. 2000. Measurement of crack tip strain field in wood at the scale of growth rings. J. Mater. Sci. 35(2000):6267-6275.

78. Thuvander, F., and L.A. Berglund. 2000. In situ observations of fracture mechanism for radial cracks in wood. J. Mater. Sci. 35(2000):6277-6283.

79. Tomin, V.M. 1977. Crack propagation in wood by vibration stresses. Holztechnologie. 18(1):22-26.

80. USDA Forest Products Laboratory. 1994. Moisture Content and the Properties of Clear Southern Pine. Research Paper FPL-RP-531. U.S. Department of Agriculture Forest Product Laboratory, Madison, WI

81. USDA Forest Products Laboratory. 1999. Wood Handbook: Wood as an Engineering Material. U.S. Department of Agriculture Forest Product Laboratory, Madison, WI.

82. Vasic, S, I. Smith and E. Landis. 2002. Fracture zone characterization – Micro mechanical study. Wood Fiber Sci. 34(1):42-56.

83. Voluntary Product Standard PS 1-95. 1995. Construction and Industrial Plywood. National Bureau of Standards, Department of Commerce, Government Printing Office. Washington, D.C.

84. Wangaard, F.F., and R.P. Saraos. 1959. Quality of rotary-cut veneer. Forest Prod. J. 9(6):179-187.

85. Yavorsky, J.M., J.H. Cunningham, and N.G. Hundley. 1955. Survey of factors affecting strength tests of glue joints. Forest Prod. J. 5(5):306-311.

APPENDICES

Appendix A. Box Plots of Individual Lathe Check and Annual Ring Characteristics

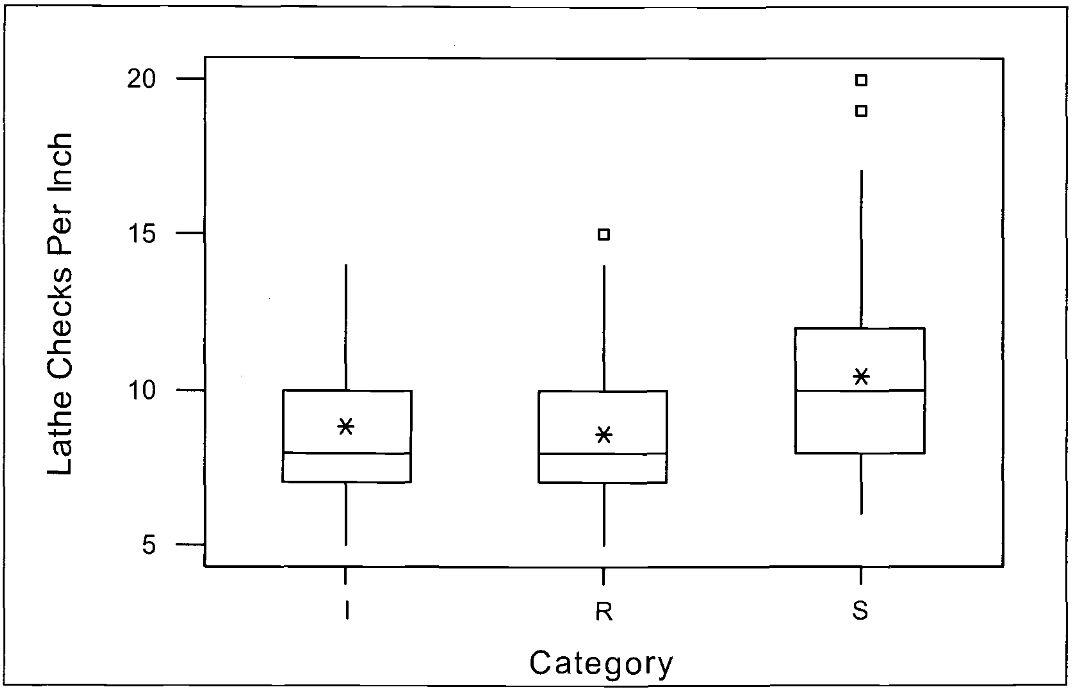


Figure A- 1. Box plot: lathe check frequency.

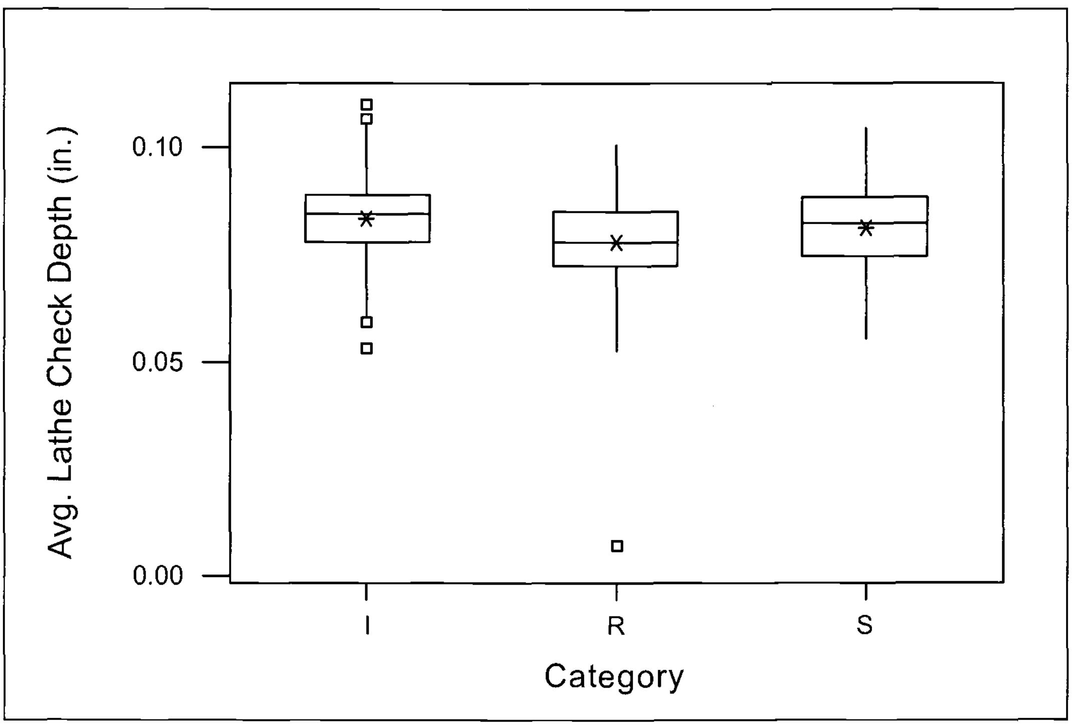


Figure A- 2. Box plot: lathe check depth.

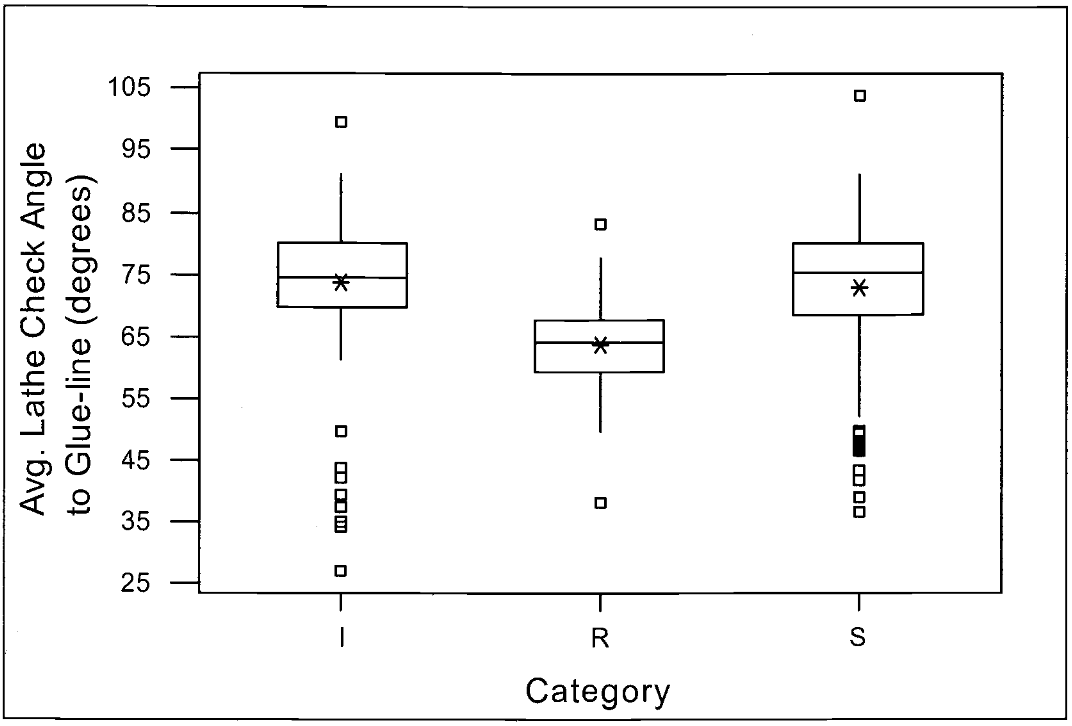


Figure A- 3. Box plot: average lathe check angle to glue-line.

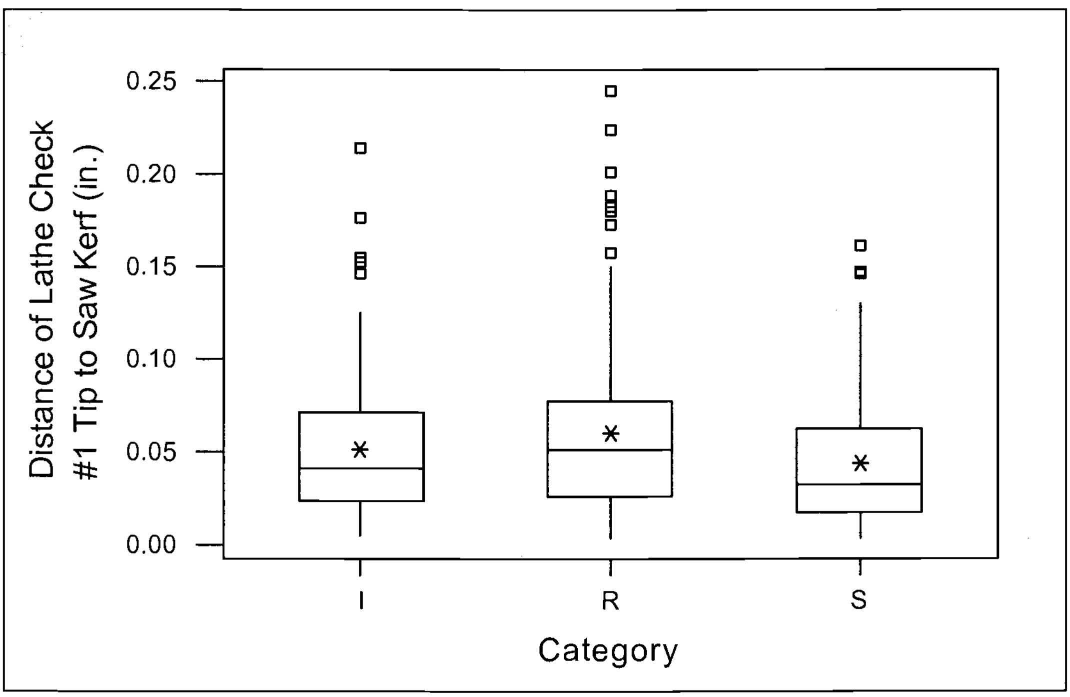


Figure A- 4. Box plot: distance of lathe check #1 tip to saw kerf.

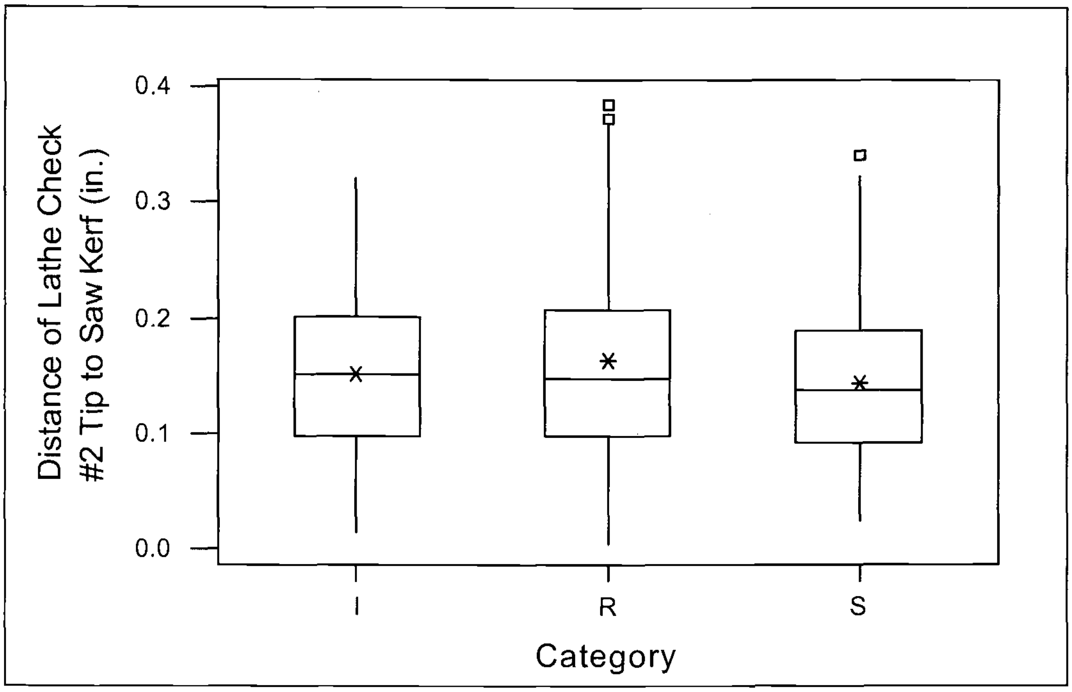


Figure A- 5. Box plot: distance of lathe check #2 tip to saw kerf.

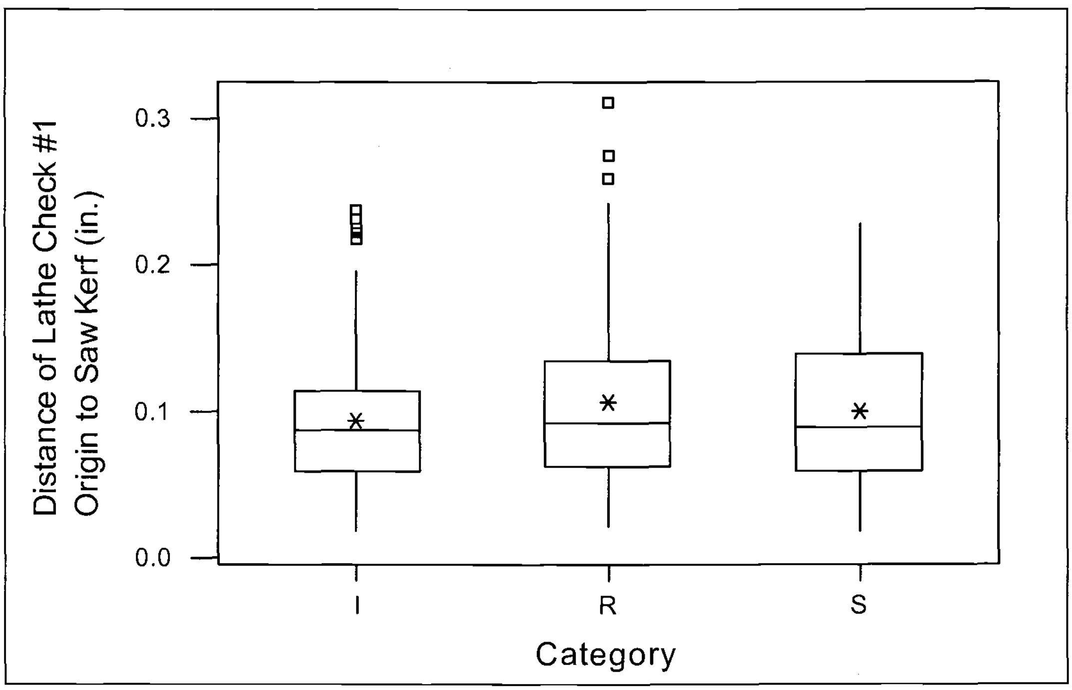


Figure A- 6. Box plot: distance of lathe check #1 origin to saw kerf.

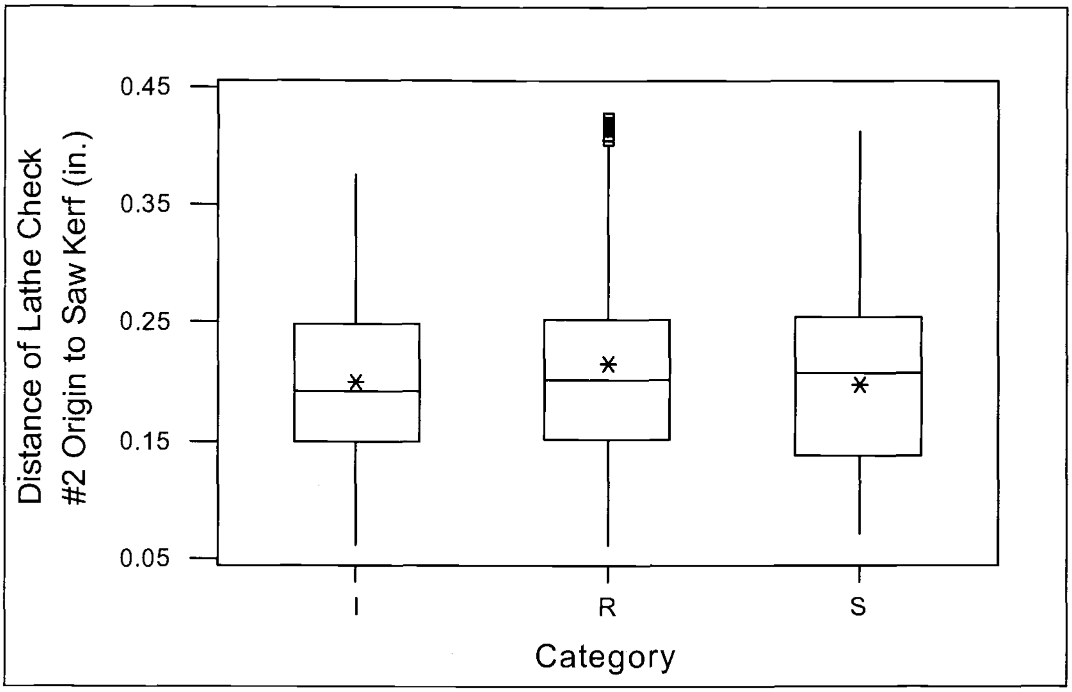


Figure A- 7. Box plot: distance of lathe check #2 origin to saw kerf.

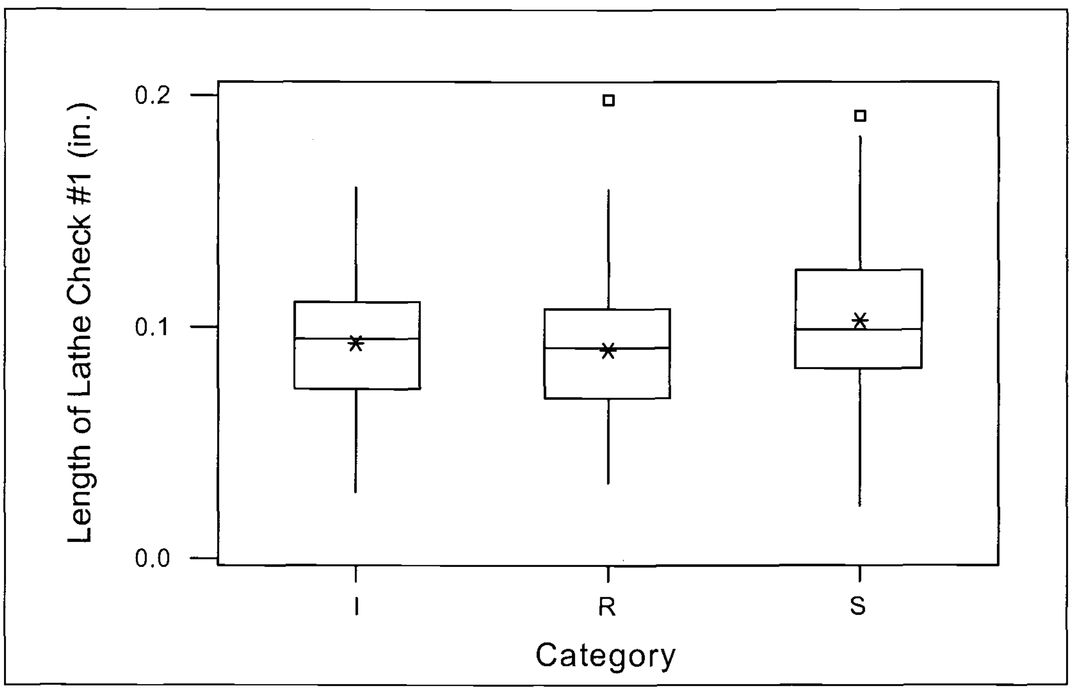


Figure A- 8. Box plot: length of lathe check #1.

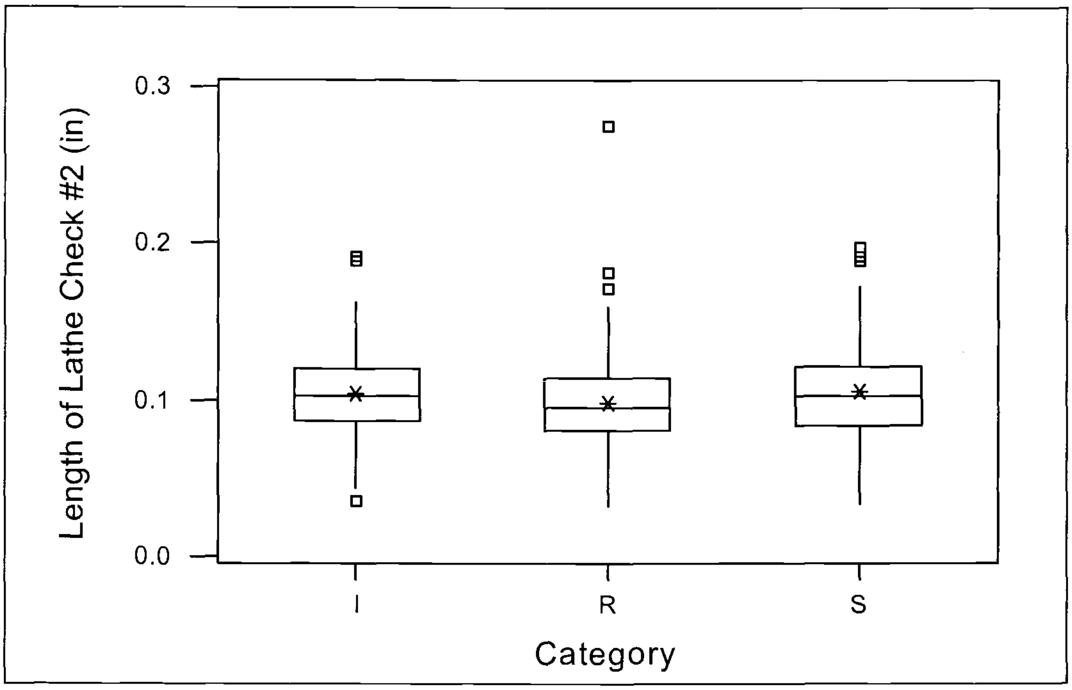


Figure A- 9. Box plot: length of lathe check #2.

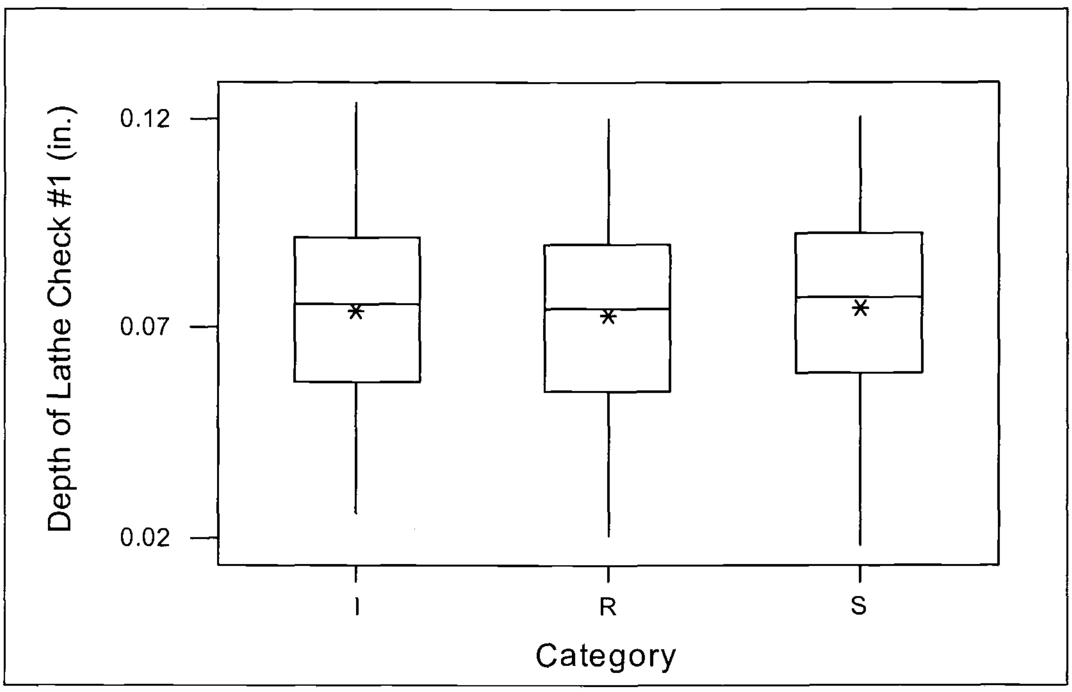


Figure A- 10. Box plot: depth of lathe check #1.

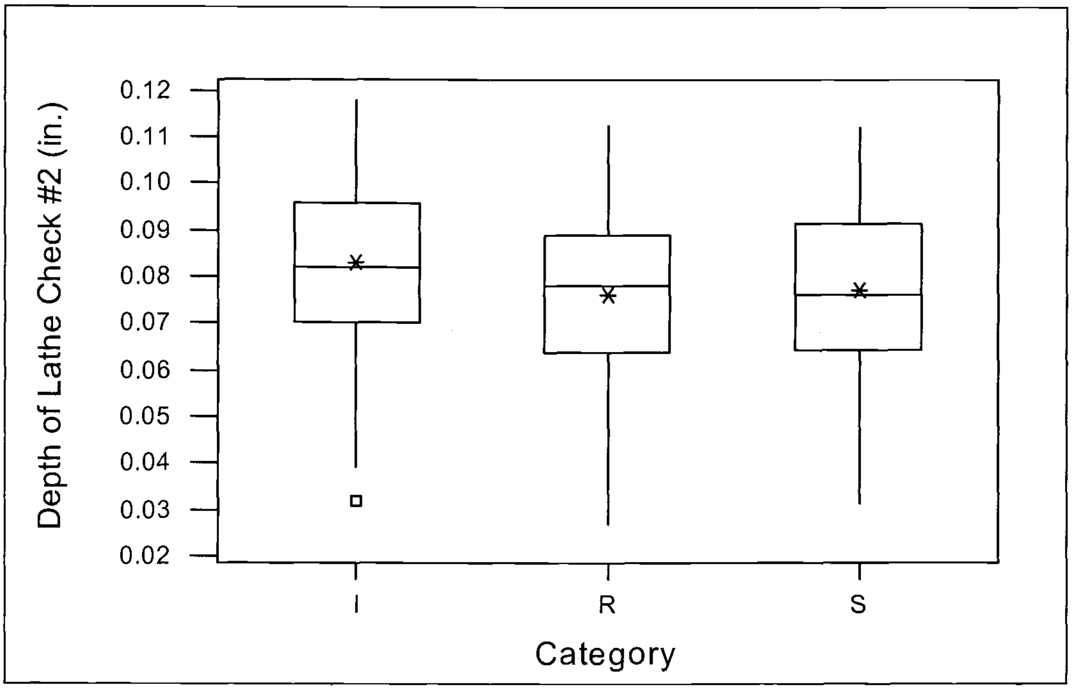


Figure A- 11. Box plot: depth of lathe check #2.

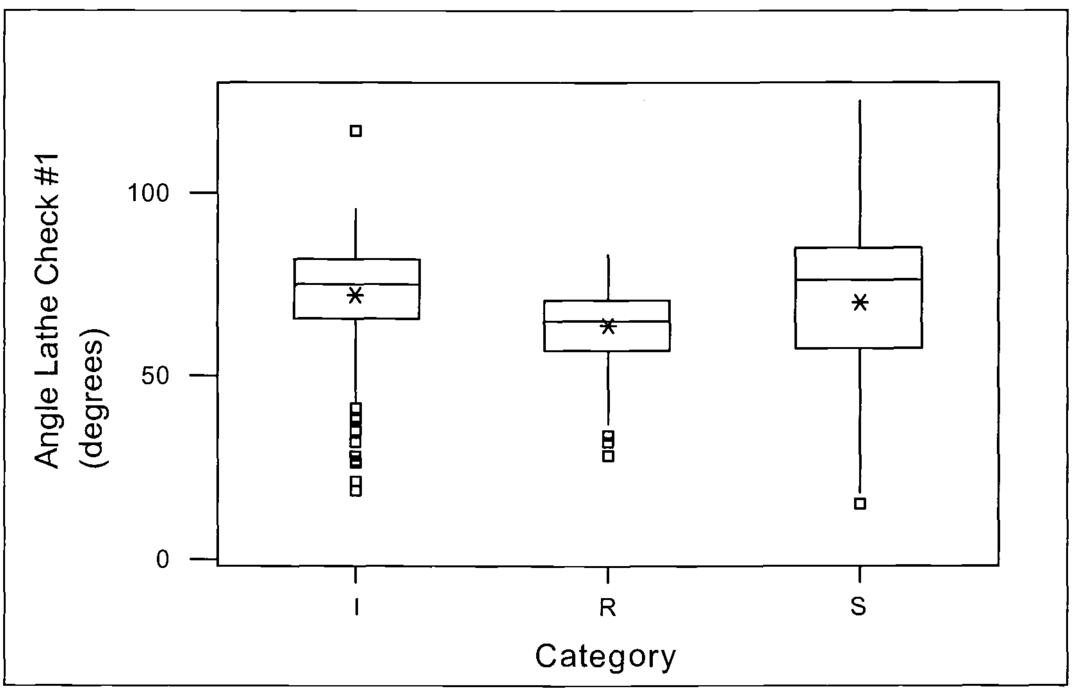


Figure A- 12. Box plot: angle of lathe check #1 to glue-line.

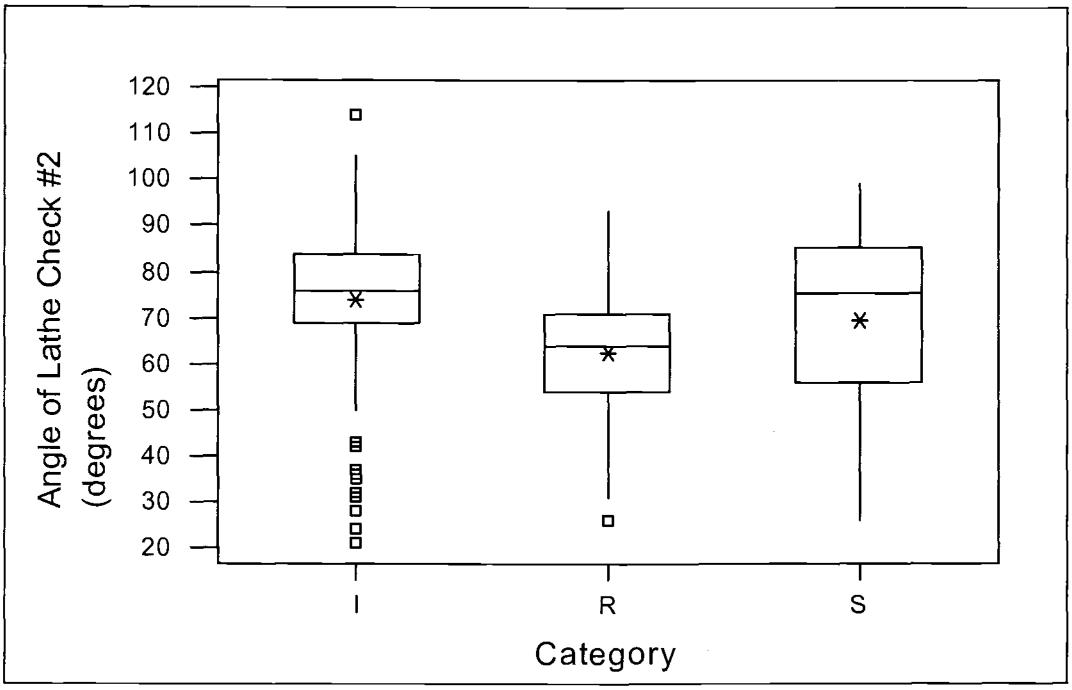


Figure A- 13. Box plot: angle of lathe check #2 to glue-line.

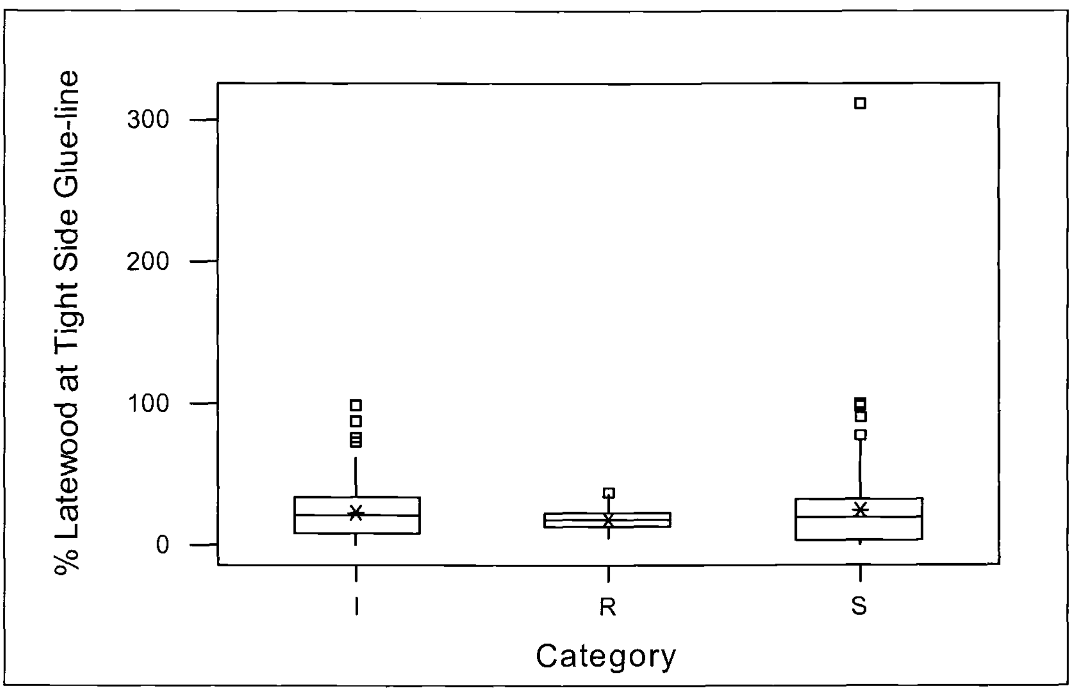


Figure A- 14. Box plot: percent latewood at tight-side glue-line.

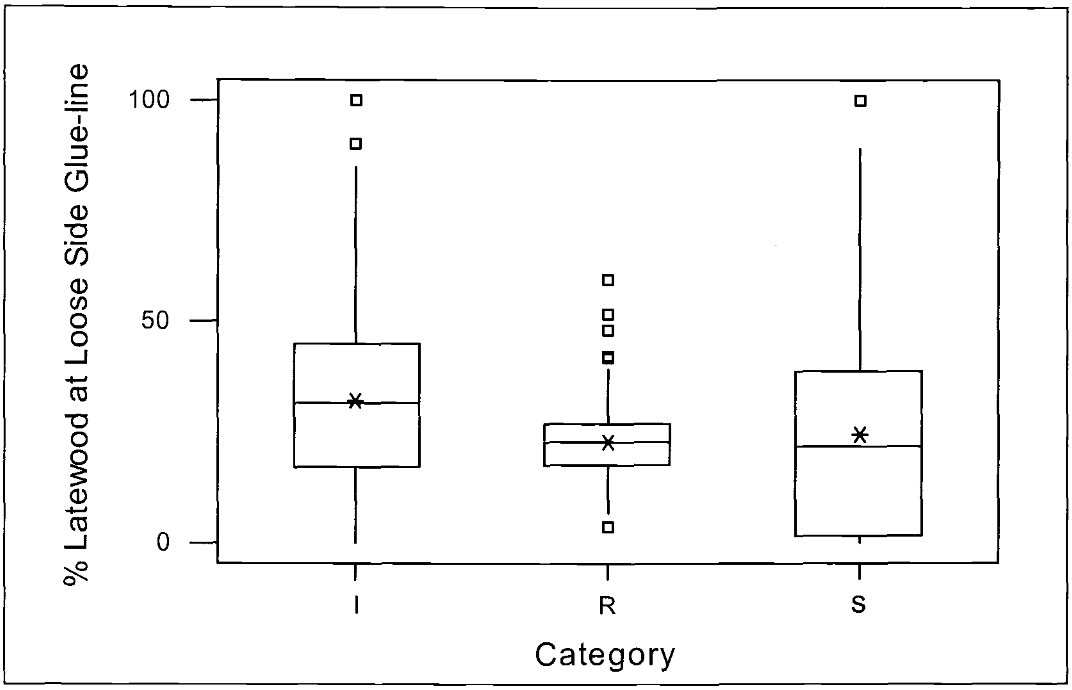


Figure A- 15. Box plot: percent latewood at loose-side glue-line.

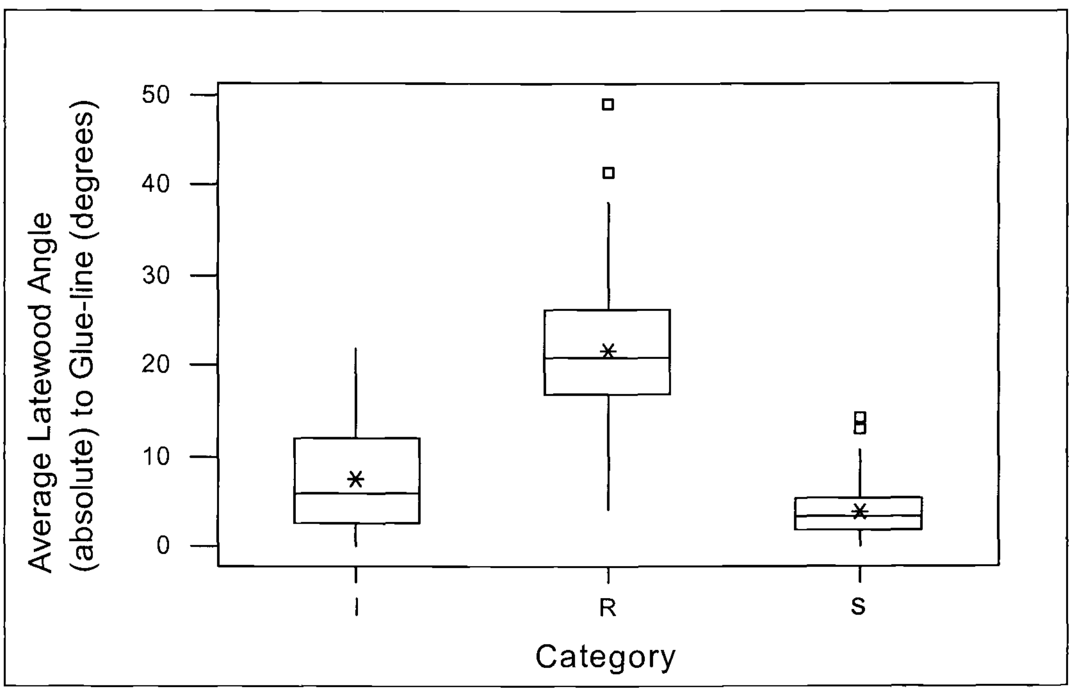


Figure A- 16. Box plot: average latewood band angle (absolute) to glue-line.

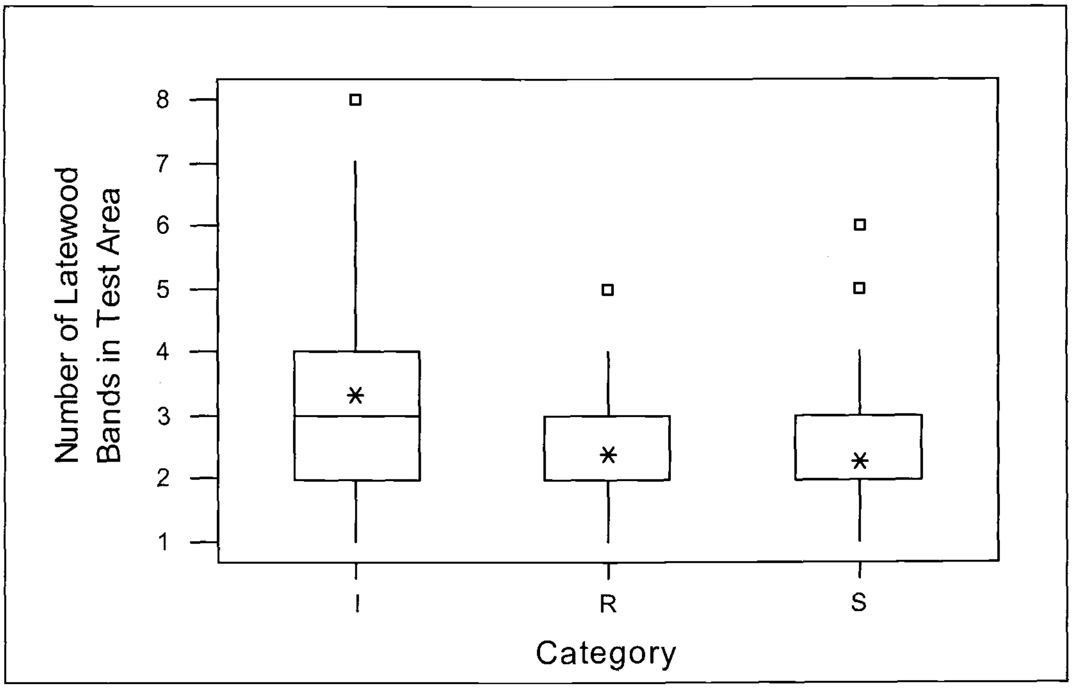


Figure A- 17. Box plot: number of latewood bands in test area.

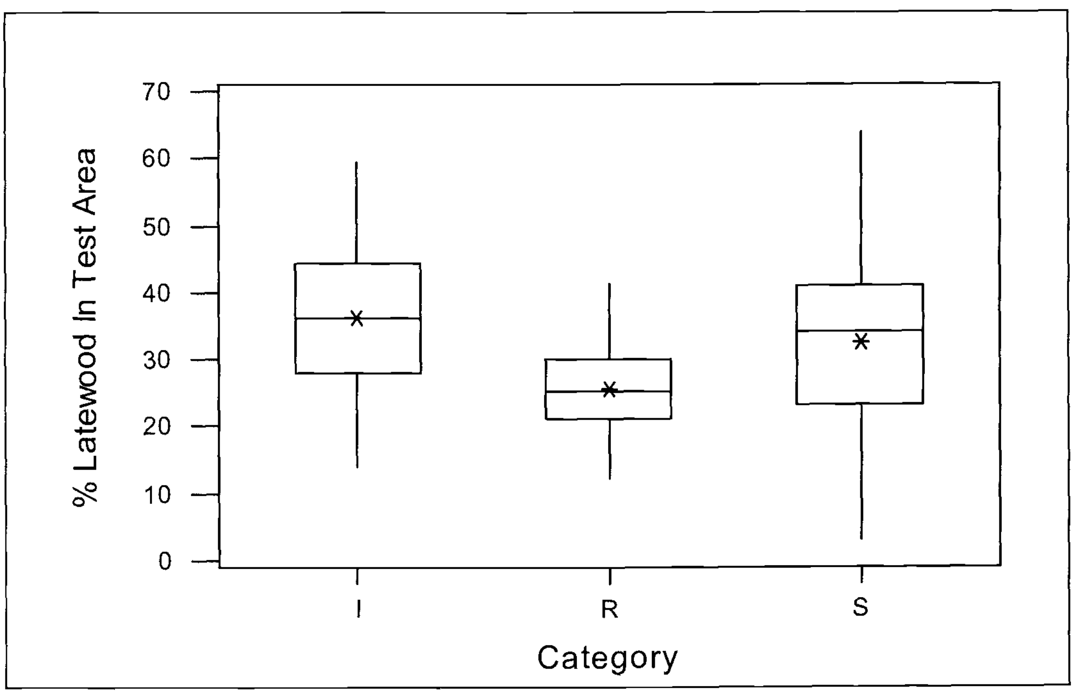


Figure A- 18. Box plot: percent latewood in test area.

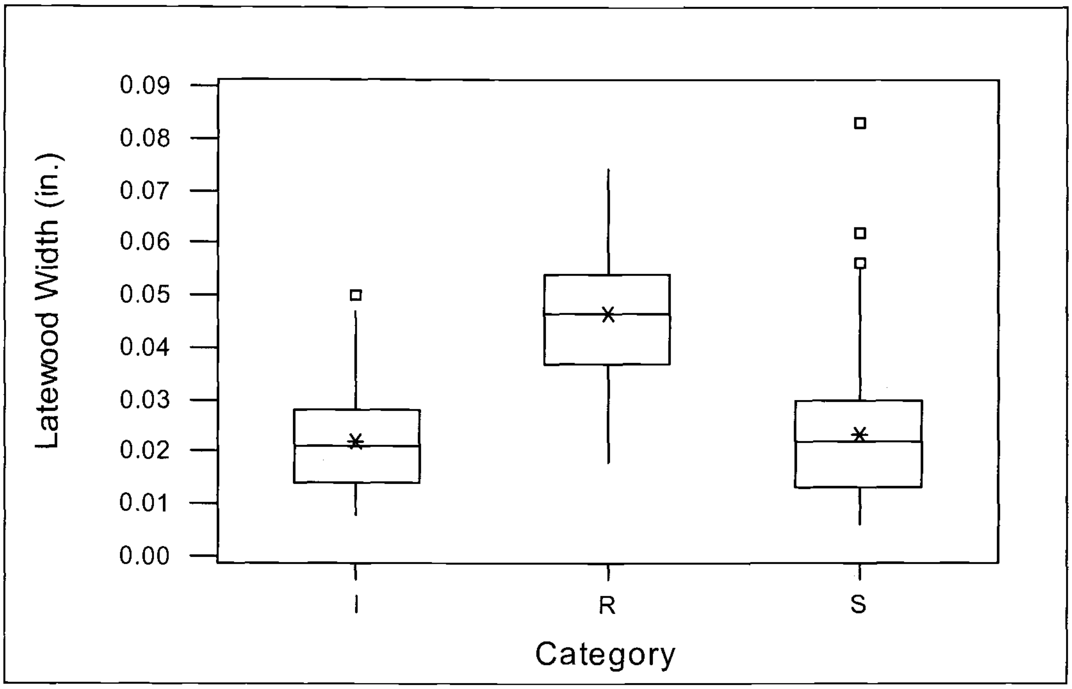


Figure A- 19. Box plot: latewood band width.

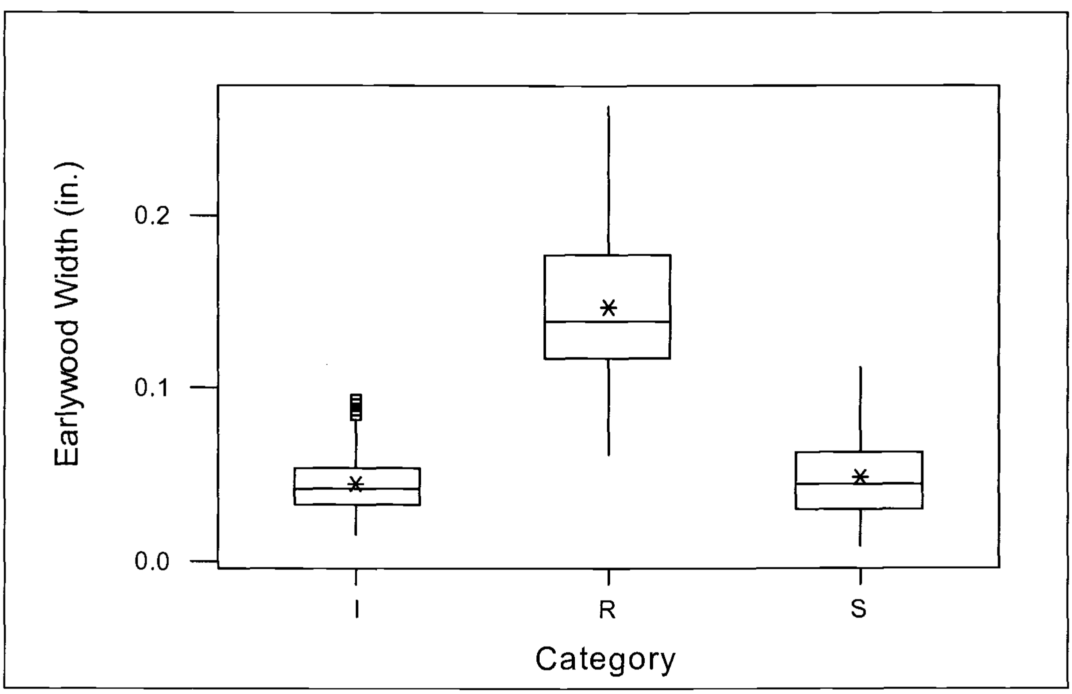


Figure A- 20. Box plot: earlywood band width.

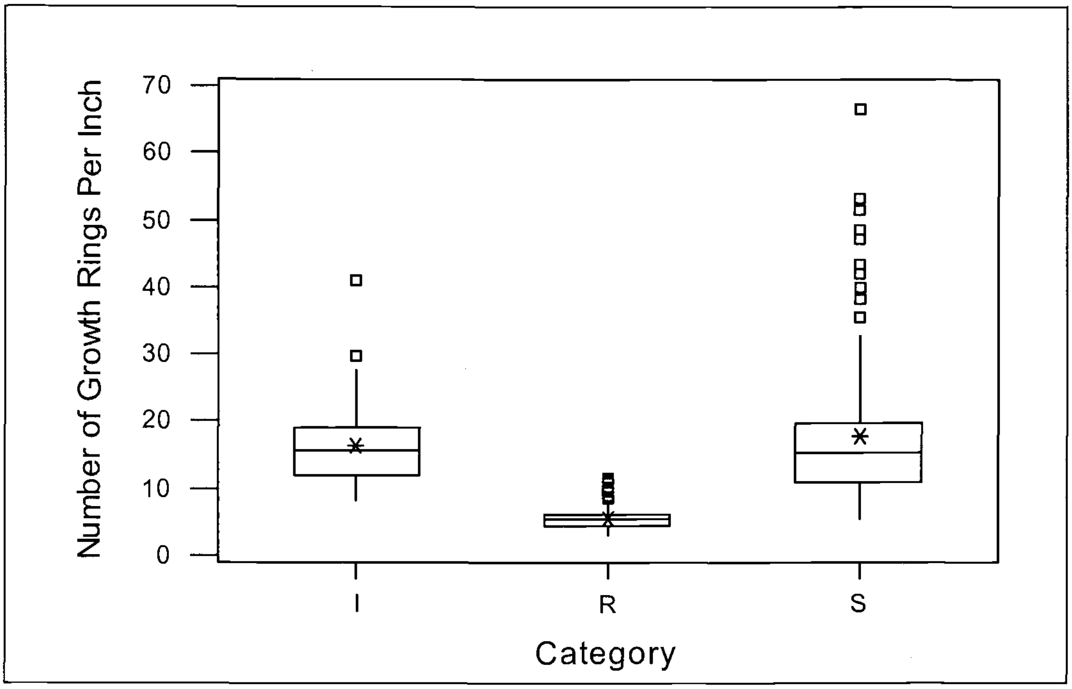


Figure A- 21. Box plot: number of growth rings per inch.

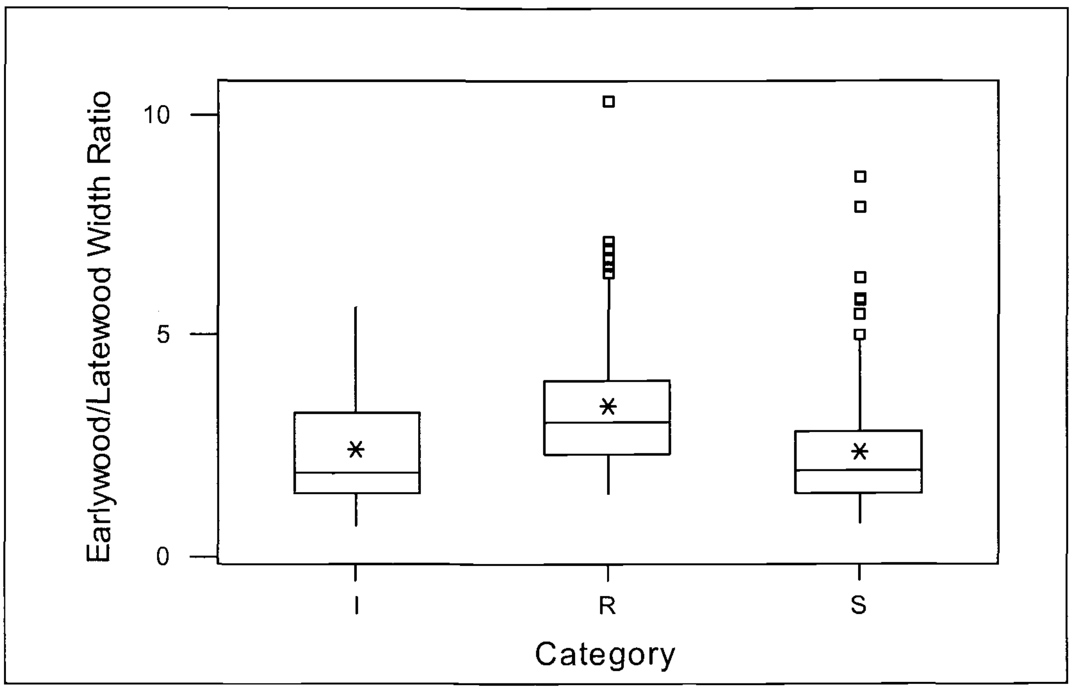


Figure A- 22. Box plot: earlywood/latewood width ratio.

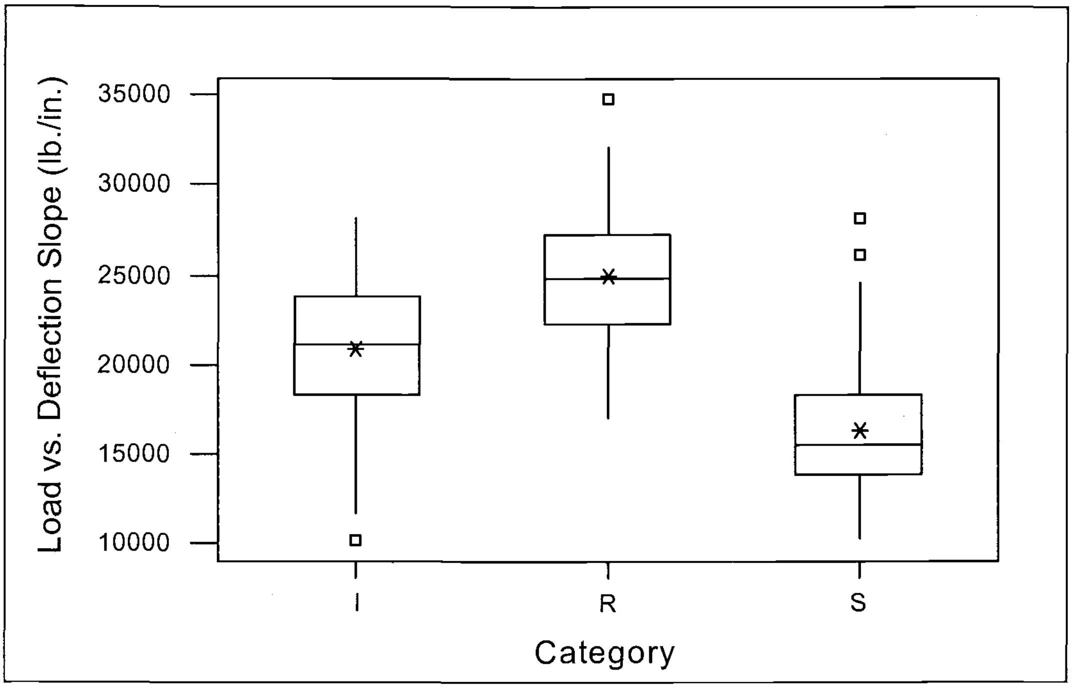


Figure A- 23. Box plot: load vs. deflection slope.

Appendix B. Box Plots of Individual Mathematical Veneer Roughness Characteristics

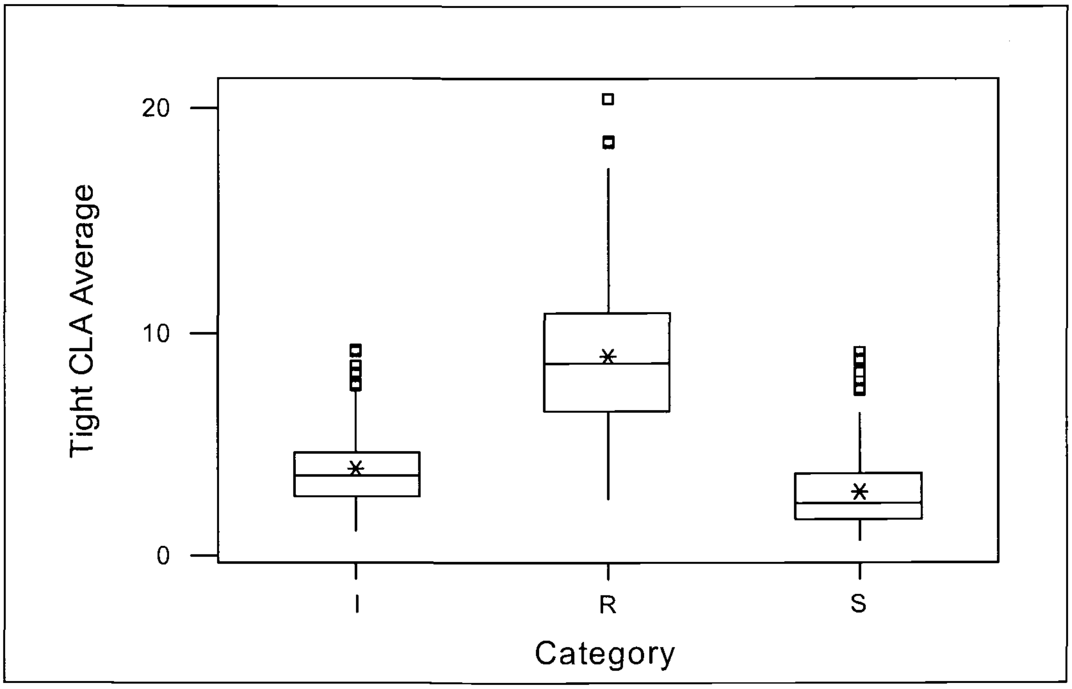


Figure B- 1. Box plot: tight-side CLA average.

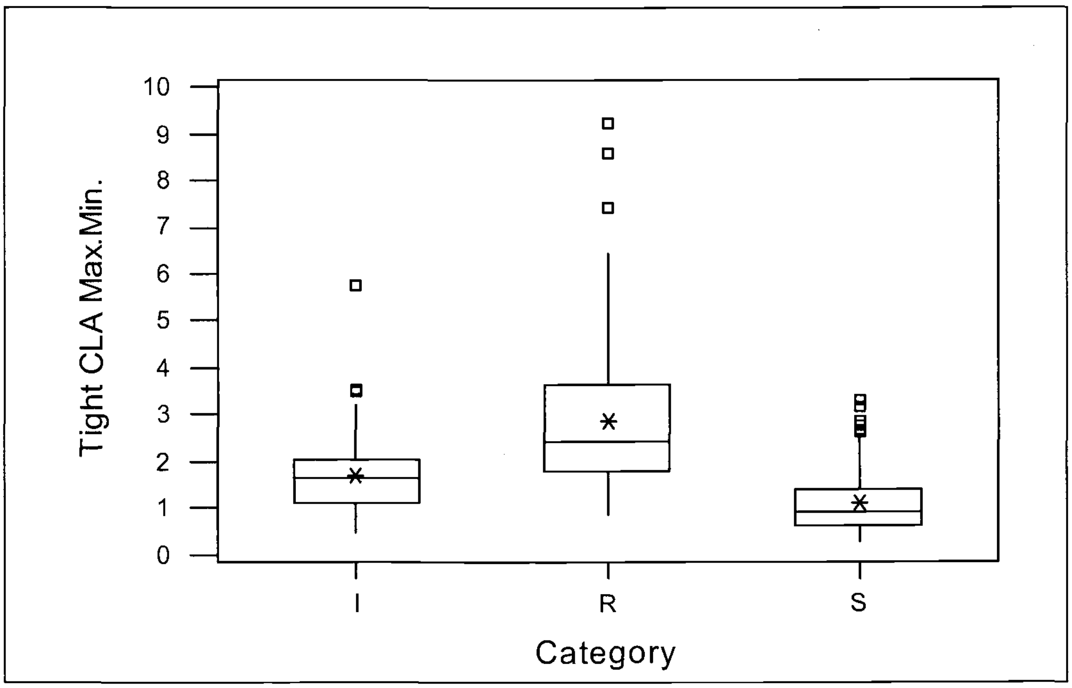


Figure B-2. Box plot: tight-side CLA max.min.

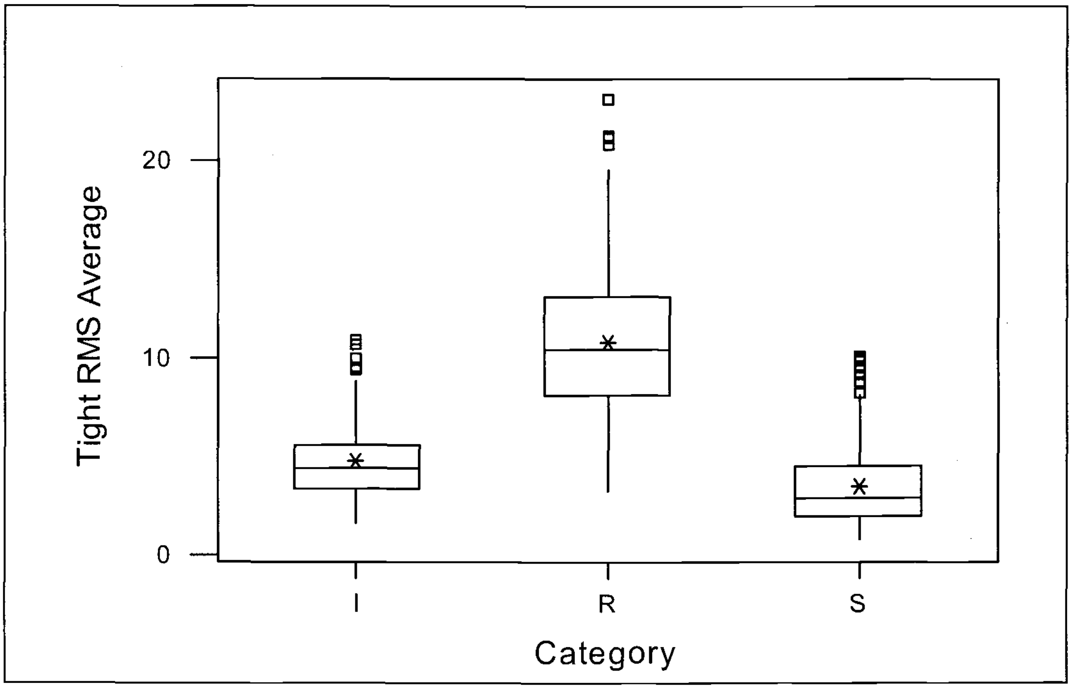


Figure B-3. Box plot: tight-side RMS average.

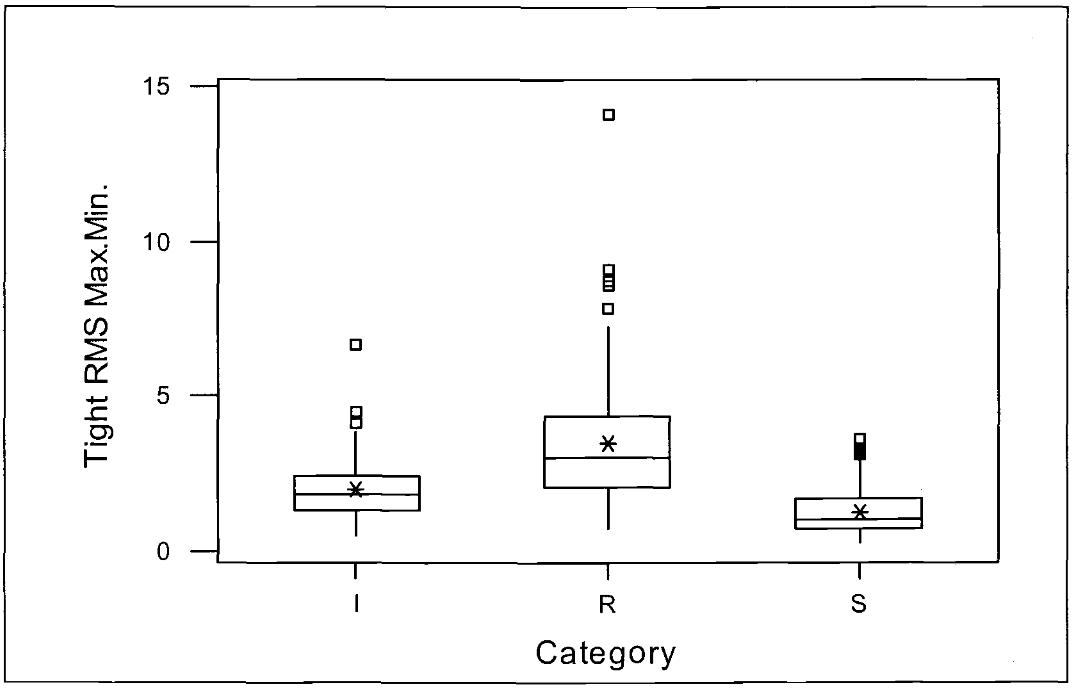


Figure B-4. Box plot: tight-side RMS max.min.

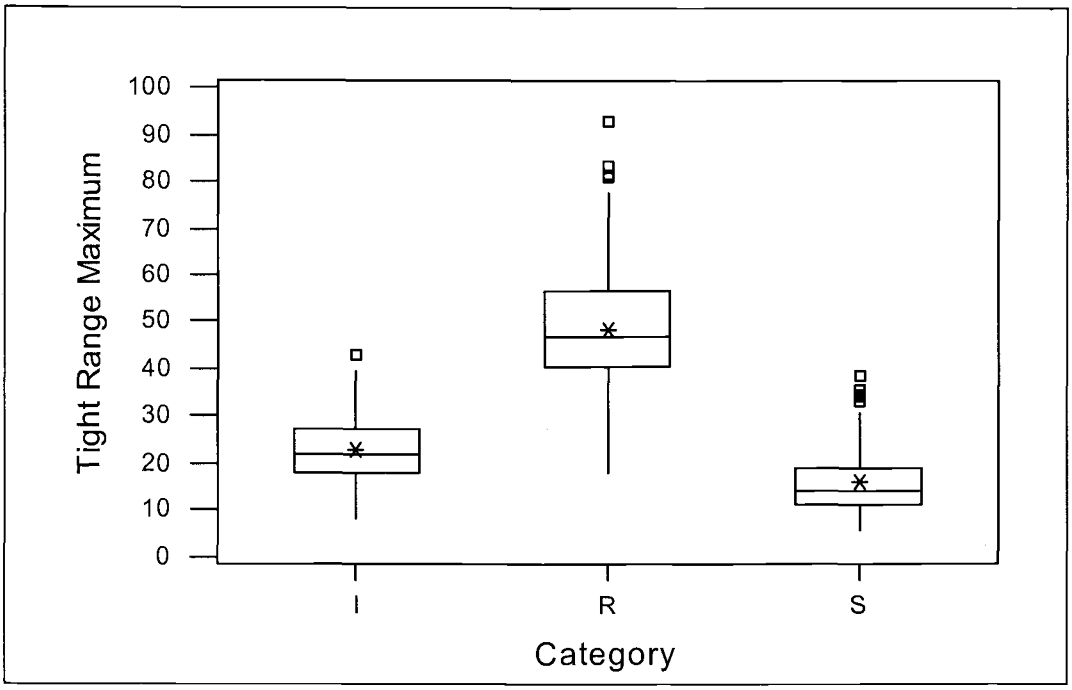


Figure B-5. Box plot: tight-side range maximum.

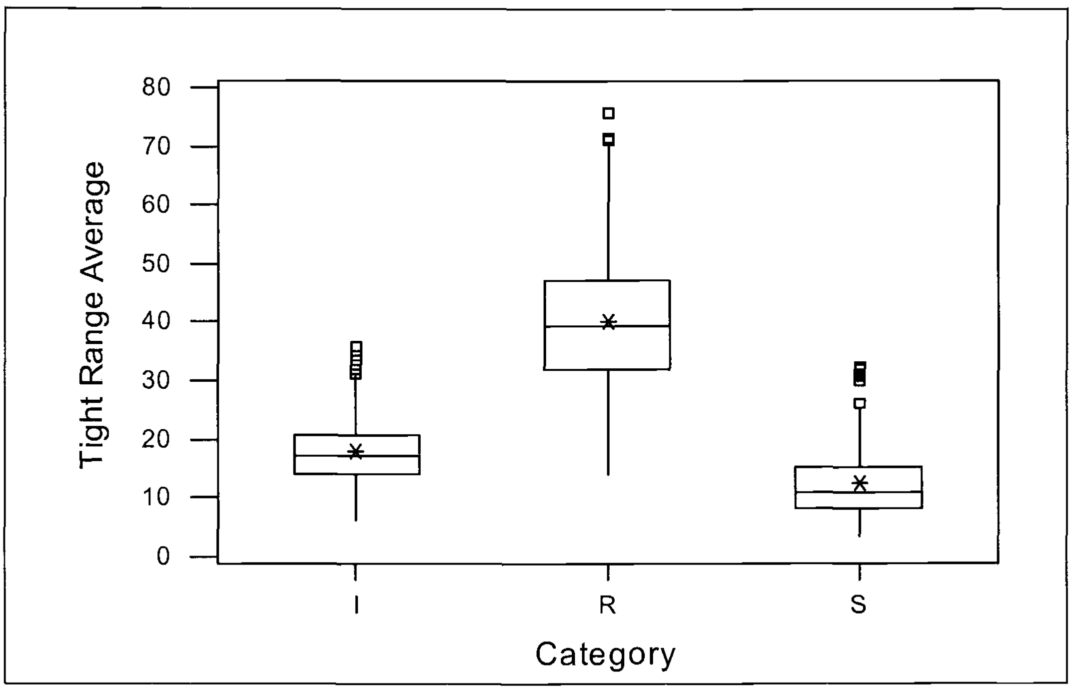


Figure B-6. Box plot: tight-side range average.

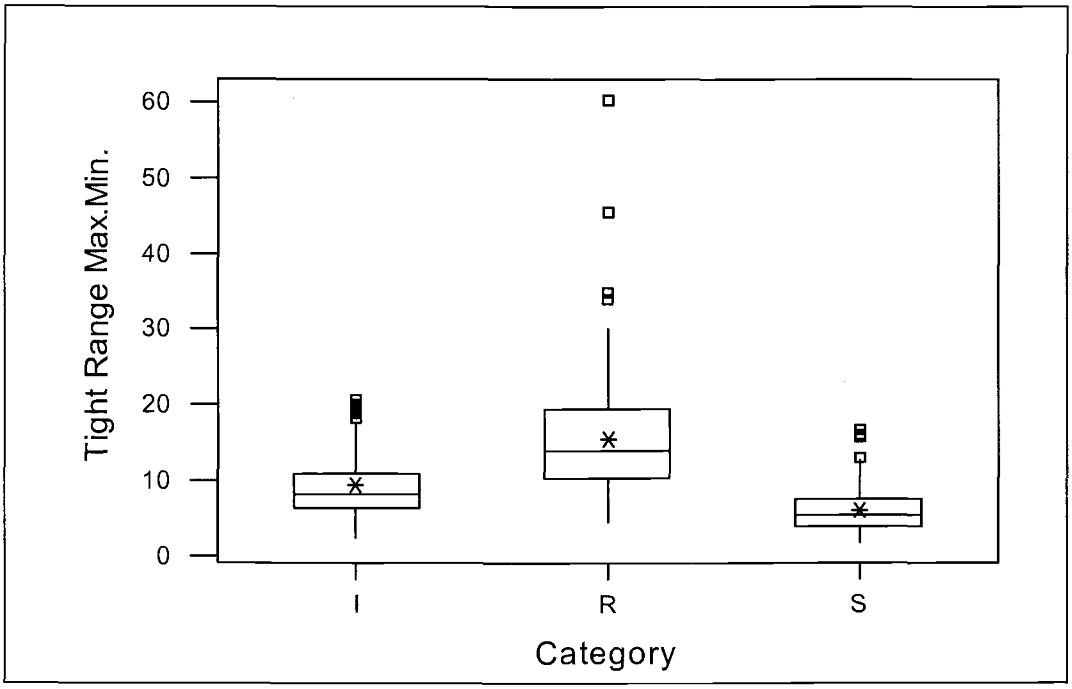


Figure B-7. Box plot: tight-side range max.min.

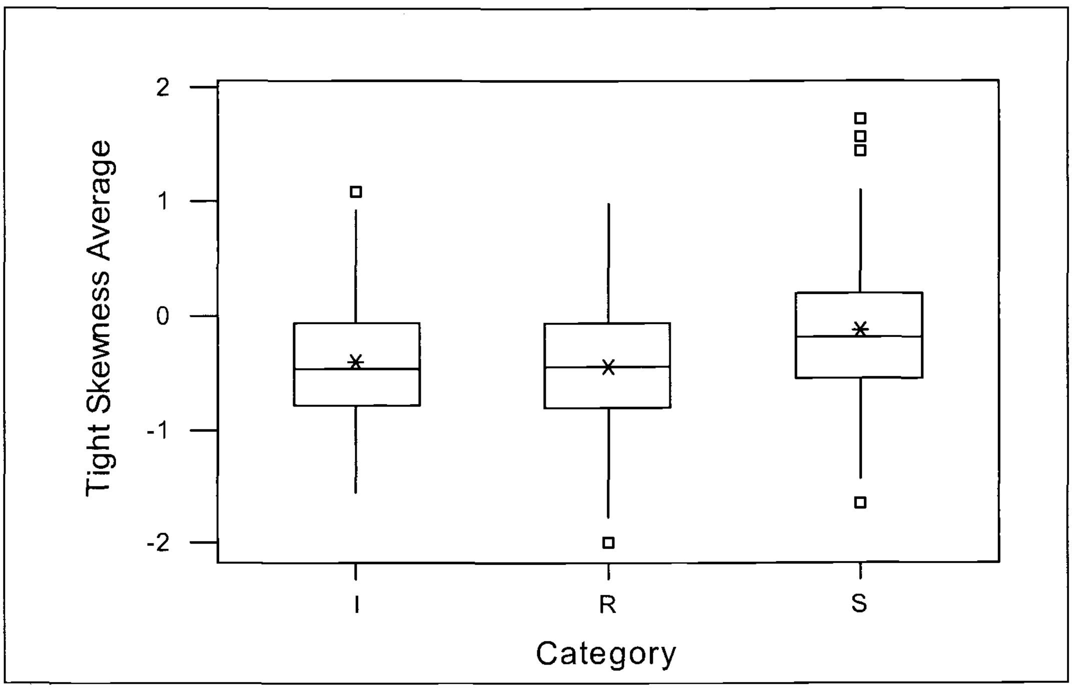


Figure B-8. Box plot: tight-side skewness average.

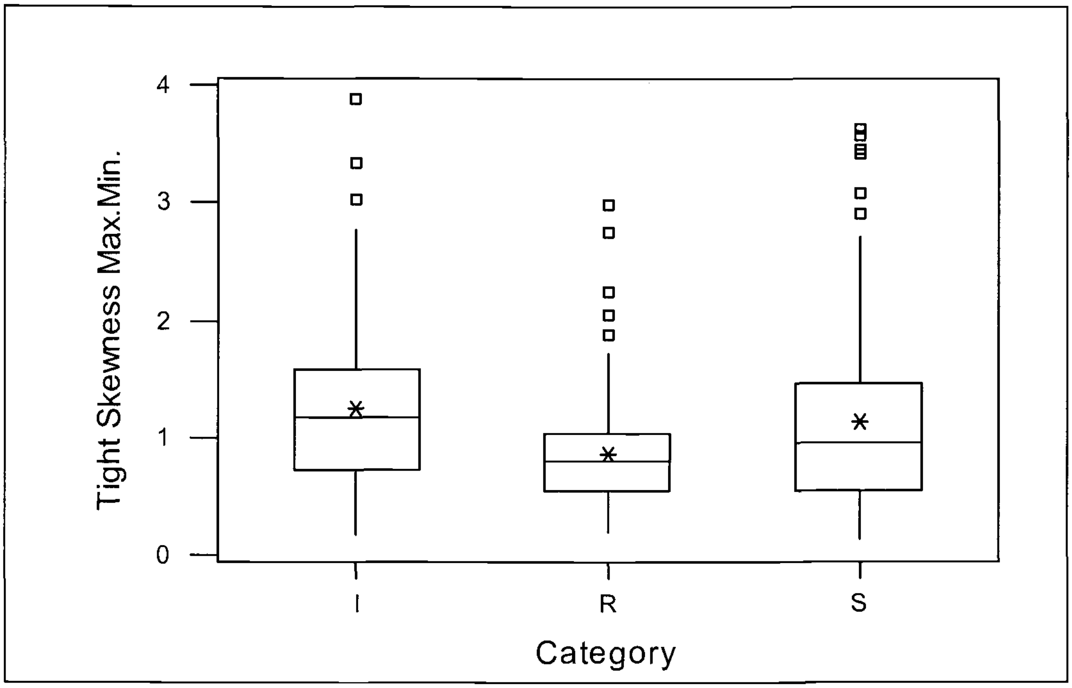


Figure B-9. Box plot: tight-side skewness max.min.

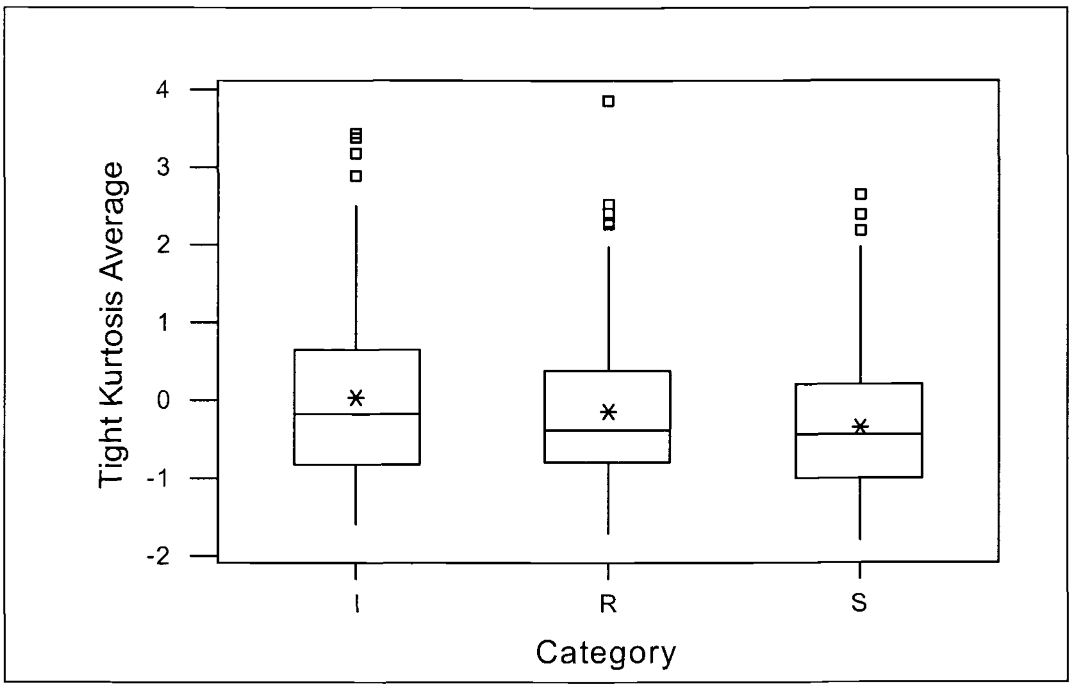


Figure B-10. Box plot: tight-side kurtosis average.

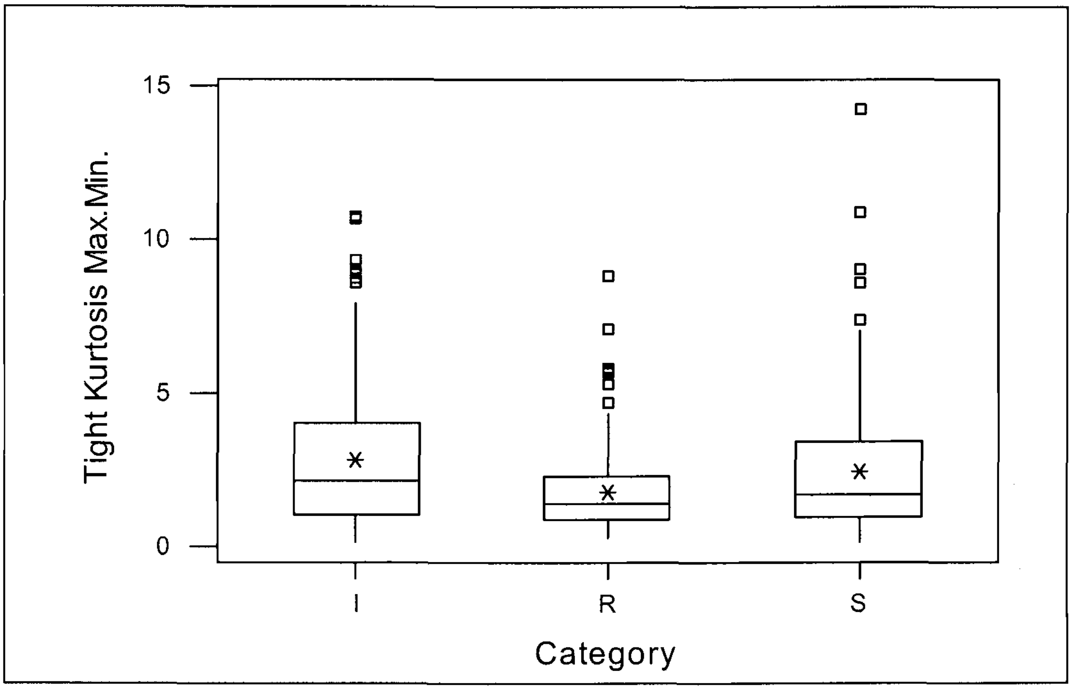


Figure B-11. Box plot: tight kurtosis max.min.

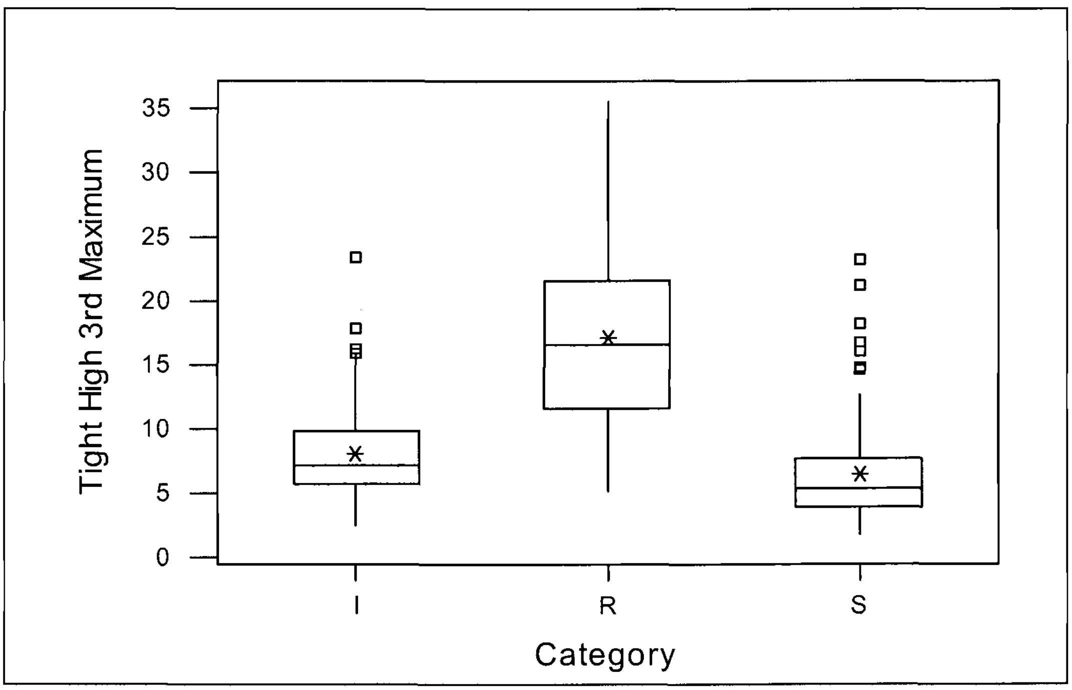


Figure B-12. Box plot: tight-side high 3rd maximum.

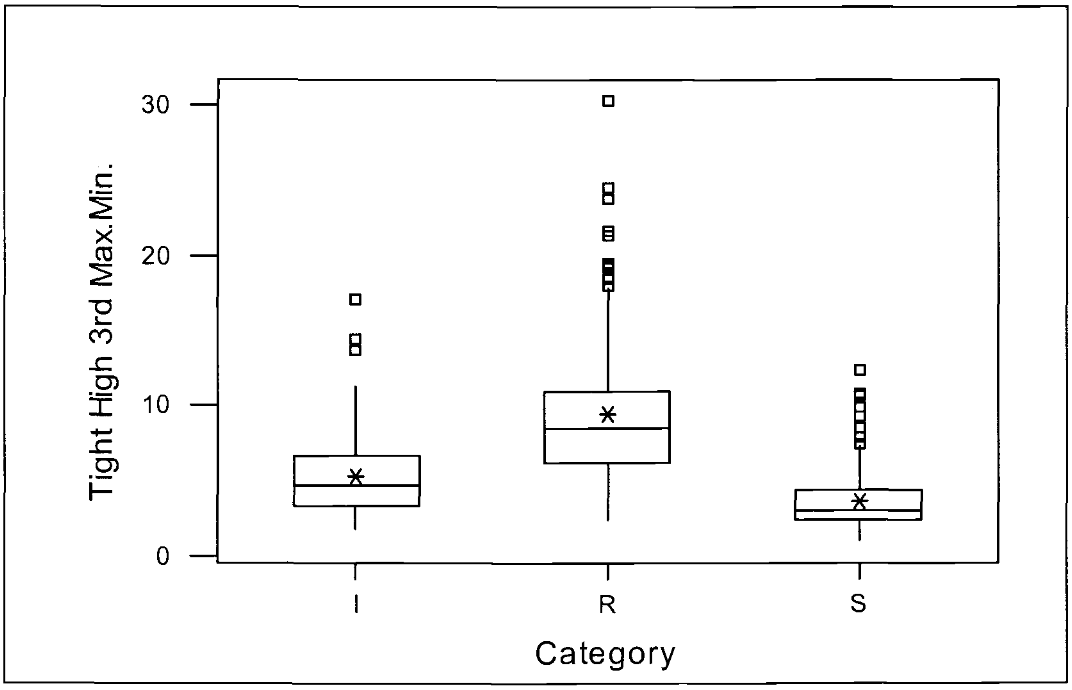


Figure B-13. Box plot: tight-side high 3rd max.min.

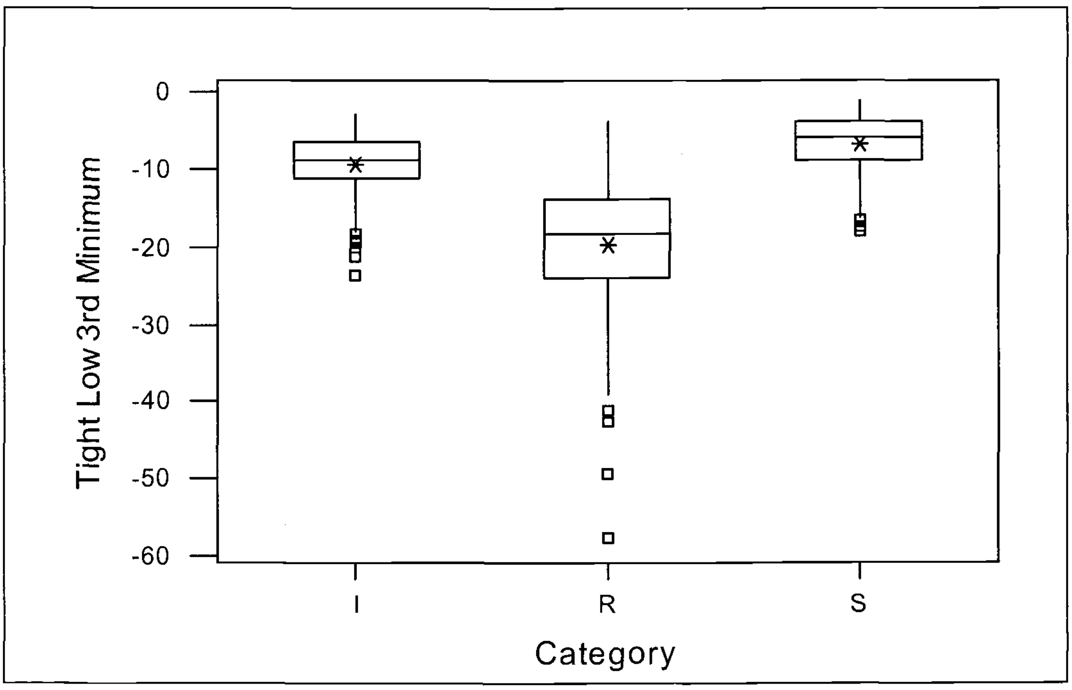


Figure B-14. Box plot: tight-side low 3rd minimum.

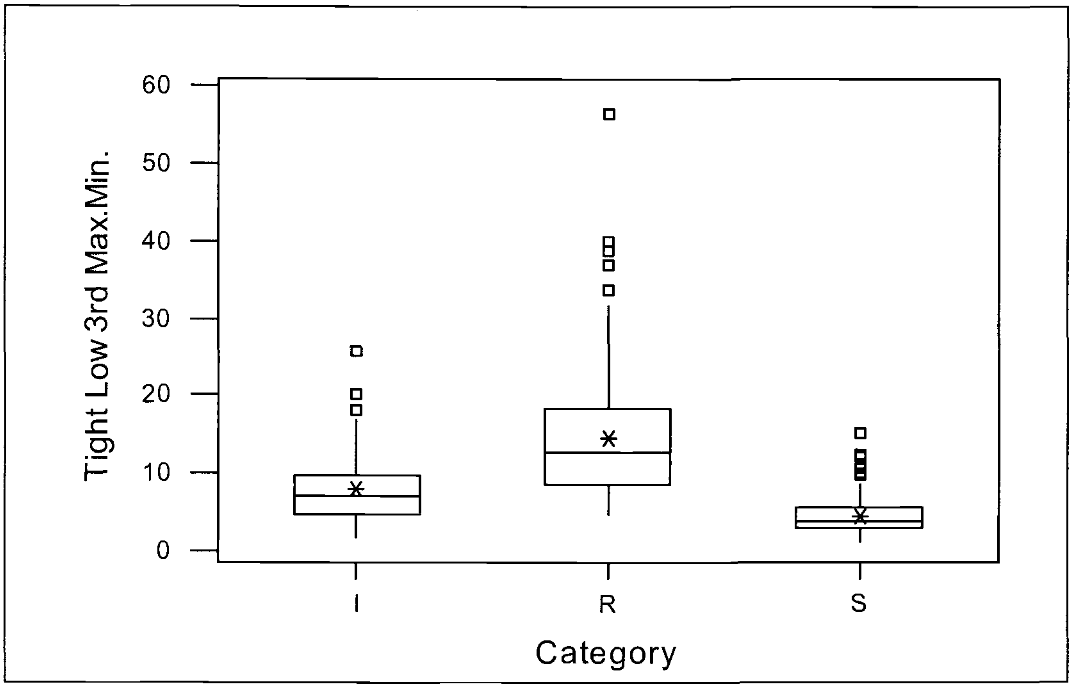


Figure B-15. Box plot: tight-side low 3rd max.min.

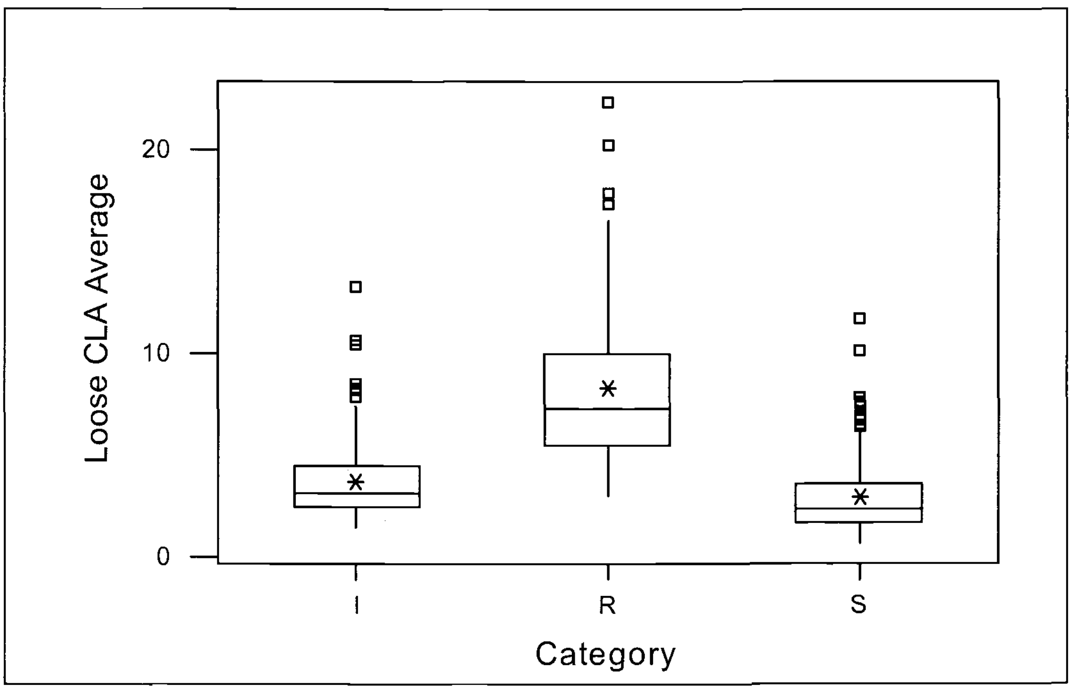


Figure B-16. Box plot: loose-side CLA average.

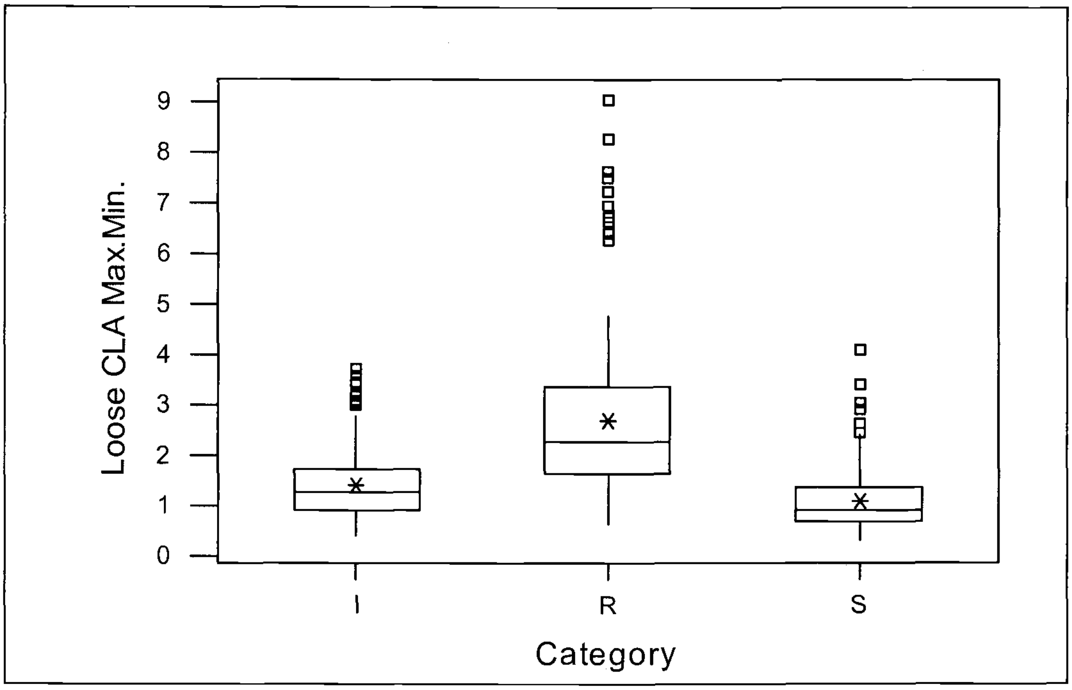


Figure B-17. Box plot: loose-side CLA max.min.

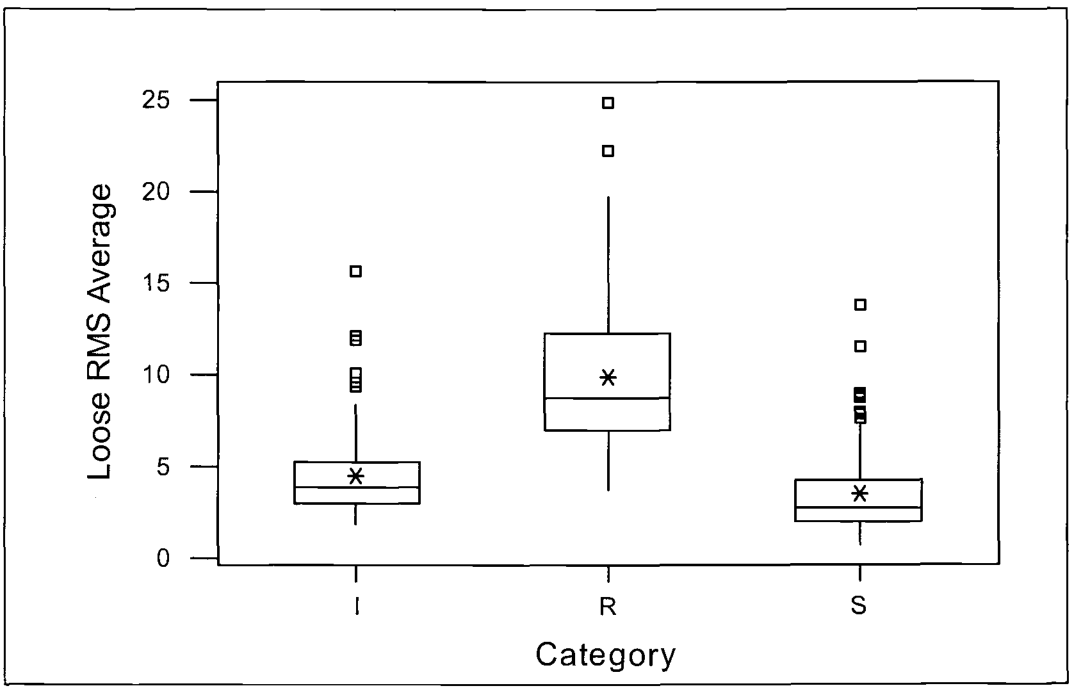


Figure B-18. Box plot: loose-side RMS average.

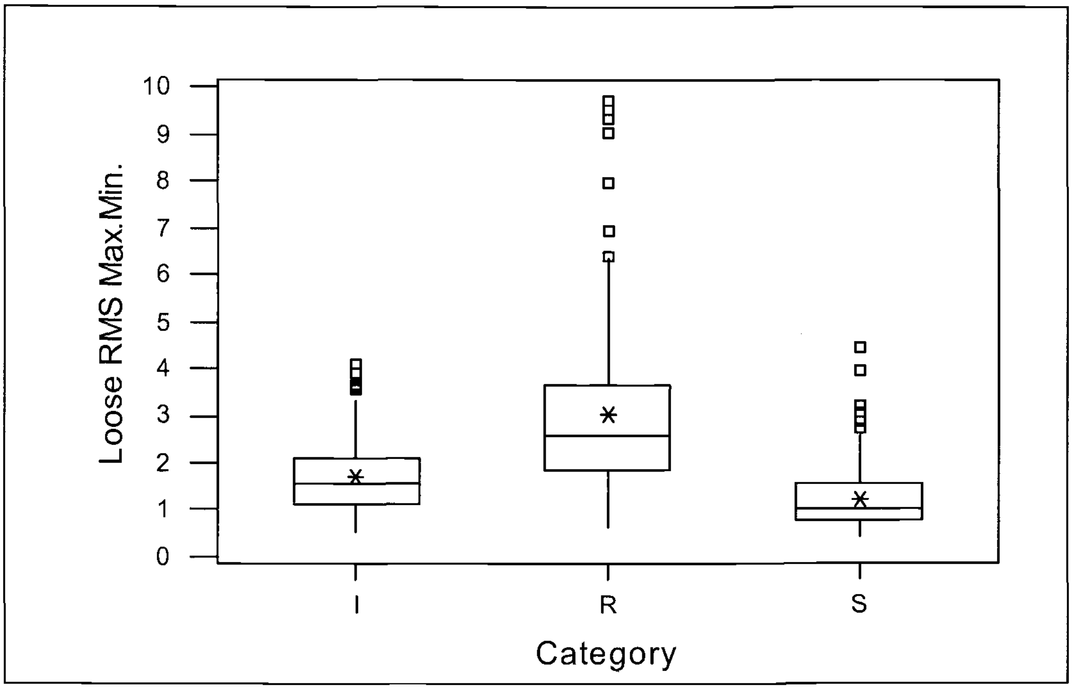


Figure B-19. Box plot: loose-side RMS max.min.

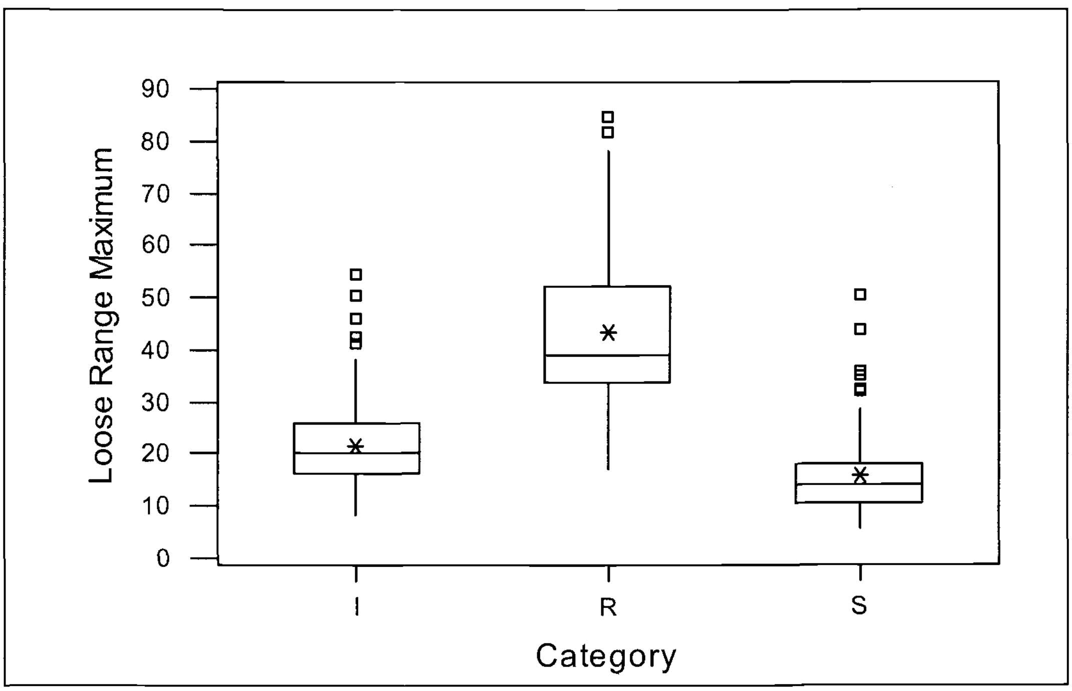


Figure B-20. Box plot: loose-side range maximum.

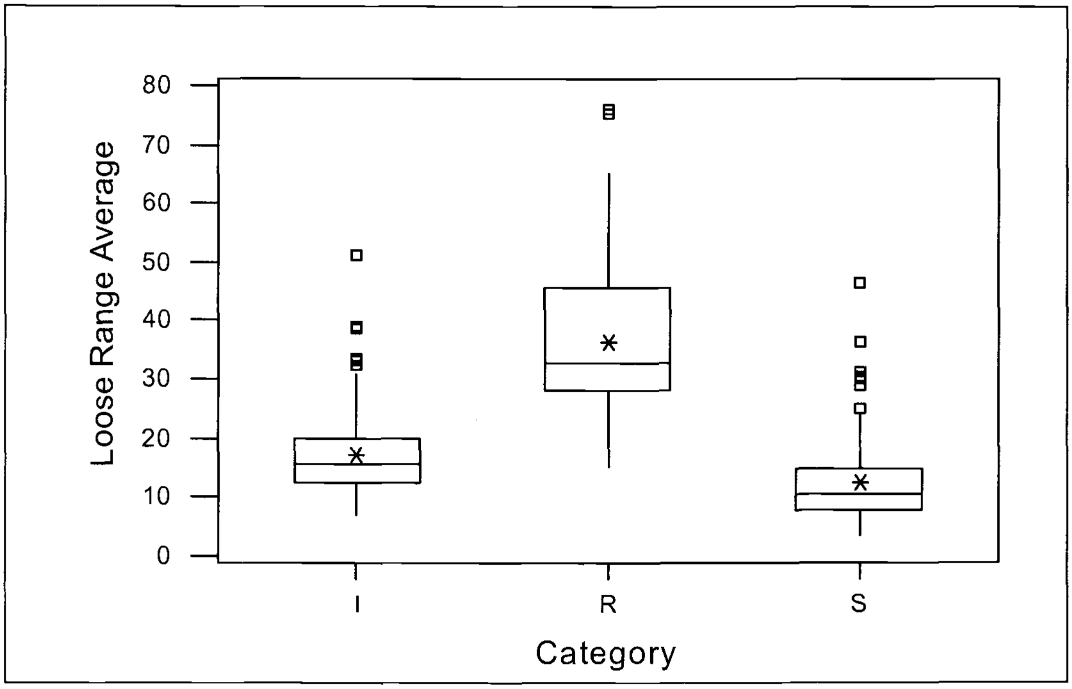


Figure B-21. Box plot: loose-side range average.

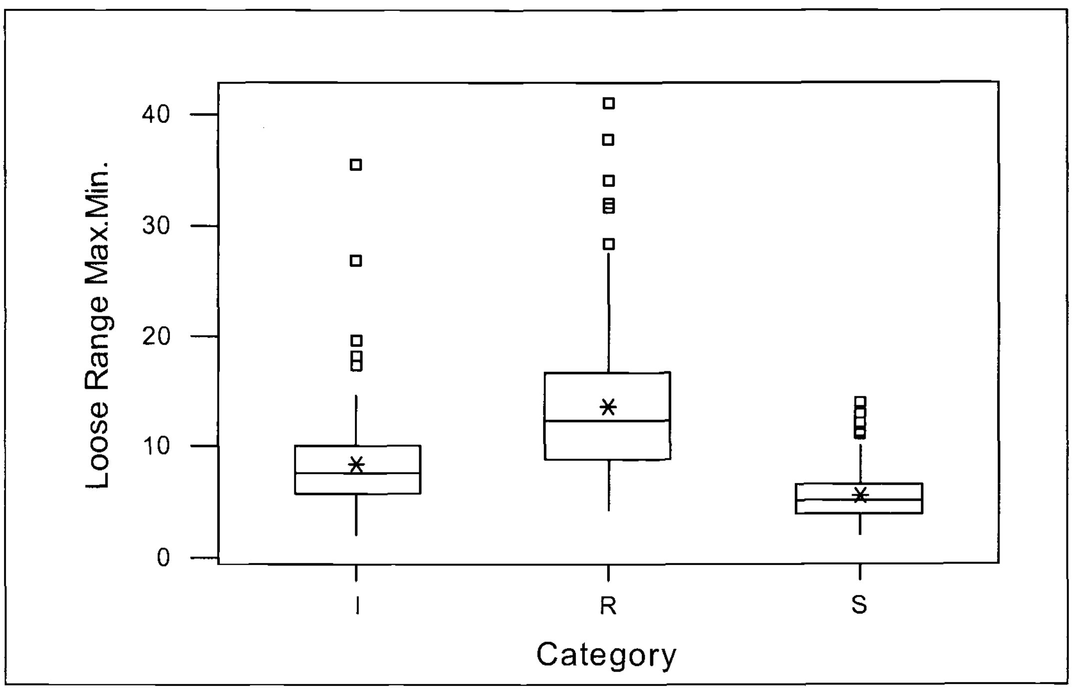


Figure B-22. Box plot: loose-side range max.min.

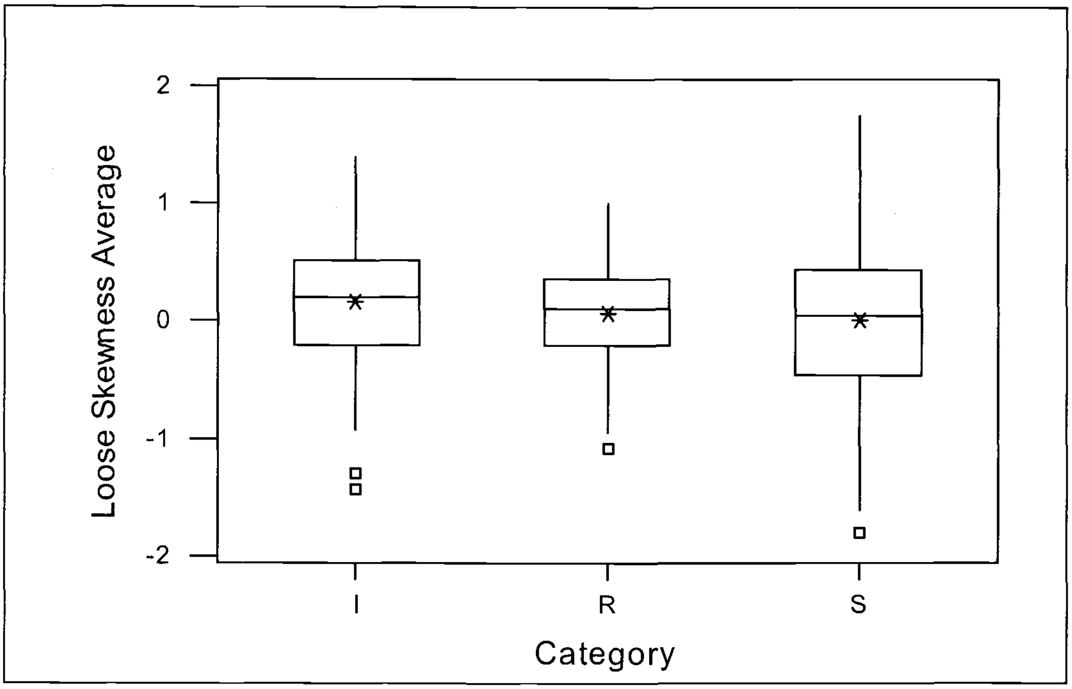


Figure B-23. Box plot: loose-side skewness average.

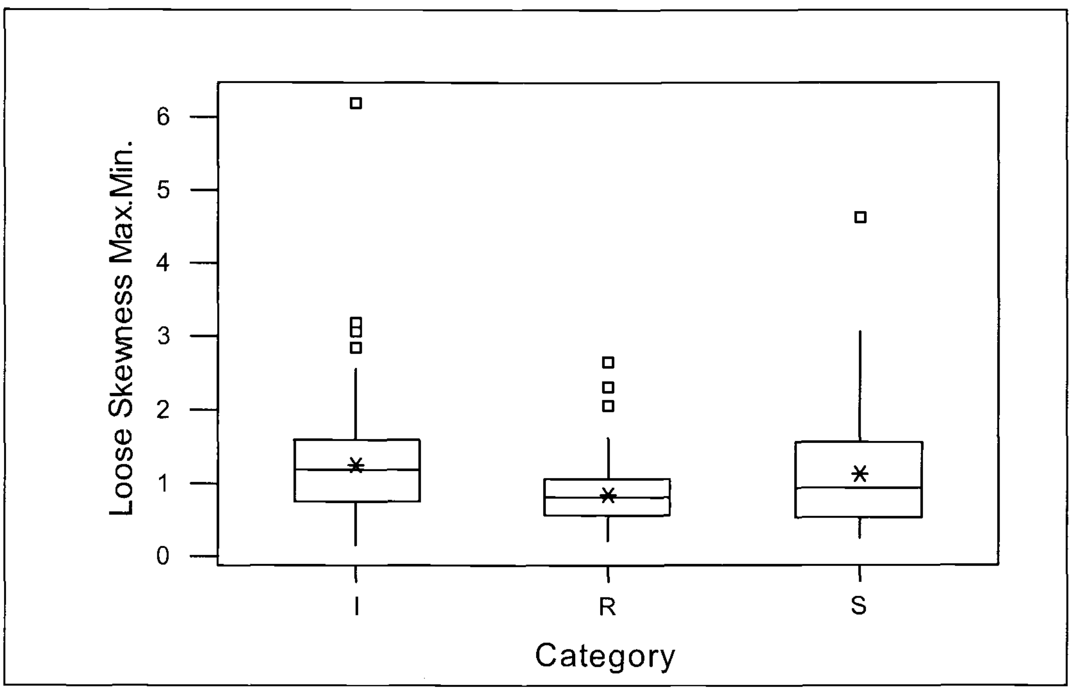


Figure B-24. Box plot: loose-side skewness max.min.

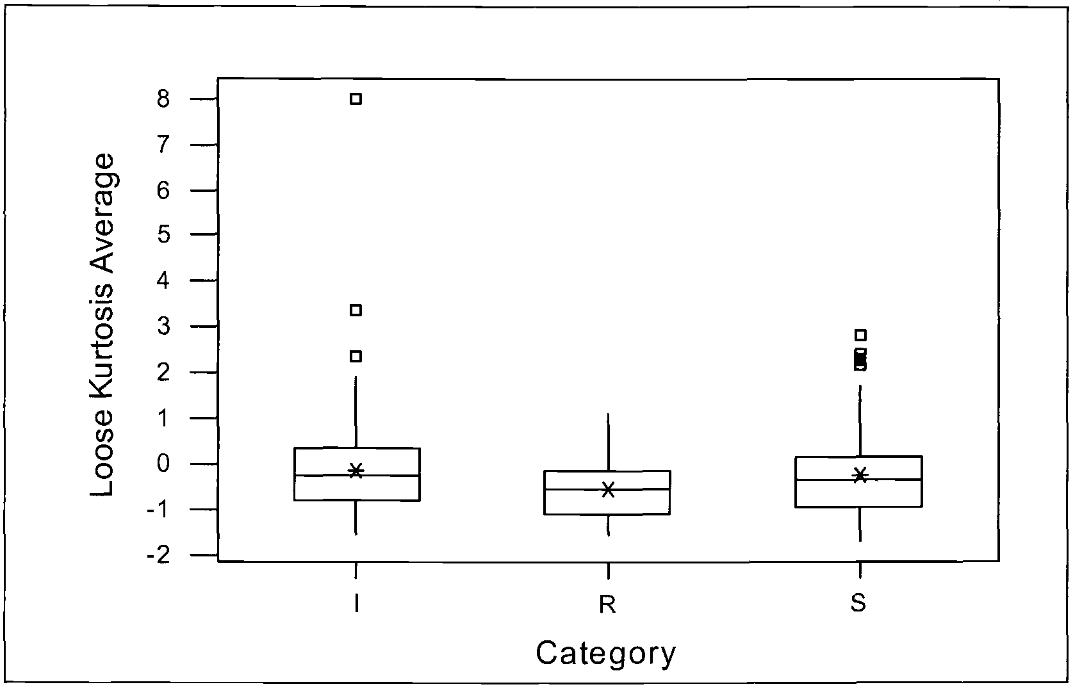


Figure B-25. Box plot: loose-side kurtosis average.

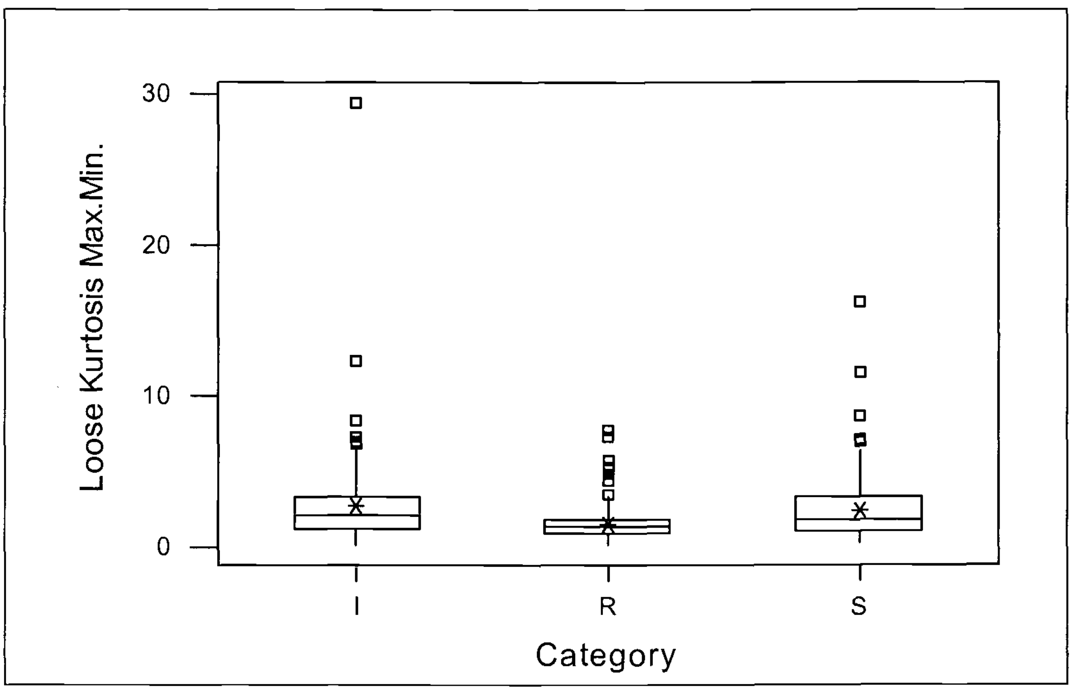


Figure B-26. Box plot: loose-side kurtosis max.min.

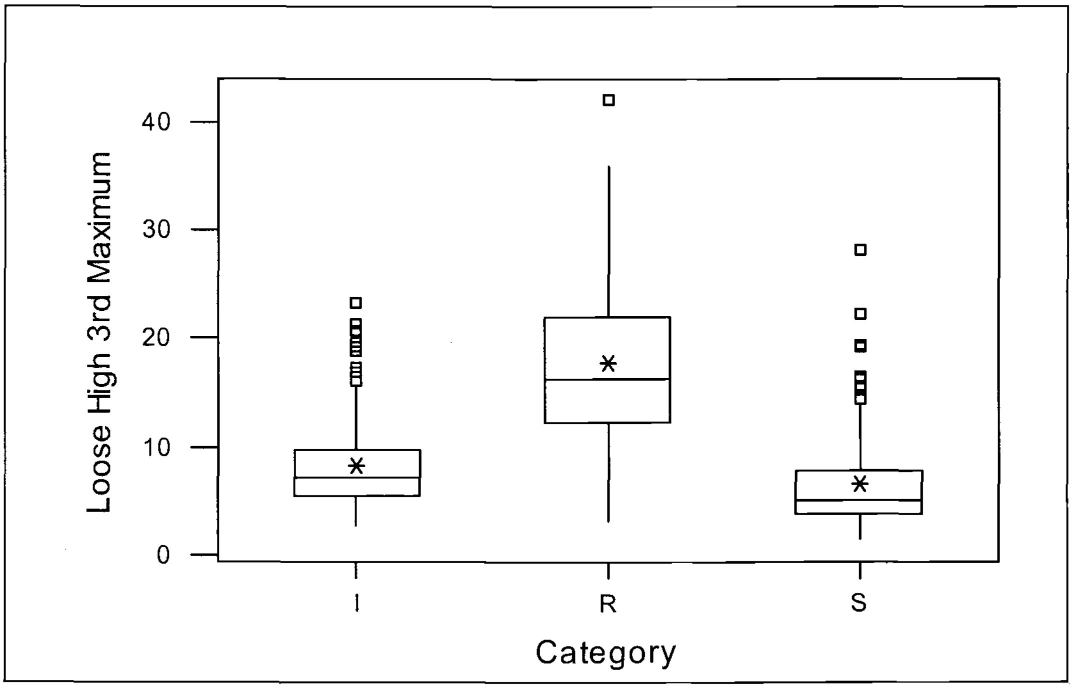


Figure B-27. Box plot: loose-side high 3rd maximum.

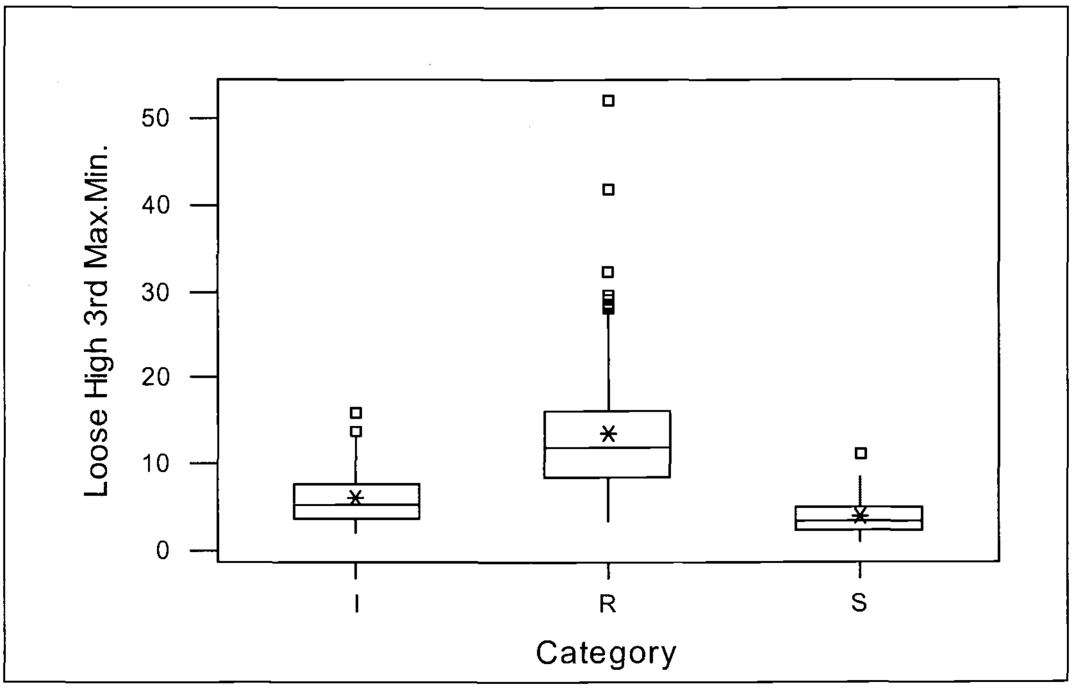


Figure B-28. Box plot: loose-side high 3rd max.min.

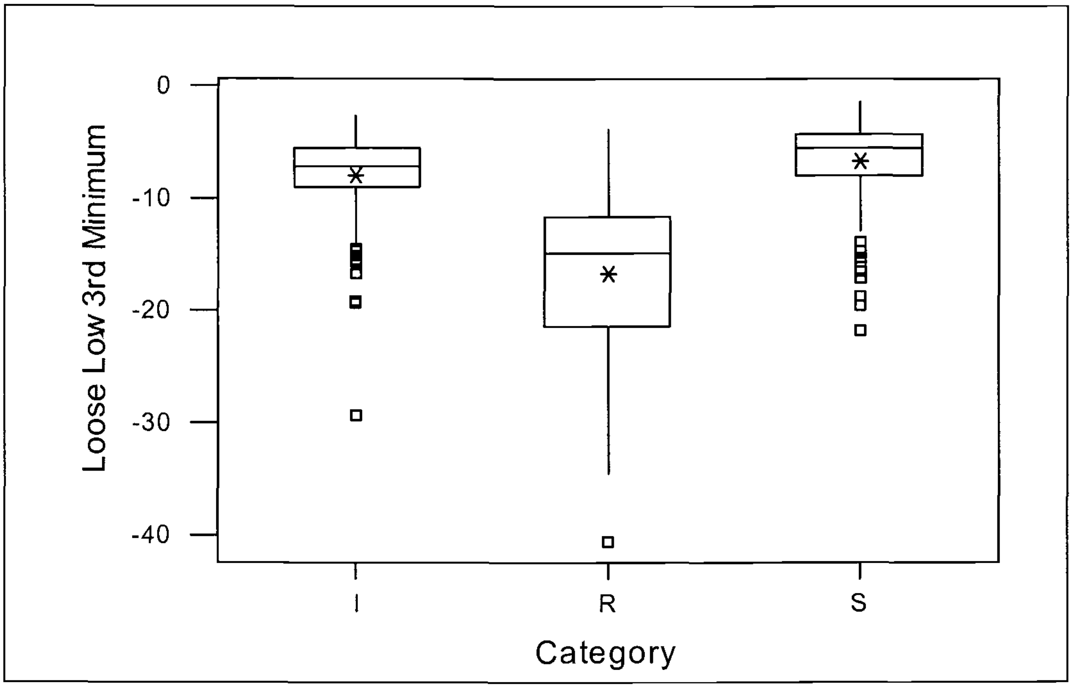


Figure B-29. Box plot: loose-side low 3rd minimum.

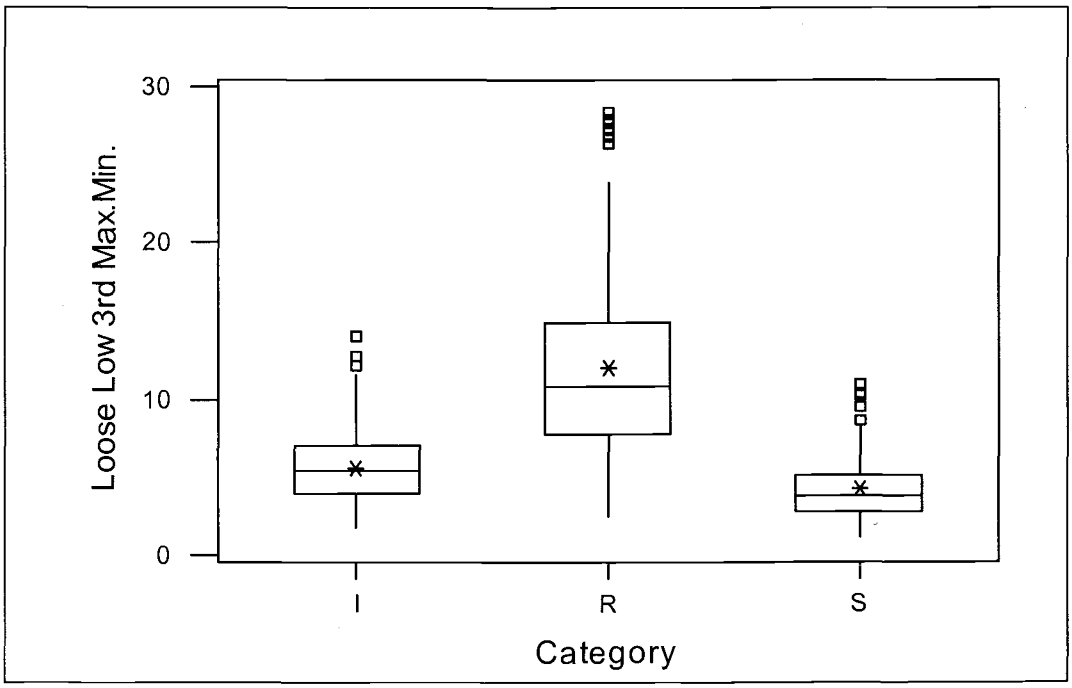


Figure B-30. Box plot: loose-side low 3rd max.min.

Appendix C. Cross Correlation Between all Variables

Table C-1. Cross correlation table (correlation and p-values) for variables 1-7.

	Check Freqency	Average Lathe Check Depth	Average Lathe Check Angle to Glue-line	Lathe Check #1 Tip Distance to Saw Kerf 1	Lathe Check #2 Tip Distance to Saw Kerf 1	Lathe Check #1 Origin Distance to Saw Kerf 1	Lathe Check #2 Origin Distance to Saw Kerf 1
Check Freqency	1.000	0.136	0.104	-0.354	-0.553	-0.362	-0.543
	0.000	0.004	0.027	0.000	0.000	0.000	0.000
Average Lathe Check Depth	0.136	1.000	0.327	-0.075	-0.029	-0.046	-0.038
	0.004	0.000	0.000	0.114	0.534	0.332	0.426
Average Lathe Check Angle to Glue-line	0.104	0.327	1.000	-0.062	-0.001	-0.169	-0.122
	0.027	0.000	0.000	0.190	0.985	0.000	0.010
Lathe Check #1 Tip Distance to Saw Kerf 1	-0.354	-0.075	-0.062	1.000	0.706	0.841	0.645
	0.000	0.114	0.190	0.000	0.000	0.000	0.000
Lathe Check #2 Tip Distance to Saw Kerf 1	-0.553	-0.029	-0.001	0.706	1.000	0.712	0.901
	0.000	0.534	0.985	0.000	0.000	0.000	0.000
Lathe Check #1 Origin Distance to Saw Kerf 1	-0.362	-0.046	-0.169	0.841	0.712	1.000	0.741
	0.000	0.332	0.000	0.000	0.000	0.000	0.000
Lathe Check #2 Origin Distance to Saw Kerf 1	-0.543	-0.038	-0.122	0.645	0.901	0.741	1.000
	0.000	0.426	0.010	0.000	0.000	0.000	0.000
Length of Lathe Check 1	-0.114	0.272	0.012	0.154	0.367	0.516	0.437
	0.016	0.000	0.793	0.001	0.000	0.000	0.000
Length of Lathe Check 2	0.017	0.257	-0.058	-0.133	-0.122	0.047	0.180
	0.715	0.000	0.219	0.005	0.010	0.316	0.000
Depth Lathe Check 1	-0.048	0.467	0.184	0.191	0.327	0.303	0.290
	0.312	0.000	0.000	0.000	0.000	0.000	0.000
Depth Lathe Check 2	0.075	0.496	0.282	-0.110	-0.067	-0.090	-0.004
	0.113	0.000	0.000	0.019	0.153	0.057	0.940
Angle Lathe Check 1	0.074	0.277	0.653	0.039	0.057	-0.139	-0.051
	0.115	0.000	0.000	0.415	0.225	0.003	0.284
Angle Lathe Check 2	0.016	0.260	0.740	-0.034	0.053	-0.140	-0.134
	0.742	0.000	0.000	0.466	0.259	0.003	0.004

Table C-1 (Continued). Cross correlation table (correlation and p-values) for variables 1-7.

	Check Freqency	Average Lathe Check Depth	Average Lathe Check Angle to Glue-line	Lathe Check #1 Tip Distance to Saw Kerf 1	Lathe Check #2 Tip Distance to Saw Kerf 1	Lathe Check #1 Origin Distance to Saw Kerf 1	Lathe Check #2 Origin Distance to Saw Kerf 1
Latewood Percent Tight Side	0.022	0.080	0.140	-0.049	-0.004	0.029	-0.025
	0.637	0.092	0.003	0.295	0.937	0.535	0.597
Latewood Percent Loose Side	-0.019	0.054	0.143	0.006	-0.005	0.039	-0.014
	0.693	0.253	0.002	0.905	0.916	0.408	0.762
Latewood Angle at Saw Kerf 1 (to glue-line)	-0.055	-0.047	-0.221	0.038	0.019	-0.050	-0.008
	0.241	0.324	0.000	0.418	0.687	0.289	0.860
Latewood Angle at Saw Kerf 2 (to glue-line)	-0.069	-0.034	-0.198	0.062	0.026	-0.032	-0.004
	0.141	0.477	0.000	0.188	0.578	0.493	0.928
Average Latewood Angle to Glue-line	-0.064	-0.041	-0.216	0.051	0.023	-0.043	-0.007
	0.174	0.382	0.000	0.276	0.624	0.365	0.888
Average Latewood Angle (absolute value) to Glue-line	-0.187	-0.169	-0.527	0.127	0.019	0.089	0.062
	0.000	0.000	0.000	0.007	0.695	0.060	0.189
Number of Latewood Bands in Test Area	-0.071	-0.017	-0.191	0.043	0.015	0.065	0.018
	0.135	0.725	0.000	0.361	0.743	0.169	0.697
Percent Latewood in Test Area	0.088	0.204	0.329	-0.038	-0.051	-0.026	-0.099
	0.063	0.000	0.000	0.425	0.281	0.589	0.035
Tight CLA Average	-0.197	-0.168	-0.299	0.091	0.058	0.042	0.075
	0.000	0.000	0.000	0.053	0.217	0.370	0.114
Tight CLA Max.Min.	-0.158	-0.058	-0.221	0.042	0.029	0.001	0.029
	0.001	0.219	0.000	0.374	0.536	0.989	0.537
Tight RMS Average	-0.202	-0.169	-0.315	0.099	0.061	0.047	0.079
	0.000	0.000	0.000	0.036	0.194	0.321	0.095
Tight RMS Max.Min.	-0.173	-0.056	-0.245	0.071	0.041	0.037	0.046
	0.000	0.235	0.000	0.133	0.383	0.437	0.331
Tight Range Max.	-0.215	-0.168	-0.359	0.121	0.066	0.064	0.082
	0.000	0.000	0.000	0.010	0.163	0.176	0.083

Table C-1 (Continued). Cross correlation table (correlation and p-values) for variables 1-7.

	Check Freqency	Average Lathe Check Depth	Average Lathe Check Angle to Glue-line	Lathe Check #1 Tip Distance to Saw Kerf 1	Lathe Check #2 Tip Distance to Saw Kerf 1	Lathe Check #1 Origin Distance to Saw Kerf 1	Lathe Check #2 Origin Distance to Saw Kerf 1
Tight Range Average	-0.206	-0.166	-0.341	0.111	0.065	0.051	0.081
	0.000	0.000	0.000	0.019	0.169	0.279	0.088
Tight Range Max.Min	-0.177	-0.080	-0.286	0.137	0.059	0.099	0.071
	0.000	0.091	0.000	0.004	0.209	0.035	0.135
Tight Skewness Average	0.076	-0.060	0.123	-0.061	-0.051	-0.043	-0.069
	0.109	0.203	0.009	0.193	0.282	0.367	0.146
Tight Skewness Max.Min.	0.070	0.024	0.027	0.017	-0.059	0.012	-0.067
	0.139	0.619	0.571	0.724	0.211	0.795	0.156
Tight Kurtosis Average	0.043	-0.009	-0.100	0.051	-0.022	0.008	-0.027
	0.363	0.853	0.034	0.285	0.636	0.868	0.565
Tight Kurtosis Max.Min.	0.073	0.014	-0.028	-0.005	-0.042	-0.007	-0.042
	0.122	0.766	0.558	0.910	0.379	0.884	0.372
Tight High 3rd Max.	-0.196	-0.178	-0.266	0.092	0.053	0.045	0.065
	0.000	0.000	0.000	0.051	0.261	0.341	0.172
Tight High 3rd Max.Min.	-0.166	-0.076	-0.227	0.077	0.062	0.022	0.062
	0.000	0.108	0.000	0.104	0.192	0.647	0.187
Tight Low 3rd Min.	0.227	0.133	0.277	-0.120	-0.099	-0.081	-0.116
	0.000	0.005	0.000	0.011	0.036	0.086	0.013
Tight Low 3rd Max.Min.	-0.242	-0.094	-0.322	0.131	0.088	0.092	0.095
	0.000	0.045	0.000	0.005	0.063	0.052	0.043
Loose CLA Average	-0.169	-0.137	-0.235	0.055	0.010	-0.009	0.004
	0.000	0.003	0.000	0.243	0.830	0.847	0.926
Loose CLA Max.Min.	-0.056	-0.086	-0.168	-0.001	-0.060	-0.076	-0.061
	0.233	0.068	0.000	0.984	0.203	0.105	0.194
Loose RMS Average	-0.176	-0.142	-0.247	0.062	0.013	-0.005	0.010
	0.000	0.003	0.000	0.188	0.782	0.919	0.829

Table C-1 (Continued). Cross correlation table (correlation and p-values) for variables 1-7.

	Check Freqency	Average Lathe Check Depth	Average Lathe Check Angle to Glue-line	Lathe Check #1 Tip Distance to Saw Kerf 1	Lathe Check #2 Tip Distance to Saw Kerf 1	Lathe Check #1 Origin Distance to Saw Kerf 1	Lathe Check #2 Origin Distance to Saw Kerf 1
Loose RMS Max.Min.	-0.081	-0.108	-0.177	0.002	-0.059	-0.074	-0.062
	0.086	0.022	0.000	0.966	0.211	0.117	0.191
Loose Range Max.	-0.213	-0.158	-0.295	0.095	0.022	0.014	0.021
	0.000	0.001	0.000	0.044	0.647	0.767	0.653
Loose Range Average	-0.203	-0.146	-0.283	0.087	0.028	0.015	0.031
	0.000	0.002	0.000	0.064	0.555	0.748	0.513
Loose Range Max.Min	-0.158	-0.137	-0.243	0.063	-0.035	-0.023	-0.042
	0.001	0.004	0.000	0.180	0.462	0.627	0.379
Loose Skewness Average	0.035	0.089	0.046	-0.055	-0.045	-0.072	-0.053
	0.464	0.058	0.333	0.241	0.341	0.129	0.260
Loose Skewness Max.Min.	0.053	0.099	0.119	0.007	-0.021	0.010	-0.018
	0.263	0.036	0.011	0.882	0.661	0.829	0.699
Loose Kurtosis Average	0.050	0.041	0.091	0.014	-0.013	0.052	0.007
	0.288	0.388	0.054	0.766	0.789	0.271	0.884
Loose Kurtosis Max.Min.	0.059	0.047	0.110	-0.009	-0.040	0.005	-0.033
	0.208	0.322	0.020	0.845	0.403	0.910	0.481
Loose High 3rd Max.	-0.162	-0.122	-0.241	0.067	0.041	0.008	0.037
	0.001	0.010	0.000	0.159	0.380	0.863	0.439
Loose High 3rd Max.Min.	-0.131	-0.087	-0.285	0.068	-0.017	-0.012	-0.010
	0.006	0.064	0.000	0.147	0.721	0.792	0.834
Loose Low 3rd Min.	0.153	0.147	0.267	-0.060	0.009	0.005	-0.003
	0.001	0.002	0.000	0.201	0.856	0.917	0.944
Loose Low 3rd Max.Min.	-0.177	-0.075	-0.310	0.071	0.043	0.006	0.047
	0.000	0.110	0.000	0.134	0.367	0.905	0.317
Latewood Width (in)	-0.124	-0.018	-0.213	0.062	0.013	0.015	0.010
	0.009	0.704	0.000	0.190	0.785	0.752	0.834

Table C-1 (Continued). Cross correlation table (correlation and p-values) for variables 1-7.

	Check Freqency	Average Lathe Check Depth	Average Lathe Check Angle to Glue-line	Lathe Check #1 Tip Distance to Saw Kerf 1	Lathe Check #2 Tip Distance to Saw Kerf 1	Lathe Check #1 Origin Distance to Saw Kerf 1	Lathe Check #2 Origin Distance to Saw Kerf 1
Earlywood Width (in)	-0.185	-0.185	-0.322	0.051	0.035	-0.006	0.045
	0.000	0.000	0.000	0.279	0.462	0.900	0.337
Growth Rings per Inch	0.186	0.098	0.177	-0.089	-0.070	-0.046	-0.101
	0.000	0.038	0.000	0.059	0.137	0.334	0.032
Earlywood/ Latewood Ratio	-0.145	-0.228	-0.219	0.021	0.052	-0.017	0.090
	0.002	0.000	0.000	0.658	0.270	0.715	0.057
Load vs. DeflectionSlope (lb./in.)	-0.290	-0.144	-0.309	0.166	0.078	0.130	0.093
	0.000	0.002	0.000	0.000	0.097	0.006	0.050
Failure Load (lbs.)	-0.382	-0.043	-0.072	0.094	0.112	0.033	0.091
	0.000	0.367	0.126	0.045	0.017	0.488	0.055
Percent Wood Failure	0.139	-0.015	0.114	-0.128	-0.113	-0.068	-0.121
	0.003	0.751	0.016	0.006	0.017	0.151	0.010

Table C-2. Cross correlation table (correlation and p-values) for variables 8-14.

	Length of Lathe Check 1	Length of Lathe Check 2	Depth Lathe Check 1	Depth Lathe Check 2	Angle Lathe Check 1	Angle Lathe Check 2	Latewood Percent Tight Side
Check Freqency	-0.114	0.017	-0.048	0.075	0.074	0.016	0.022
	0.016	0.715	0.312	0.113	0.115	0.742	0.637
Average Lathe Check Depth	0.272	0.257	0.467	0.496	0.277	0.260	0.080
	0.000	0.000	0.000	0.000	0.000	0.000	0.092
Average Lathe Check Angle to Glue-line	0.012	-0.058	0.184	0.282	0.653	0.740	0.140
	0.793	0.219	0.000	0.000	0.000	0.000	0.003
Lathe Check #1 Tip Distance to Saw Kerf 1	0.154	-0.133	0.191	-0.110	0.039	-0.034	-0.049
	0.001	0.005	0.000	0.019	0.415	0.466	0.295
Lathe Check #2 Tip Distance to Saw Kerf 1	0.367	-0.122	0.327	-0.067	0.057	0.053	-0.004
	0.000	0.010	0.000	0.153	0.225	0.259	0.937
Lathe Check #1 Origin Distance to Saw Kerf 1	0.516	0.047	0.303	-0.090	-0.139	-0.140	0.029
	0.000	0.316	0.000	0.057	0.003	0.003	0.535
Lathe Check #2 Origin Distance to Saw Kerf 1	0.437	0.180	0.290	-0.004	-0.051	-0.134	-0.025
	0.000	0.000	0.000	0.940	0.284	0.004	0.597
Length of Lathe Check 1	1.000	0.167	0.746	0.093	0.080	-0.014	0.095
	0.000	0.000	0.000	0.048	0.090	0.770	0.044
Length of Lathe Check 2	0.167	1.000	0.028	0.653	-0.107	-0.124	0.043
	0.000	0.000	0.557	0.000	0.024	0.009	0.364
Depth Lathe Check 1	0.746	0.028	1.000	0.140	0.400	0.137	0.042
	0.000	0.557	0.000	0.003	0.000	0.004	0.370
Depth Lathe Check 2	0.093	0.653	0.140	1.000	0.188	0.328	0.072
	0.048	0.000	0.003	0.000	0.000	0.000	0.127
Angle Lathe Check 1	0.080	-0.107	0.400	0.188	1.000	0.517	-0.023
	0.090	0.024	0.000	0.000	0.000	0.000	0.620
Angle Lathe Check 2	-0.014	-0.124	0.137	0.328	0.517	1.000	0.174
	0.770	0.009	0.004	0.000	0.000	0.000	0.000

Table C-2 (Continued). Cross correlation table (correlation and p-values) for variables 8-14.

	Length of Lathe Check 1	Length of Lathe Check 2	Depth Lathe Check 1	Depth Lathe Check 2	Angle Lathe Check 1	Angle Lathe Check 2	Latewood Percent Tight Side
Latewood Percent Tight Side	0.095	0.043	0.042	0.072	-0.023	0.174	1.000
	0.044	0.364	0.370	0.127	0.620	0.000	0.000
Latewood Percent Loose Side	0.111	0.019	0.080	0.052	0.120	0.126	0.261
	0.019	0.682	0.089	0.276	0.011	0.007	0.000
Latewood Angle at Saw Kerf 1 (to glue-line)	-0.153	-0.099	-0.023	-0.024	-0.093	-0.142	-0.079
	0.001	0.037	0.624	0.614	0.049	0.003	0.092
Latewood Angle at Saw Kerf 2 (to glue-line)	-0.127	-0.120	0.001	-0.038	-0.050	-0.118	-0.079
	0.007	0.011	0.984	0.422	0.291	0.012	0.095
Average Latewood Angle to Glue-line	-0.145	-0.112	-0.012	-0.032	-0.074	-0.134	-0.082
	0.002	0.017	0.805	0.503	0.116	0.004	0.084
Average Latewood Angle (absolute value) to Glue-line	-0.116	-0.003	-0.062	-0.099	-0.293	-0.313	-0.071
	0.013	0.948	0.187	0.036	0.000	0.000	0.131
Number of Latewood Bands in Test Area	-0.023	0.053	-0.047	-0.068	-0.186	-0.127	0.126
	0.630	0.261	0.324	0.150	0.000	0.007	0.007
Percent Latewood in Test Area	0.069	0.047	0.074	0.116	0.180	0.259	0.372
	0.147	0.320	0.117	0.014	0.000	0.000	0.000
Tight CLA Average	-0.129	-0.032	-0.064	-0.039	-0.163	-0.159	-0.164
	0.006	0.496	0.178	0.406	0.001	0.001	0.000
Tight CLA Max.Min.	-0.085	-0.066	-0.003	-0.047	-0.183	-0.144	-0.099
	0.073	0.160	0.944	0.325	0.000	0.002	0.037
Tight RMS Average	-0.129	-0.032	-0.060	-0.038	-0.169	-0.173	-0.166
	0.006	0.500	0.207	0.417	0.000	0.000	0.000
Tight RMS Max.Min.	-0.062	-0.052	0.002	-0.036	-0.202	-0.160	-0.092
	0.187	0.273	0.975	0.448	0.000	0.001	0.051
Tight Range Max.	-0.129	-0.038	-0.054	-0.042	-0.212	-0.213	-0.165
	0.006	0.417	0.252	0.370	0.000	0.000	0.000

Table C-2 (Continued). Cross correlation table (correlation and p-values) for variables 8-14.

	Length of Lathe Check 1	Length of Lathe Check 2	Depth Lathe Check 1	Depth Lathe Check 2	Angle Lathe Check 1	Angle Lathe Check 2	Latewood Percent Tight Side
Tight Range Average	-0.133	-0.039	-0.052	-0.037	-0.182	-0.196	-0.166
	0.005	0.413	0.272	0.430	0.000	0.000	0.000
Tight Range Max.Min	-0.059	-0.022	-0.010	-0.024	-0.233	-0.192	-0.095
	0.208	0.640	0.836	0.608	0.000	0.000	0.043
Tight Skewness Average	-0.016	-0.037	-0.043	-0.042	0.013	0.041	-0.007
	0.737	0.429	0.366	0.377	0.787	0.383	0.879
Tight Skewness Max.Min.	-0.017	0.012	-0.063	0.001	-0.049	-0.013	0.114
	0.725	0.808	0.184	0.978	0.300	0.785	0.015
Tight Kurtosis Average	-0.027	-0.016	-0.007	-0.019	-0.057	-0.109	0.050
	0.569	0.731	0.880	0.683	0.228	0.020	0.295
Tight Kurtosis Max.Min.	-0.020	0.037	-0.047	0.000	-0.068	-0.046	0.081
	0.679	0.434	0.321	0.998	0.148	0.329	0.088
Tight High 3rd Max.	-0.127	-0.039	-0.064	-0.047	-0.165	-0.168	-0.153
	0.007	0.411	0.174	0.317	0.000	0.000	0.001
Tight High 3rd Max.Min.	-0.163	-0.066	-0.097	-0.023	-0.157	-0.111	-0.069
	0.000	0.165	0.039	0.619	0.001	0.018	0.144
Tight Low 3rd Min.	0.078	0.014	0.012	0.014	0.160	0.133	0.132
	0.099	0.764	0.800	0.774	0.001	0.005	0.005
Tight Low 3rd Max.Min.	-0.057	-0.006	0.000	-0.009	-0.195	-0.170	-0.048
	0.224	0.894	0.997	0.846	0.000	0.000	0.310
Loose CLA Average	-0.156	-0.075	-0.079	-0.033	-0.100	-0.113	-0.131
	0.001	0.111	0.096	0.482	0.034	0.016	0.005
Loose CLA Max.Min.	-0.164	0.003	-0.058	0.030	-0.083	-0.092	-0.090
	0.000	0.954	0.218	0.529	0.078	0.052	0.055
Loose RMS Average	-0.159	-0.070	-0.080	-0.029	-0.106	-0.122	-0.132
	0.001	0.136	0.090	0.542	0.025	0.010	0.005

Table C-2 (Continued). Cross correlation table (correlation and p-values) for variables 8-14.

	Length of Lathe Check 1	Length of Lathe Check 2	Depth Lathe Check 1	Depth Lathe Check 2	Angle Lathe Check 1	Angle Lathe Check 2	Latewood Percent Tight Side
Loose RMS Max.Min.	-0.174	-0.006	-0.077	0.025	-0.085	-0.089	-0.081
	0.000	0.894	0.101	0.598	0.073	0.059	0.088
Loose Range Max.	-0.182	-0.063	-0.098	-0.026	-0.140	-0.159	-0.132
	0.000	0.181	0.038	0.582	0.003	0.001	0.005
Loose Range Average	-0.161	-0.059	-0.076	-0.023	-0.127	-0.149	-0.135
	0.001	0.211	0.105	0.624	0.007	0.002	0.004
Loose Range Max.Min	-0.197	-0.036	-0.124	-0.016	-0.138	-0.137	-0.073
	0.000	0.450	0.009	0.736	0.003	0.004	0.124
Loose Skewness Average	0.009	0.077	0.047	0.112	0.049	0.065	0.072
	0.849	0.103	0.318	0.018	0.302	0.170	0.127
Loose Skewness Max.Min.	-0.014	0.044	-0.021	0.058	0.024	0.031	0.047
	0.766	0.350	0.656	0.219	0.608	0.517	0.317
Loose Kurtosis Average	0.044	0.044	-0.013	0.048	-0.001	0.022	0.067
	0.355	0.353	0.790	0.312	0.981	0.639	0.156
Loose Kurtosis Max.Min.	-0.038	0.038	-0.058	0.040	0.006	0.020	0.058
	0.416	0.419	0.218	0.403	0.893	0.676	0.223
Loose High 3rd Max.	-0.131	-0.051	-0.056	-0.002	-0.097	-0.119	-0.113
	0.005	0.280	0.237	0.972	0.039	0.012	0.016
Loose High 3rd Max.Min.	-0.179	-0.030	-0.073	-0.008	-0.154	-0.148	-0.067
	0.000	0.526	0.123	0.859	0.001	0.002	0.158
Loose Low 3rd Min.	0.166	0.059	0.096	0.046	0.132	0.145	0.116
	0.000	0.213	0.043	0.330	0.005	0.002	0.014
Loose Low 3rd Max.Min.	-0.114	-0.069	-0.012	-0.038	-0.146	-0.179	-0.100
	0.015	0.142	0.795	0.420	0.002	0.000	0.035
Latewood Width (in)	-0.060	-0.092	0.037	-0.051	-0.050	-0.111	0.053
	0.200	0.051	0.437	0.284	0.290	0.018	0.259

Table C-2 (Continued). Cross correlation table (correlation and p-values) for variables 8-14.

	Length of Lathe Check 1	Length of Lathe Check 2	Depth Lathe Check 1	Depth Lathe Check 2	Angle Lathe Check 1	Angle Lathe Check 2	Latewood Percent Tight Side
Earlywood Width (in)	-0.133	-0.085	-0.046	-0.057	-0.138	-0.175	-0.173
	0.005	0.073	0.326	0.225	0.003	0.000	0.000
Growth Rings per Inch	0.021	0.035	-0.040	-0.007	0.006	0.052	0.042
	0.659	0.463	0.394	0.882	0.905	0.268	0.371
Earlywood/ Latewood Ratio	-0.110	0.010	-0.100	-0.013	-0.114	-0.133	-0.343
	0.020	0.831	0.034	0.777	0.015	0.005	0.000
Load vs. DeflectionSlope (lb./in.)	-0.075	-0.027	-0.043	-0.053	-0.131	-0.150	0.091
	0.111	0.574	0.362	0.263	0.005	0.001	0.054
Failure Load (lbs.)	-0.036	-0.061	-0.012	0.051	-0.013	0.007	-0.014
	0.442	0.195	0.804	0.278	0.784	0.886	0.759
Percent Wood Failure	0.028	-0.017	-0.062	-0.017	0.006	0.023	0.110
	0.558	0.723	0.191	0.722	0.904	0.628	0.019

Table C-3. Cross correlation table (correlation and p-values) for variables 15-21.

	Latewood Percent Loose Side	Latewood Angle at Saw Kerf 1 (to glue-line)	Latewood Angle at Saw Kerf 2 (to glue-line)	Average Latewood Angle to Glue-line	Average Latewood Angle (absolute value) to Glue-line	Number of Latewood Bands in Test Area	Percent Latewood in Test Area
Check Freqency	-0.019	-0.055	-0.069	-0.064	-0.187	-0.071	0.088
	0.693	0.241	0.141	0.174	0.000	0.135	0.063
Average Lathe Check Depth	0.054	-0.047	-0.034	-0.041	-0.169	-0.017	0.204
	0.253	0.324	0.477	0.382	0.000	0.725	0.000
Average Lathe Check Angle to Glue-line	0.143	-0.221	-0.198	-0.216	-0.527	-0.191	0.329
	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Lathe Check #1 Tip Distance to Saw Kerf 1	0.006	0.038	0.062	0.051	0.127	0.043	-0.038
	0.905	0.418	0.188	0.276	0.007	0.361	0.425
Lathe Check #2 Tip Distance to Saw Kerf 1	-0.005	0.019	0.026	0.023	0.019	0.015	-0.051
	0.916	0.687	0.578	0.624	0.695	0.743	0.281
Lathe Check #1 Origin Distance to Saw Kerf 1	0.039	-0.050	-0.032	-0.043	0.089	0.065	-0.026
	0.408	0.289	0.493	0.365	0.060	0.169	0.589
Lathe Check #2 Origin Distance to Saw Kerf 1	-0.014	-0.008	-0.004	-0.007	0.062	0.018	-0.099
	0.762	0.860	0.928	0.888	0.189	0.697	0.035
Length of Lathe Check 1	0.111	-0.153	-0.127	-0.145	-0.116	-0.023	0.069
	0.019	0.001	0.007	0.002	0.013	0.630	0.147
Length of Lathe Check 2	0.019	-0.099	-0.120	-0.112	-0.003	0.053	0.047
	0.682	0.037	0.011	0.017	0.948	0.261	0.320
Depth Lathe Check 1	0.080	-0.023	0.001	-0.012	-0.062	-0.047	0.074
	0.089	0.624	0.984	0.805	0.187	0.324	0.117
Depth Lathe Check 2	0.052	-0.024	-0.038	-0.032	-0.099	-0.068	0.116
	0.276	0.614	0.422	0.503	0.036	0.150	0.014
Angle Lathe Check 1	0.120	-0.093	-0.050	-0.074	-0.293	-0.186	0.180
	0.011	0.049	0.291	0.116	0.000	0.000	0.000
Angle Lathe Check 2	0.126	-0.142	-0.118	-0.134	-0.313	-0.127	0.259
	0.007	0.003	0.012	0.004	0.000	0.007	0.000

Table C-3 (Continued). Cross correlation table (correlation and p-values) for variables 15-21.

	Latewood Percent Loose Side	Latewood Angle at Saw Kerf 1 (to glue-line)	Latewood Angle at Saw Kerf 2 (to glue-line)	Average Latewood Angle to Glue-line	Average Latewood Angle (absolute value) to Glue-line	Number of Latewood Bands in Test Area	Percent Latewood in Test Area
Latewood Percent Tight Side	0.261	-0.079	-0.079	-0.082	-0.071	0.126	0.372
	0.000	0.092	0.095	0.084	0.131	0.007	0.000
Latewood Percent Loose Side	1.000	-0.025	-0.030	-0.028	-0.066	0.239	0.481
	0.000	0.601	0.523	0.550	0.165	0.000	0.000
Latewood Angle at Saw Kerf 1 (to glue-line)	-0.025	1.000	0.882	0.972	0.474	-0.032	-0.116
	0.601	0.000	0.000	0.000	0.000	0.493	0.014
Latewood Angle at Saw Kerf 2 (to glue-line)	-0.030	0.882	1.000	0.968	0.481	-0.001	-0.114
	0.523	0.000	0.000	0.000	0.000	0.985	0.016
Average Latewood Angle to Glue-line	-0.028	0.972	0.968	1.000	0.492	-0.018	-0.119
	0.550	0.000	0.000	0.000	0.000	0.705	0.012
Average Latewood Angle (absolute value) to Glue-line	-0.066	0.474	0.481	0.492	1.000	0.212	-0.195
	0.165	0.000	0.000	0.000	0.000	0.000	0.000
Number of Latewood Bands in Test Area	0.239	-0.032	-0.001	-0.018	0.212	1.000	0.346
	0.000	0.493	0.985	0.705	0.000	0.000	0.000
Percent Latewood in Test Area	0.481	-0.116	-0.114	-0.119	-0.195	0.346	1.000
	0.000	0.014	0.016	0.012	0.000	0.000	0.000
Tight CLA Average	-0.129	0.370	0.399	0.396	0.554	-0.164	-0.350
	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Max.Min.	-0.070	0.330	0.315	0.332	0.410	-0.075	-0.201
	0.135	0.000	0.000	0.000	0.000	0.112	0.000
Tight RMS Average	-0.131	0.391	0.419	0.417	0.579	-0.158	-0.354
	0.005	0.000	0.000	0.000	0.000	0.001	0.000
Tight RMS Max.Min.	-0.068	0.315	0.289	0.312	0.408	-0.055	-0.183
	0.152	0.000	0.000	0.000	0.000	0.244	0.000
Tight Range Max.	-0.132	0.428	0.449	0.452	0.630	-0.128	-0.360
	0.005	0.000	0.000	0.000	0.000	0.007	0.000

Table C-3 (Continued). Cross correlation table (correlation and p-values) for variables 15-21.

	Latewood Percent Loose Side	Latewood Angle at Saw Kerf 1 (to glue-line)	Latewood Angle at Saw Kerf 2 (to glue-line)	Average Latewood Angle to Glue-line	Average Latewood Angle (absolute value) to Glue-line	Number of Latewood Bands in Test Area	Percent Latewood in Test Area
Tight Range Average	-0.132	0.430	0.458	0.457	0.624	-0.136	-0.357
	0.005	0.000	0.000	0.000	0.000	0.004	0.000
Tight Range Max.Min	-0.074	0.296	0.274	0.294	0.438	-0.039	-0.209
	0.115	0.000	0.000	0.000	0.000	0.406	0.000
Tight Skewness Average	-0.072	-0.160	-0.150	-0.160	-0.255	-0.119	-0.062
	0.126	0.001	0.001	0.001	0.000	0.012	0.191
Tight Skewness Max.Min.	0.122	-0.151	-0.179	-0.170	-0.143	0.199	0.198
	0.010	0.001	0.000	0.000	0.002	0.000	0.000
Tight Kurtosis Average	0.036	0.083	0.054	0.071	0.093	0.158	0.093
	0.446	0.080	0.255	0.135	0.048	0.001	0.048
Tight Kurtosis Max.Min.	0.093	-0.097	-0.137	-0.120	-0.086	0.163	0.180
	0.048	0.039	0.003	0.011	0.067	0.001	0.000
Tight High 3rd Max.	-0.116	0.333	0.374	0.364	0.477	-0.147	-0.323
	0.014	0.000	0.000	0.000	0.000	0.002	0.000
Tight High 3rd Max.Min.	-0.033	0.252	0.295	0.282	0.459	-0.062	-0.221
	0.483	0.000	0.000	0.000	0.000	0.187	0.000
Tight Low 3rd Min.	0.098	-0.316	-0.340	-0.337	-0.519	0.145	0.276
	0.038	0.000	0.000	0.000	0.000	0.002	0.000
Tight Low 3rd Max.Min.	-0.063	0.282	0.266	0.282	0.538	0.018	-0.144
	0.186	0.000	0.000	0.000	0.000	0.698	0.002
Loose CLA Average	-0.085	0.233	0.263	0.256	0.490	-0.162	-0.283
	0.071	0.000	0.000	0.000	0.000	0.001	0.000
Loose CLA Max.Min.	-0.028	0.251	0.277	0.272	0.372	-0.103	-0.214
	0.559	0.000	0.000	0.000	0.000	0.028	0.000
Loose RMS Average	-0.089	0.246	0.277	0.269	0.512	-0.159	-0.287
	0.059	0.000	0.000	0.000	0.000	0.001	0.000

Table C-3 (Continued). Cross correlation table (correlation and p-values) for variables 15-21.

	Latewood Percent Loose Side	Latewood Angle at Saw Kerf 1 (to glue-line)	Latewood Angle at Saw Kerf 2 (to glue-line)	Average Latewood Angle to Glue-line	Average Latewood Angle (absolute value) to Glue-line	Number of Latewood Bands in Test Area	Percent Latewood in Test Area
Loose RMS Max.Min.	-0.020	0.238	0.275	0.264	0.385	-0.067	-0.192
	0.671	0.000	0.000	0.000	0.000	0.157	0.000
Loose Range Max.	-0.092	0.291	0.330	0.320	0.590	-0.118	-0.298
	0.050	0.000	0.000	0.000	0.000	0.012	0.000
Loose Range Average	-0.098	0.279	0.316	0.306	0.577	-0.137	-0.299
	0.038	0.000	0.000	0.000	0.000	0.004	0.000
Loose Range Max.Min	-0.041	0.213	0.262	0.244	0.447	0.000	-0.190
	0.386	0.000	0.000	0.000	0.000	0.994	0.000
Loose Skewness Average	0.135	-0.041	-0.044	-0.044	0.035	0.082	0.111
	0.004	0.388	0.353	0.355	0.464	0.083	0.018
Loose Skewness Max.Min.	0.084	-0.089	-0.089	-0.092	-0.160	0.197	0.147
	0.075	0.059	0.060	0.051	0.001	0.000	0.002
Loose Kurtosis Average	0.025	-0.105	-0.098	-0.105	-0.116	0.140	0.093
	0.598	0.026	0.037	0.026	0.014	0.003	0.048
Loose Kurtosis Max.Min.	0.073	-0.130	-0.122	-0.130	-0.163	0.151	0.112
	0.120	0.006	0.010	0.006	0.000	0.001	0.017
Loose High 3rd Max.	-0.086	0.272	0.292	0.290	0.511	-0.145	-0.276
	0.068	0.000	0.000	0.000	0.000	0.002	0.000
Loose High 3rd Max.Min.	-0.034	0.287	0.300	0.303	0.544	-0.024	-0.218
	0.471	0.000	0.000	0.000	0.000	0.613	0.000
Loose Low 3rd Min.	0.098	-0.295	-0.327	-0.320	-0.516	0.151	0.276
	0.037	0.000	0.000	0.000	0.000	0.001	0.000
Loose Low 3rd Max.Min.	-0.109	0.350	0.406	0.389	0.566	-0.064	-0.269
	0.021	0.000	0.000	0.000	0.000	0.175	0.000
Latewood Width (in)	0.069	0.346	0.348	0.358	0.578	-0.318	-0.011
	0.145	0.000	0.000	0.000	0.000	0.000	0.818

Table C-3 (Continued). Cross correlation table (correlation and p-values) for variables 15-21.

	Latewood Percent Loose Side	Latewood Angle at Saw Kerf 1 (to glue-line)	Latewood Angle at Saw Kerf 2 (to glue-line)	Average Latewood Angle to Glue-line	Average Latewood Angle (absolute value) to Glue-line	Number of Latewood Bands in Test Area	Percent Latewood in Test Area
Earlywood Width (in)	-0.186	0.445	0.430	0.452	0.631	-0.367	-0.467
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Growth Rings per Inch	0.091	-0.325	-0.324	-0.335	-0.491	0.522	0.321
	0.054	0.000	0.000	0.000	0.000	0.000	0.000
Earlywood/ Latewood Ratio	-0.407	0.187	0.159	0.179	0.179	-0.284	-0.738
	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Load vs. DeflectionSlope (lb./in.)	0.149	0.342	0.376	0.370	0.683	0.193	0.118
	0.002	0.000	0.000	0.000	0.000	0.000	0.012
Failure Load (lbs.)	0.129	0.103	0.096	0.103	0.175	-0.006	0.075
	0.006	0.029	0.041	0.029	0.000	0.898	0.110
Percent Wood Failure	-0.045	-0.194	-0.226	-0.216	-0.255	0.065	0.015
	0.341	0.000	0.000	0.000	0.000	0.170	0.743

Table C-4. Cross correlation table (correlation and p-values) for variables 22-28.

	Tight CLA Average	Tight CLA Max.Min.	Tight RMS Average	Tight RMS Max.Min.	Tight Range Max.	Tight Range Average	Tight Range Max.Min
Check Freqency	-0.197	-0.158	-0.202	-0.173	-0.215	-0.206	-0.177
	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Average Lathe Check Depth	-0.168	-0.058	-0.169	-0.056	-0.168	-0.166	-0.080
	0.000	0.219	0.000	0.235	0.000	0.000	0.091
Average Lathe Check Angle to Glue-line	-0.299	-0.221	-0.315	-0.245	-0.359	-0.341	-0.286
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lathe Check #1 Tip Distance to Saw Kerf 1	0.091	0.042	0.099	0.071	0.121	0.111	0.137
	0.053	0.374	0.036	0.133	0.010	0.019	0.004
Lathe Check #2 Tip Distance to Saw Kerf 1	0.058	0.029	0.061	0.041	0.066	0.065	0.059
	0.217	0.536	0.194	0.383	0.163	0.169	0.209
Lathe Check #1 Origin Distance to Saw Kerf 1	0.042	0.001	0.047	0.037	0.064	0.051	0.099
	0.370	0.989	0.321	0.437	0.176	0.279	0.035
Lathe Check #2 Origin Distance to Saw Kerf 1	0.075	0.029	0.079	0.046	0.082	0.081	0.071
	0.114	0.537	0.095	0.331	0.083	0.088	0.135
Length of Lathe Check 1	-0.129	-0.085	-0.129	-0.062	-0.129	-0.133	-0.059
	0.006	0.073	0.006	0.187	0.006	0.005	0.208
Length of Lathe Check 2	-0.032	-0.066	-0.032	-0.052	-0.038	-0.039	-0.022
	0.496	0.160	0.500	0.273	0.417	0.413	0.640
Depth Lathe Check 1	-0.064	-0.003	-0.060	0.002	-0.054	-0.052	-0.010
	0.178	0.944	0.207	0.975	0.252	0.272	0.836
Depth Lathe Check 2	-0.039	-0.047	-0.038	-0.036	-0.042	-0.037	-0.024
	0.406	0.325	0.417	0.448	0.370	0.430	0.608
Angle Lathe Check 1	-0.163	-0.183	-0.169	-0.202	-0.212	-0.182	-0.233
	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Angle Lathe Check 2	-0.159	-0.144	-0.173	-0.160	-0.213	-0.196	-0.192
	0.001	0.002	0.000	0.001	0.000	0.000	0.000

Table C-4 (Continued). Cross correlation table (correlation and p-values) for variables 22-28.

	Tight CLA Average	Tight CLA Max.Min.	Tight RMS Average	Tight RMS Max.Min.	Tight Range Max.	Tight Range Average	Tight Range Max.Min
Latewood Percent Tight Side	-0.164	-0.099	-0.166	-0.092	-0.165	-0.166	-0.095
	0.000	0.037	0.000	0.051	0.000	0.000	0.043
Latewood Percent Loose Side	-0.129	-0.070	-0.131	-0.068	-0.132	-0.132	-0.074
	0.006	0.135	0.005	0.152	0.005	0.005	0.115
Latewood Angle at Saw Kerf 1 (to glue-line)	0.370	0.330	0.391	0.315	0.428	0.430	0.296
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latewood Angle at Saw Kerf 2 (to glue-line)	0.399	0.315	0.419	0.289	0.449	0.458	0.274
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average Latewood Angle to Glue-line	0.396	0.332	0.417	0.312	0.452	0.457	0.294
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average Latewood Angle (absolute value) to Glue-line	0.554	0.410	0.579	0.408	0.630	0.624	0.438
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Number of Latewood Bands in Test Area	-0.164	-0.075	-0.158	-0.055	-0.128	-0.136	-0.039
	0.000	0.112	0.001	0.244	0.007	0.004	0.406
Percent Latewood in Test Area	-0.350	-0.201	-0.354	-0.183	-0.360	-0.357	-0.209
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Average	1.000	0.612	0.995	0.540	0.932	0.964	0.481
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Max.Min.	0.612	1.000	0.627	0.957	0.711	0.634	0.784
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Average	0.995	0.627	1.000	0.568	0.955	0.983	0.518
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Max.Min.	0.540	0.957	0.568	1.000	0.700	0.597	0.885
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.	0.932	0.711	0.955	0.700	1.000	0.980	0.713
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-4 (Continued). Cross correlation table (correlation and p-values) for variables 22-28.

	Tight CLA Average	Tight CLA Max.Min.	Tight RMS Average	Tight RMS Max.Min.	Tight Range Max.	Tight Range Average	Tight Range Max.Min
Tight Range Average	0.964	0.634	0.983	0.597	0.980	1.000	0.577
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.Min	0.481	0.784	0.518	0.885	0.713	0.577	1.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Skewness Average	-0.041	-0.137	-0.073	-0.206	-0.140	-0.120	-0.233
	0.390	0.004	0.121	0.000	0.003	0.011	0.000
Tight Skewness Max.Min.	-0.485	-0.090	-0.462	0.003	-0.315	-0.403	0.108
	0.000	0.056	0.000	0.954	0.000	0.000	0.021
Tight Kurtosis Average	-0.266	-0.024	-0.201	0.092	-0.045	-0.083	0.192
	0.000	0.618	0.000	0.050	0.339	0.080	0.000
Tight Kurtosis Max.Min.	-0.414	-0.093	-0.386	0.000	-0.251	-0.322	0.118
	0.000	0.049	0.000	0.993	0.000	0.000	0.013
Tight High 3rd Max.	0.889	0.568	0.894	0.511	0.875	0.893	0.487
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight High 3rd Max.Min.	0.542	0.540	0.558	0.547	0.631	0.586	0.564
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Min.	-0.884	-0.689	-0.895	-0.669	-0.892	-0.886	-0.611
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Max.Min.	0.583	0.587	0.609	0.614	0.679	0.643	0.613
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Average	0.746	0.461	0.743	0.424	0.716	0.730	0.389
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Max.Min.	0.540	0.436	0.545	0.410	0.542	0.544	0.384
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose RMS Average	0.755	0.472	0.754	0.436	0.733	0.745	0.406
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-4 (Continued). Cross correlation table (correlation and p-values) for variables 22-28.

	Tight CLA Average	Tight CLA Max.Min.	Tight RMS Average	Tight RMS Max.Min.	Tight Range Max.	Tight Range Average	Tight Range Max.Min
Loose RMS Max.Min.	0.508	0.419	0.513	0.394	0.513	0.513	0.373
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.	0.769	0.522	0.775	0.491	0.778	0.782	0.478
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Average	0.768	0.503	0.773	0.473	0.770	0.778	0.456
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.Min	0.502	0.415	0.510	0.394	0.539	0.525	0.415
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Skewness Average	0.022	0.070	0.022	0.073	0.021	0.017	0.039
	0.646	0.135	0.634	0.124	0.657	0.724	0.412
Loose Skewness Max.Min.	-0.305	-0.105	-0.301	-0.089	-0.261	-0.285	-0.061
	0.000	0.025	0.000	0.058	0.000	0.000	0.195
Loose Kurtosis Average	-0.265	-0.106	-0.253	-0.078	-0.206	-0.224	-0.040
	0.000	0.025	0.000	0.100	0.000	0.000	0.393
Loose Kurtosis Max.Min.	-0.228	-0.102	-0.229	-0.090	-0.210	-0.225	-0.069
	0.000	0.030	0.000	0.058	0.000	0.000	0.146
Loose High 3rd Max.	0.702	0.475	0.707	0.439	0.697	0.708	0.393
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose High 3rd Max.Min.	0.552	0.370	0.560	0.352	0.579	0.581	0.362
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Low 3rd Min.	-0.710	-0.450	-0.714	-0.420	-0.710	-0.719	-0.409
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Low 3rd Max.Min.	0.493	0.402	0.514	0.405	0.573	0.555	0.436
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latewood Width (in)	0.482	0.356	0.496	0.351	0.526	0.521	0.360
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-4 (Continued). Cross correlation table (correlation and p-values) for variables 22-28.

	Tight CLA Average	Tight CLA Max.Min.	Tight RMS Average	Tight RMS Max.Min.	Tight Range Max.	Tight Range Average	Tight Range Max.Min
Earlywood Width (in)	0.673	0.465	0.688	0.446	0.711	0.710	0.449
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Growth Rings per Inch	-0.515	-0.376	-0.529	-0.364	-0.552	-0.551	-0.367
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Earlywood/ Latewood Ratio	0.368	0.245	0.375	0.226	0.378	0.380	0.225
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Load vs. DeflectionSlope (lb./in.)	0.466	0.400	0.484	0.405	0.538	0.521	0.438
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Failure Load (lbs.)	0.179	0.233	0.185	0.241	0.220	0.196	0.258
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percent Wood Failure	-0.349	-0.274	-0.359	-0.276	-0.375	-0.369	-0.280
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-5. Cross correlation table (correlation and p-values) for variables 29-35.

	Tight Skewness Average	Tight Skewness Max.Min.	Tight Kurtosis Average	Tight Kurtosis Max.Min.	Tight High 3rd Max.	Tight High 3rd Max.Min.	Tight Low 3rd Min.
Check Freqency	0.076	0.070	0.043	0.073	-0.196	-0.166	0.227
	0.109	0.139	0.363	0.122	0.000	0.000	0.000
Average Lathe Check Depth	-0.060	0.024	-0.009	0.014	-0.178	-0.076	0.133
	0.203	0.619	0.853	0.766	0.000	0.108	0.005
Average Lathe Check Angle to Glue-line	0.123	0.027	-0.100	-0.028	-0.266	-0.227	0.277
	0.009	0.571	0.034	0.558	0.000	0.000	0.000
Lathe Check #1 Tip Distance to Saw Kerf 1	-0.061	0.017	0.051	-0.005	0.092	0.077	-0.120
	0.193	0.724	0.285	0.910	0.051	0.104	0.011
Lathe Check #2 Tip Distance to Saw Kerf 1	-0.051	-0.059	-0.022	-0.042	0.053	0.062	-0.099
	0.282	0.211	0.636	0.379	0.261	0.192	0.036
Lathe Check #1 Origin Distance to Saw Kerf 1	-0.043	0.012	0.008	-0.007	0.045	0.022	-0.081
	0.367	0.795	0.868	0.884	0.341	0.647	0.086
Lathe Check #2 Origin Distance to Saw Kerf 1	-0.069	-0.067	-0.027	-0.042	0.065	0.062	-0.116
	0.146	0.156	0.565	0.372	0.172	0.187	0.013
Length of Lathe Check 1	-0.016	-0.017	-0.027	-0.020	-0.127	-0.163	0.078
	0.737	0.725	0.569	0.679	0.007	0.000	0.099
Length of Lathe Check 2	-0.037	0.012	-0.016	0.037	-0.039	-0.066	0.014
	0.429	0.808	0.731	0.434	0.411	0.165	0.764
Depth Lathe Check 1	-0.043	-0.063	-0.007	-0.047	-0.064	-0.097	0.012
	0.366	0.184	0.880	0.321	0.174	0.039	0.800
Depth Lathe Check 2	-0.042	0.001	-0.019	0.000	-0.047	-0.023	0.014
	0.377	0.978	0.683	0.998	0.317	0.619	0.774
Angle Lathe Check 1	0.013	-0.049	-0.057	-0.068	-0.165	-0.157	0.160
	0.787	0.300	0.228	0.148	0.000	0.001	0.001
Angle Lathe Check 2	0.041	-0.013	-0.109	-0.046	-0.168	-0.111	0.133
	0.383	0.785	0.020	0.329	0.000	0.018	0.005

Table C-5 (Continued). Cross correlation table (correlation and p-values) for variables 29-35.

	Tight Skewness Average	Tight Skewness Max.Min.	Tight Kurtosis Average	Tight Kurtosis Max.Min.	Tight High 3rd Max.	Tight High 3rd Max.Min.	Tight Low 3rd Min.
Latewood Percent Tight Side	-0.007	0.114	0.050	0.081	-0.153	-0.069	0.132
	0.879	0.015	0.295	0.088	0.001	0.144	0.005
Latewood Percent Loose Side	-0.072	0.122	0.036	0.093	-0.116	-0.033	0.098
	0.126	0.010	0.446	0.048	0.014	0.483	0.038
Latewood Angle at Saw Kerf 1 (to glue-line)	-0.160	-0.151	0.083	-0.097	0.333	0.252	-0.316
	0.001	0.001	0.080	0.039	0.000	0.000	0.000
Latewood Angle at Saw Kerf 2 (to glue-line)	-0.150	-0.179	0.054	-0.137	0.374	0.295	-0.340
	0.001	0.000	0.255	0.003	0.000	0.000	0.000
Average Latewood Angle to Glue-line	-0.160	-0.170	0.071	-0.120	0.364	0.282	-0.337
	0.001	0.000	0.135	0.011	0.000	0.000	0.000
Average Latewood Angle (absolute value) to Glue-line	-0.255	-0.143	0.093	-0.086	0.477	0.459	-0.519
	0.000	0.002	0.048	0.067	0.000	0.000	0.000
Number of Latewood Bands in Test Area	-0.119	0.199	0.158	0.163	-0.147	-0.062	0.145
	0.012	0.000	0.001	0.001	0.002	0.187	0.002
Percent Latewood in Test Area	-0.062	0.198	0.093	0.180	-0.323	-0.221	0.276
	0.191	0.000	0.048	0.000	0.000	0.000	0.000
Tight CLA Average	-0.041	-0.485	-0.266	-0.414	0.889	0.542	-0.884
	0.390	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Max.Min.	-0.137	-0.090	-0.024	-0.093	0.568	0.540	-0.689
	0.004	0.056	0.618	0.049	0.000	0.000	0.000
Tight RMS Average	-0.073	-0.462	-0.201	-0.386	0.894	0.558	-0.895
	0.121	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Max.Min.	-0.206	0.003	0.092	0.000	0.511	0.547	-0.669
	0.000	0.954	0.050	0.993	0.000	0.000	0.000
Tight Range Max.	-0.140	-0.315	-0.045	-0.251	0.875	0.631	-0.892
	0.003	0.000	0.339	0.000	0.000	0.000	0.000

Table C-5 (Continued). Cross correlation table (correlation and p-values) for variables 29-35.

	Tight Skewness Average	Tight Skewness Max.Min.	Tight Kurtosis Average	Tight Kurtosis Max.Min.	Tight High 3rd Max.	Tight High 3rd Max.Min.	Tight Low 3rd Min.
Tight Range Average	-0.120	-0.403	-0.083	-0.322	0.893	0.586	-0.886
	0.011	0.000	0.080	0.000	0.000	0.000	0.000
Tight Range Max.Min	-0.233	0.108	0.192	0.118	0.487	0.564	-0.611
	0.000	0.021	0.000	0.013	0.000	0.000	0.000
Tight Skewness Average	1.000	-0.109	-0.444	-0.329	0.205	-0.008	0.227
	0.000	0.020	0.000	0.000	0.000	0.860	0.000
Tight Skewness Max.Min.	-0.109	1.000	0.574	0.827	-0.389	-0.081	0.348
	0.020	0.000	0.000	0.000	0.000	0.087	0.000
Tight Kurtosis Average	-0.444	0.574	1.000	0.705	-0.226	-0.048	0.124
	0.000	0.000	0.000	0.000	0.000	0.309	0.008
Tight Kurtosis Max.Min.	-0.329	0.827	0.705	1.000	-0.387	-0.094	0.276
	0.000	0.000	0.000	0.000	0.000	0.047	0.000
Tight High 3rd Max.	0.205	-0.389	-0.226	-0.387	1.000	0.605	-0.740
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight High 3rd Max.Min.	-0.008	-0.081	-0.048	-0.094	0.605	1.000	-0.534
	0.860	0.087	0.309	0.047	0.000	0.000	0.000
Tight Low 3rd Min.	0.227	0.348	0.124	0.276	-0.740	-0.534	1.000
	0.000	0.000	0.008	0.000	0.000	0.000	0.000
Tight Low 3rd Max.Min.	-0.226	-0.106	0.057	-0.072	0.532	0.455	-0.725
	0.000	0.024	0.225	0.128	0.000	0.000	0.000
Loose CLA Average	0.033	-0.341	-0.196	-0.302	0.695	0.478	-0.649
	0.483	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Max.Min.	-0.096	-0.150	-0.025	-0.123	0.483	0.404	-0.525
	0.041	0.001	0.599	0.009	0.000	0.000	0.000
Loose RMS Average	0.027	-0.341	-0.186	-0.303	0.709	0.486	-0.661
	0.567	0.000	0.000	0.000	0.000	0.000	0.000

Table C-5 (Continued). Cross correlation table (correlation and p-values) for variables 29-35.

	Tight Skewness Average	Tight Skewness Max.Min.	Tight Kurtosis Average	Tight Kurtosis Max.Min.	Tight High 3rd Max.	Tight High 3rd Max.Min.	Tight Low 3rd Min.
Loose RMS Max.Min.	-0.106	-0.131	-0.014	-0.113	0.463	0.397	-0.497
	0.024	0.005	0.765	0.016	0.000	0.000	0.000
Loose Range Max.	-0.022	-0.302	-0.130	-0.273	0.731	0.535	-0.691
	0.638	0.000	0.006	0.000	0.000	0.000	0.000
Loose Range Average	0.000	-0.325	-0.150	-0.290	0.730	0.514	-0.685
	1.000	0.000	0.001	0.000	0.000	0.000	0.000
Loose Range Max.Min	-0.093	-0.106	-0.011	-0.107	0.487	0.437	-0.475
	0.049	0.024	0.816	0.023	0.000	0.000	0.000
Loose Skewness Average	-0.438	-0.065	-0.005	0.007	-0.144	0.023	-0.148
	0.000	0.167	0.923	0.884	0.002	0.626	0.002
Loose Skewness Max.Min.	-0.109	0.302	0.134	0.251	-0.269	-0.062	0.225
	0.020	0.000	0.005	0.000	0.000	0.189	0.000
Loose Kurtosis Average	-0.034	0.219	0.199	0.186	-0.205	-0.127	0.194
	0.465	0.000	0.000	0.000	0.000	0.007	0.000
Loose Kurtosis Max.Min.	-0.055	0.195	0.069	0.180	-0.217	-0.089	0.171
	0.246	0.000	0.146	0.000	0.000	0.060	0.000
Loose High 3rd Max.	-0.089	-0.331	-0.132	-0.271	0.628	0.447	-0.645
	0.059	0.000	0.005	0.000	0.000	0.000	0.000
Loose High 3rd Max.Min.	-0.115	-0.166	-0.053	-0.133	0.506	0.484	-0.494
	0.014	0.000	0.260	0.005	0.000	0.000	0.000
Loose Low 3rd Min.	-0.108	0.275	0.133	0.263	-0.719	-0.461	0.597
	0.022	0.000	0.005	0.000	0.000	0.000	0.000
Loose Low 3rd Max.Min.	-0.131	-0.148	0.032	-0.128	0.447	0.431	-0.468
	0.005	0.002	0.494	0.007	0.000	0.000	0.000
Latewood Width (in)	-0.155	-0.195	0.017	-0.129	0.452	0.380	-0.473
	0.001	0.000	0.712	0.006	0.000	0.000	0.000

Table C-5 (Continued). Cross correlation table (correlation and p-values) for variables 29-35.

	Tight Skewness Average	Tight Skewness Max.Min.	Tight Kurtosis Average	Tight Kurtosis Max.Min.	Tight High 3rd Max.	Tight High 3rd Max.Min.	Tight Low 3rd Min.
Earlywood Width (in)	-0.063	-0.282	-0.048	-0.224	0.658	0.492	-0.601
	0.185	0.000	0.305	0.000	0.000	0.000	0.000
Growth Rings per Inch	0.144	0.247	-0.006	0.147	-0.473	-0.382	0.488
	0.002	0.000	0.902	0.002	0.000	0.000	0.000
Earlywood/ Latewood Ratio	0.057	-0.197	-0.064	-0.159	0.365	0.230	-0.294
	0.224	0.000	0.172	0.001	0.000	0.000	0.000
Load vs. DeflectionSlope (lb./in.)	-0.213	-0.104	0.072	-0.058	0.440	0.494	-0.509
	0.000	0.028	0.128	0.218	0.000	0.000	0.000
Failure Load (lbs.)	-0.072	-0.053	0.061	-0.025	0.211	0.267	-0.250
	0.130	0.261	0.197	0.595	0.000	0.000	0.000
Percent Wood Failure	0.112	0.072	-0.001	0.059	-0.300	-0.389	0.457
	0.018	0.125	0.983	0.215	0.000	0.000	0.000

Table C-6. Cross correlation table (correlation and p-values) for variables 36-42.

	Tight Low 3rd Max.Min.	Loose CLA Average	Loose CLA Max.Min.	Loose RMS Average	Loose RMS Max.Min.	Loose Range Max.	Loose Range Average
Check Freqency	-0.242	-0.169	-0.056	-0.176	-0.081	-0.213	-0.203
	0.000	0.000	0.233	0.000	0.086	0.000	0.000
Average Lathe Check Depth	-0.094	-0.137	-0.086	-0.142	-0.108	-0.158	-0.146
	0.045	0.003	0.068	0.003	0.022	0.001	0.002
Average Lathe Check Angle to Glue-line	-0.322	-0.235	-0.168	-0.247	-0.177	-0.295	-0.283
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lathe Check #1 Tip Distance to Saw Kerf 1	0.131	0.055	-0.001	0.062	0.002	0.095	0.087
	0.005	0.243	0.984	0.188	0.966	0.044	0.064
Lathe Check #2 Tip Distance to Saw Kerf 1	0.088	0.010	-0.060	0.013	-0.059	0.022	0.028
	0.063	0.830	0.203	0.782	0.211	0.647	0.555
Lathe Check #1 Origin Distance to Saw Kerf 1	0.092	-0.009	-0.076	-0.005	-0.074	0.014	0.015
	0.052	0.847	0.105	0.919	0.117	0.767	0.748
Lathe Check #2 Origin Distance to Saw Kerf 1	0.095	0.004	-0.061	0.010	-0.062	0.021	0.031
	0.043	0.926	0.194	0.829	0.191	0.653	0.513
Length of Lathe Check 1	-0.057	-0.156	-0.164	-0.159	-0.174	-0.182	-0.161
	0.224	0.001	0.000	0.001	0.000	0.000	0.001
Length of Lathe Check 2	-0.006	-0.075	0.003	-0.070	-0.006	-0.063	-0.059
	0.894	0.111	0.954	0.136	0.894	0.181	0.211
Depth Lathe Check 1	0.000	-0.079	-0.058	-0.080	-0.077	-0.098	-0.076
	0.997	0.096	0.218	0.090	0.101	0.038	0.105
Depth Lathe Check 2	-0.009	-0.033	0.030	-0.029	0.025	-0.026	-0.023
	0.846	0.482	0.529	0.542	0.598	0.582	0.624
Angle Lathe Check 1	-0.195	-0.100	-0.083	-0.106	-0.085	-0.140	-0.127
	0.000	0.034	0.078	0.025	0.073	0.003	0.007
Angle Lathe Check 2	-0.170	-0.113	-0.092	-0.122	-0.089	-0.159	-0.149
	0.000	0.016	0.052	0.010	0.059	0.001	0.002

Table C-6 (Continued). Cross correlation table (correlation and p-values) for variables 36-42.

	Tight Low 3rd Max.Min.	Loose CLA Average	Loose CLA Max.Min.	Loose RMS Average	Loose RMS Max.Min.	Loose Range Max.	Loose Range Average
Latewood Percent Tight Side	-0.048	-0.131	-0.090	-0.132	-0.081	-0.132	-0.135
	0.310	0.005	0.055	0.005	0.088	0.005	0.004
Latewood Percent Loose Side	-0.063	-0.085	-0.028	-0.089	-0.020	-0.092	-0.098
	0.186	0.071	0.559	0.059	0.671	0.050	0.038
Latewood Angle at Saw Kerf 1 (to glue-line)	0.282	0.233	0.251	0.246	0.238	0.291	0.279
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latewood Angle at Saw Kerf 2 (to glue-line)	0.266	0.263	0.277	0.277	0.275	0.330	0.316
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average Latewood Angle to Glue-line	0.282	0.256	0.272	0.269	0.264	0.320	0.306
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Average Latewood Angle (absolute value) to Glue-line	0.538	0.490	0.372	0.512	0.385	0.590	0.577
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Number of Latewood Bands in Test Area	0.018	-0.162	-0.103	-0.159	-0.067	-0.118	-0.137
	0.698	0.001	0.028	0.001	0.157	0.012	0.004
Percent Latewood in Test Area	-0.144	-0.283	-0.214	-0.287	-0.192	-0.298	-0.299
	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Average	0.583	0.746	0.540	0.755	0.508	0.769	0.768
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Max.Min.	0.587	0.461	0.436	0.472	0.419	0.522	0.503
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Average	0.609	0.743	0.545	0.754	0.513	0.775	0.773
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Max.Min.	0.614	0.424	0.410	0.436	0.394	0.491	0.473
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.	0.679	0.716	0.542	0.733	0.513	0.778	0.770
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-6 (Continued). Cross correlation table (correlation and p-values) for variables 36-42.

	Tight Low 3rd Max.Min.	Loose CLA Average	Loose CLA Max.Min.	Loose RMS Average	Loose RMS Max.Min.	Loose Range Max.	Loose Range Average
Tight Range Average	0.643	0.730	0.544	0.745	0.513	0.782	0.778
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.Min	0.613	0.389	0.384	0.406	0.373	0.478	0.456
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Skewness Average	-0.226	0.033	-0.096	0.027	-0.106	-0.022	0.000
	0.000	0.483	0.041	0.567	0.024	0.638	1.000
Tight Skewness Max.Min.	-0.106	-0.341	-0.150	-0.341	-0.131	-0.302	-0.325
	0.024	0.000	0.001	0.000	0.005	0.000	0.000
Tight Kurtosis Average	0.057	-0.196	-0.025	-0.186	-0.014	-0.130	-0.150
	0.225	0.000	0.599	0.000	0.765	0.006	0.001
Tight Kurtosis Max.Min.	-0.072	-0.302	-0.123	-0.303	-0.113	-0.273	-0.290
	0.128	0.000	0.009	0.000	0.016	0.000	0.000
Tight High 3rd Max.	0.532	0.695	0.483	0.709	0.463	0.731	0.730
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight High 3rd Max.Min.	0.455	0.478	0.404	0.486	0.397	0.535	0.514
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Min.	-0.725	-0.649	-0.525	-0.661	-0.497	-0.691	-0.685
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Max.Min.	1.000	0.400	0.381	0.421	0.386	0.478	0.468
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Average	0.400	1.000	0.596	0.997	0.540	0.935	0.969
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Max.Min.	0.381	0.596	1.000	0.601	0.955	0.651	0.603
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose RMS Average	0.421	0.997	0.601	1.000	0.555	0.953	0.983
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-6 (Continued). Cross correlation table (correlation and p-values) for variables 36-42.

	Tight Low 3rd Max.Min.	Loose CLA Average	Loose CLA Max.Min.	Loose RMS Average	Loose RMS Max.Min.	Loose Range Max.	Loose Range Average
Loose RMS Max.Min.	0.386	0.540	0.955	0.555	1.000	0.656	0.577
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.	0.478	0.935	0.651	0.953	0.656	1.000	0.981
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Average	0.468	0.969	0.603	0.983	0.577	0.981	1.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.Min	0.379	0.509	0.697	0.535	0.820	0.731	0.598
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Skewness Average	0.077	0.030	0.094	0.032	0.129	0.052	0.032
	0.105	0.527	0.046	0.498	0.006	0.269	0.504
Loose Skewness Max.Min.	-0.104	-0.474	-0.160	-0.460	-0.060	-0.319	-0.406
	0.027	0.000	0.001	0.000	0.205	0.000	0.000
Loose Kurtosis Average	-0.080	-0.441	-0.201	-0.405	-0.088	-0.249	-0.315
	0.089	0.000	0.000	0.000	0.062	0.000	0.000
Loose Kurtosis Max.Min.	-0.123	-0.375	-0.108	-0.360	-0.009	-0.219	-0.313
	0.009	0.000	0.021	0.000	0.845	0.000	0.000
Loose High 3rd Max.	0.433	0.916	0.604	0.923	0.579	0.898	0.917
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose High 3rd Max.Min.	0.390	0.635	0.588	0.649	0.584	0.703	0.671
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Low 3rd Min.	-0.399	-0.882	-0.587	-0.890	-0.557	-0.876	-0.891
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Low 3rd Max.Min.	0.487	0.459	0.428	0.477	0.424	0.545	0.533
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latewood Width (in)	0.425	0.480	0.388	0.497	0.387	0.538	0.529
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-6 (Continued). Cross correlation table (correlation and p-values) for variables 36-42.

	Tight Low 3rd Max.Min.	Loose CLA Average	Loose CLA Max.Min.	Loose RMS Average	Loose RMS Max.Min.	Loose Range Max.	Loose Range Average
Earlywood Width (in)	0.449	0.618	0.492	0.635	0.480	0.673	0.668
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Growth Rings per Inch	-0.373	-0.468	-0.369	-0.483	-0.360	-0.516	-0.514
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Earlywood/ Latewood Ratio	0.165	0.274	0.209	0.276	0.193	0.282	0.288
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Load vs. DeflectionSlope (lb./in.)	0.520	0.489	0.408	0.506	0.418	0.578	0.551
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Failure Load (lbs.)	0.314	0.269	0.250	0.276	0.268	0.325	0.303
	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percent Wood Failure	-0.422	-0.360	-0.331	-0.375	-0.316	-0.415	-0.411
	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-7. Cross correlation table (correlation and p-values) for variables 43-50.

	Loose Range Max.Min	Loose Skewness Average	Loose Skewness Max.Min.	Loose Kurtosis Average	Loose Kurtosis Max.Min.	Loose High 3rd Max.	Loose High 3rd Max.Min.	Loose Low 3rd Min.
Check Freqency	-0.158	0.035	0.053	0.050	0.059	-0.162	-0.131	0.153
	0.001	0.464	0.263	0.288	0.208	0.001	0.006	0.001
Average Lathe Check Depth	-0.137	0.089	0.099	0.041	0.047	-0.122	-0.087	0.147
	0.004	0.058	0.036	0.388	0.322	0.010	0.064	0.002
Average Lathe Check Angle to Glue-line	-0.243	0.046	0.119	0.091	0.110	-0.241	-0.285	0.267
	0.000	0.333	0.011	0.054	0.020	0.000	0.000	0.000
Lathe Check #1 Tip Distance to Saw Kerf 1	0.063	-0.055	0.007	0.014	-0.009	0.067	0.068	-0.060
	0.180	0.241	0.882	0.766	0.845	0.159	0.147	0.201
Lathe Check #2 Tip Distance to Saw Kerf 1	-0.035	-0.045	-0.021	-0.013	-0.040	0.041	-0.017	0.009
	0.462	0.341	0.661	0.789	0.403	0.380	0.721	0.856
Lathe Check #1 Origin Distance to Saw Kerf 1	-0.023	-0.072	0.010	0.052	0.005	0.008	-0.012	0.005
	0.627	0.129	0.829	0.271	0.910	0.863	0.792	0.917
Lathe Check #2 Origin Distance to Saw Kerf 1	-0.042	-0.053	-0.018	0.007	-0.033	0.037	-0.010	-0.003
	0.379	0.260	0.699	0.884	0.481	0.439	0.834	0.944
Length of Lathe Check 1	-0.197	0.009	-0.014	0.044	-0.038	-0.131	-0.179	0.166
	0.000	0.849	0.766	0.355	0.416	0.005	0.000	0.000
Length of Lathe Check 2	-0.036	0.077	0.044	0.044	0.038	-0.051	-0.030	0.059
	0.450	0.103	0.350	0.353	0.419	0.280	0.526	0.213
Depth Lathe Check 1	-0.124	0.047	-0.021	-0.013	-0.058	-0.056	-0.073	0.096
	0.009	0.318	0.656	0.790	0.218	0.237	0.123	0.043
Depth Lathe Check 2	-0.016	0.112	0.058	0.048	0.040	-0.002	-0.008	0.046
	0.736	0.018	0.219	0.312	0.403	0.972	0.859	0.330
Angle Lathe Check 1	-0.138	0.049	0.024	-0.001	0.006	-0.097	-0.154	0.132
	0.003	0.302	0.608	0.981	0.893	0.039	0.001	0.005
Angle Lathe Check 2	-0.137	0.065	0.031	0.022	0.020	-0.119	-0.148	0.145
	0.004	0.170	0.517	0.639	0.676	0.012	0.002	0.002

Table C-7 (Continued). Cross correlation table (correlation and p-values) for variables 43-50.

	Loose Range Max.Min	Loose Skewness Average	Loose Skewness Max.Min.	Loose Kurtosis Average	Loose Kurtosis Max.Min.	Loose High 3rd Max.	Loose High 3rd Max.Min.	Loose Low 3rd Min.
Latewood Percent Tight Side	-0.073	0.072	0.047	0.067	0.058	-0.113	-0.067	0.116
	0.124	0.127	0.317	0.156	0.223	0.016	0.158	0.014
Latewood Percent Loose Side	-0.041	0.135	0.084	0.025	0.073	-0.086	-0.034	0.098
	0.386	0.004	0.075	0.598	0.120	0.068	0.471	0.037
Latewood Angle at Saw Kerf 1 (to glue-line)	0.213	-0.041	-0.089	-0.105	-0.130	0.272	0.287	-0.295
	0.000	0.388	0.059	0.026	0.006	0.000	0.000	0.000
Latewood Angle at Saw Kerf 2 (to glue-line)	0.262	-0.044	-0.089	-0.098	-0.122	0.292	0.300	-0.327
	0.000	0.353	0.060	0.037	0.010	0.000	0.000	0.000
Average Latewood Angle to Glue-line	0.244	-0.044	-0.092	-0.105	-0.130	0.290	0.303	-0.320
	0.000	0.355	0.051	0.026	0.006	0.000	0.000	0.000
Average Latewood Angle (absolute value) to Glue-line	0.447	0.035	-0.160	-0.116	-0.163	0.511	0.544	-0.516
	0.000	0.464	0.001	0.014	0.000	0.000	0.000	0.000
Number of Latewood Bands in Test Area	0.000	0.082	0.197	0.140	0.151	-0.145	-0.024	0.151
	0.994	0.083	0.000	0.003	0.001	0.002	0.613	0.001
Percent Latewood in Test Area	-0.190	0.111	0.147	0.093	0.112	-0.276	-0.218	0.276
	0.000	0.018	0.002	0.048	0.017	0.000	0.000	0.000
Tight CLA Average	0.502	0.022	-0.305	-0.265	-0.228	0.702	0.552	-0.710
	0.000	0.646	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Max.Min.	0.415	0.070	-0.105	-0.106	-0.102	0.475	0.370	-0.450
	0.000	0.135	0.025	0.025	0.030	0.000	0.000	0.000
Tight RMS Average	0.510	0.022	-0.301	-0.253	-0.229	0.707	0.560	-0.714
	0.000	0.634	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Max.Min.	0.394	0.073	-0.089	-0.078	-0.090	0.439	0.352	-0.420
	0.000	0.124	0.058	0.100	0.058	0.000	0.000	0.000
Tight Range Max.	0.539	0.021	-0.261	-0.206	-0.210	0.697	0.579	-0.710
	0.000	0.657	0.000	0.000	0.000	0.000	0.000	0.000

Table C-7 (Continued). Cross correlation table (correlation and p-values) for variables 43-50.

	Loose Range Max.Min	Loose Skewness Average	Loose Skewness Max.Min.	Loose Kurtosis Average	Loose Kurtosis Max.Min.	Loose High 3rd Max.	Loose High 3rd Max.Min.	Loose Low 3rd Min.
Tight Range Average	0.525	0.017	-0.285	-0.224	-0.225	0.708	0.581	-0.719
	0.000	0.724	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.Min	0.415	0.039	-0.061	-0.040	-0.069	0.393	0.362	-0.409
	0.000	0.412	0.195	0.393	0.146	0.000	0.000	0.000
Tight Skewness Average	-0.093	-0.438	-0.109	-0.034	-0.055	-0.089	-0.115	-0.108
	0.049	0.000	0.020	0.465	0.246	0.059	0.014	0.022
Tight Skewness Max.Min.	-0.106	-0.065	0.302	0.219	0.195	-0.331	-0.166	0.275
	0.024	0.167	0.000	0.000	0.000	0.000	0.000	0.000
Tight Kurtosis Average	-0.011	-0.005	0.134	0.199	0.069	-0.132	-0.053	0.133
	0.816	0.923	0.005	0.000	0.146	0.005	0.260	0.005
Tight Kurtosis Max.Min.	-0.107	0.007	0.251	0.186	0.180	-0.271	-0.133	0.263
	0.023	0.884	0.000	0.000	0.000	0.000	0.005	0.000
Tight High 3rd Max.	0.487	-0.144	-0.269	-0.205	-0.217	0.628	0.506	-0.719
	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Tight High 3rd Max.Min.	0.437	0.023	-0.062	-0.127	-0.089	0.447	0.484	-0.461
	0.000	0.626	0.189	0.007	0.060	0.000	0.000	0.000
Tight Low 3rd Min.	-0.475	-0.148	0.225	0.194	0.171	-0.645	-0.494	0.597
	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Max.Min.	0.379	0.077	-0.104	-0.080	-0.123	0.433	0.390	-0.399
	0.000	0.105	0.027	0.089	0.009	0.000	0.000	0.000
Loose CLA Average	0.509	0.030	-0.474	-0.441	-0.375	0.916	0.635	-0.882
	0.000	0.527	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Max.Min.	0.697	0.094	-0.160	-0.201	-0.108	0.604	0.588	-0.587
	0.000	0.046	0.001	0.000	0.021	0.000	0.000	0.000
Loose RMS Average	0.535	0.032	-0.460	-0.405	-0.360	0.923	0.649	-0.890
	0.000	0.498	0.000	0.000	0.000	0.000	0.000	0.000

Table C-7 (Continued). Cross correlation table (correlation and p-values) for variables 43-50.

	Loose Range Max.Min	Loose Skewness Average	Loose Skewness Max.Min.	Loose Kurtosis Average	Loose Kurtosis Max.Min.	Loose High 3rd Max.	Loose High 3rd Max.Min.	Loose Low 3rd Min.
Loose RMS Max.Min.	0.820	0.129	-0.060	-0.088	-0.009	0.579	0.584	-0.557
	0.000	0.006	0.205	0.062	0.845	0.000	0.000	0.000
Loose Range Max.	0.731	0.052	-0.319	-0.249	-0.219	0.898	0.703	-0.876
	0.000	0.269	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Average	0.598	0.032	-0.406	-0.315	-0.313	0.917	0.671	-0.891
	0.000	0.504	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.Min	1.000	0.126	0.087	0.063	0.147	0.552	0.611	-0.542
	0.000	0.007	0.064	0.181	0.002	0.000	0.000	0.000
Loose Skewness Average	0.126	1.000	0.108	0.041	0.122	0.233	0.125	0.199
	0.007	0.000	0.022	0.391	0.010	0.000	0.008	0.000
Loose Skewness Max.Min.	0.087	0.108	1.000	0.700	0.846	-0.410	-0.156	0.410
	0.064	0.022	0.000	0.000	0.000	0.000	0.001	0.000
Loose Kurtosis Average	0.063	0.041	0.700	1.000	0.772	-0.356	-0.194	0.331
	0.181	0.391	0.000	0.000	0.000	0.000	0.000	0.000
Loose Kurtosis Max.Min.	0.147	0.122	0.846	0.772	1.000	-0.333	-0.160	0.324
	0.002	0.010	0.000	0.000	0.000	0.000	0.001	0.000
Loose High 3rd Max.	0.552	0.233	-0.410	-0.356	-0.333	1.000	0.661	-0.758
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose High 3rd Max.Min.	0.611	0.125	-0.156	-0.194	-0.160	0.661	1.000	-0.624
	0.000	0.008	0.001	0.000	0.001	0.000	0.000	0.000
Loose Low 3rd Min.	-0.542	0.199	0.410	0.331	0.324	-0.758	-0.624	1.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Low 3rd Max.Min.	0.430	-0.059	-0.199	-0.157	-0.171	0.451	0.477	-0.575
	0.000	0.211	0.000	0.001	0.000	0.000	0.000	0.000
Latewood Width (in)	0.404	0.030	-0.170	-0.132	-0.154	0.483	0.477	-0.483
	0.000	0.522	0.000	0.005	0.001	0.000	0.000	0.000

Table C-7 (Continued). Cross correlation table (correlation and p-values) for variables 43-50.

	Loose Range Max.Min	Loose Skewness Average	Loose Skewness Max.Min.	Loose Kurtosis Average	Loose Kurtosis Max.Min.	Loose High 3rd Max.	Loose High 3rd Max.Min.	Loose Low 3rd Min.
Earlywood Width (in)	0.474	-0.066	-0.241	-0.193	-0.203	0.609	0.508	-0.628
	0.000	0.161	0.000	0.000	0.000	0.000	0.000	0.000
Growth Rings per Inch	-0.357	0.018	0.224	0.169	0.195	-0.484	-0.410	0.481
	0.000	0.702	0.000	0.000	0.000	0.000	0.000	0.000
Earlywood/ Latewood Ratio	0.167	-0.103	-0.143	-0.110	-0.116	0.265	0.155	-0.281
	0.000	0.028	0.002	0.020	0.014	0.000	0.001	0.000
Load vs. DeflectionSlope (lb./in.)	0.507	0.045	-0.114	-0.040	-0.139	0.480	0.518	-0.490
	0.000	0.343	0.016	0.401	0.003	0.000	0.000	0.000
Failure Load (lbs.)	0.314	0.027	-0.025	-0.026	-0.065	0.265	0.287	-0.248
	0.000	0.570	0.601	0.586	0.168	0.000	0.000	0.000
Percent Wood Failure	-0.351	-0.023	0.096	0.025	0.120	-0.387	-0.370	0.357
	0.000	0.632	0.043	0.595	0.011	0.000	0.000	0.000

Table C-8. Cross correlation table (correlation and p-values) for variables 51-58.

	Loose Low 3rd Max.Min.	Latewood Width (in)	Earlywood Width (in)	Growth Rings per Inch	Earlywood/ Latewood Ratio	Load vs. Deflection Slope (lb./in.)	Failure Load (lbs.)	Percent Wood Failure
Check Freqency	-0.177	-0.124	-0.185	0.186	-0.145	-0.290	-0.382	0.139
	0.000	0.009	0.000	0.000	0.002	0.000	0.000	0.003
Average Lathe Check Depth	-0.075	-0.018	-0.185	0.098	-0.228	-0.144	-0.043	-0.015
	0.110	0.704	0.000	0.038	0.000	0.002	0.367	0.751
Average Lathe Check Angle to Glue-line	-0.310	-0.213	-0.322	0.177	-0.219	-0.309	-0.072	0.114
	0.000	0.000	0.000	0.000	0.000	0.000	0.126	0.016
Lathe Check #1 Tip Distance to Saw Kerf 1	0.071	0.062	0.051	-0.089	0.021	0.166	0.094	-0.128
	0.134	0.190	0.279	0.059	0.658	0.000	0.045	0.006
Lathe Check #2 Tip Distance to Saw Kerf 1	0.043	0.013	0.035	-0.070	0.052	0.078	0.112	-0.113
	0.367	0.785	0.462	0.137	0.270	0.097	0.017	0.017
Lathe Check #1 Origin Distance to Saw Kerf 1	0.006	0.015	-0.006	-0.046	-0.017	0.130	0.033	-0.068
	0.905	0.752	0.900	0.334	0.715	0.006	0.488	0.151
Lathe Check #2 Origin Distance to Saw Kerf 1	0.047	0.010	0.045	-0.101	0.090	0.093	0.091	-0.121
	0.317	0.834	0.337	0.032	0.057	0.050	0.055	0.010
Length of Lathe Check 1	-0.114	-0.060	-0.133	0.021	-0.110	-0.075	-0.036	0.028
	0.015	0.200	0.005	0.659	0.020	0.111	0.442	0.558
Length of Lathe Check 2	-0.069	-0.092	-0.085	0.035	0.010	-0.027	-0.061	-0.017
	0.142	0.051	0.073	0.463	0.831	0.574	0.195	0.723
Depth Lathe Check 1	-0.012	0.037	-0.046	-0.040	-0.100	-0.043	-0.012	-0.062
	0.795	0.437	0.326	0.394	0.034	0.362	0.804	0.191
Depth Lathe Check 2	-0.038	-0.051	-0.057	-0.007	-0.013	-0.053	0.051	-0.017
	0.420	0.284	0.225	0.882	0.777	0.263	0.278	0.722
Angle Lathe Check 1	-0.146	-0.050	-0.138	0.006	-0.114	-0.131	-0.013	0.006
	0.002	0.290	0.003	0.905	0.015	0.005	0.784	0.904
Angle Lathe Check 2	-0.179	-0.111	-0.175	0.052	-0.133	-0.150	0.007	0.023
	0.000	0.018	0.000	0.268	0.005	0.001	0.886	0.628

Table C-8 (Continued). Cross correlation table (correlation and p-values) for variables 51-58.

	Loose Low 3rd Max.Min.	Latewood Width (in)	Earlywood Width (in)	Growth Rings per Inch	Earlywood/ Latewood Ratio	Load vs. Deflection Slope (lb./in.)	Failure Load (lbs.)	Percent Wood Failure
Latewood Percent Tight Side	-0.100	0.053	-0.173	0.042	-0.343	0.091	-0.014	0.110
	0.035	0.259	0.000	0.371	0.000	0.054	0.759	0.019
Latewood Percent Loose Side	-0.109	0.069	-0.186	0.091	-0.407	0.149	0.129	-0.045
	0.021	0.145	0.000	0.054	0.000	0.002	0.006	0.341
Latewood Angle at Saw Kerf 1 (to glue-line)	0.350	0.346	0.445	-0.325	0.187	0.342	0.103	-0.194
	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000
Latewood Angle at Saw Kerf 2 (to glue-line)	0.406	0.348	0.430	-0.324	0.159	0.376	0.096	-0.226
	0.000	0.000	0.000	0.000	0.001	0.000	0.041	0.000
Average Latewood Angle to Glue-line	0.389	0.358	0.452	-0.335	0.179	0.370	0.103	-0.216
	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.000
Average Latewood Angle (absolute value) to Glue-line	0.566	0.578	0.631	-0.491	0.179	0.683	0.175	-0.255
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Number of Latewood Bands in Test Area	-0.064	-0.318	-0.367	0.522	-0.284	0.193	-0.006	0.065
	0.175	0.000	0.000	0.000	0.000	0.000	0.898	0.170
Percent Latewood in Test Area	-0.269	-0.011	-0.467	0.321	-0.738	0.118	0.075	0.015
	0.000	0.818	0.000	0.000	0.000	0.012	0.110	0.743
Tight CLA Average	0.493	0.482	0.673	-0.515	0.368	0.466	0.179	-0.349
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight CLA Max.Min.	0.402	0.356	0.465	-0.376	0.245	0.400	0.233	-0.274
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Average	0.514	0.496	0.688	-0.529	0.375	0.484	0.185	-0.359
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight RMS Max.Min.	0.405	0.351	0.446	-0.364	0.226	0.405	0.241	-0.276
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.	0.573	0.526	0.711	-0.552	0.378	0.538	0.220	-0.375
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-8 (Continued). Cross correlation table (correlation and p-values) for variables 51-58.

	Loose Low 3rd Max.Min.	Latewood Width (in)	Earlywood Width (in)	Growth Rings per Inch	Earlywood/ Latewood Ratio	Load vs. Deflection Slope (lb./in.)	Failure Load (lbs.)	Percent Wood Failure
Tight Range Average	0.555	0.521	0.710	-0.551	0.380	0.521	0.196	-0.369
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Range Max.Min	0.436	0.360	0.449	-0.367	0.225	0.438	0.258	-0.280
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Skewness Average	-0.131	-0.155	-0.063	0.144	0.057	-0.213	-0.072	0.112
	0.005	0.001	0.185	0.002	0.224	0.000	0.130	0.018
Tight Skewness Max.Min.	-0.148	-0.195	-0.282	0.247	-0.197	-0.104	-0.053	0.072
	0.002	0.000	0.000	0.000	0.000	0.028	0.261	0.125
Tight Kurtosis Average	0.032	0.017	-0.048	-0.006	-0.064	0.072	0.061	-0.001
	0.494	0.712	0.305	0.902	0.172	0.128	0.197	0.983
Tight Kurtosis Max.Min.	-0.128	-0.129	-0.224	0.147	-0.159	-0.058	-0.025	0.059
	0.007	0.006	0.000	0.002	0.001	0.218	0.595	0.215
Tight High 3rd Max.	0.447	0.452	0.658	-0.473	0.365	0.440	0.211	-0.300
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight High 3rd Max.Min.	0.431	0.380	0.492	-0.382	0.230	0.434	0.200	-0.275
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Min.	-0.468	-0.473	-0.601	0.488	-0.294	-0.452	-0.177	0.394
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tight Low 3rd Max.Min.	0.487	0.425	0.449	-0.373	0.165	0.466	0.195	-0.352
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Average	0.459	0.480	0.618	-0.468	0.274	0.404	0.190	-0.208
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose CLA Max.Min.	0.428	0.388	0.492	-0.369	0.209	0.316	0.151	-0.269
	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000
Loose RMS Average	0.477	0.497	0.635	-0.483	0.276	0.425	0.198	-0.223
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table C-8 (Continued). Cross correlation table (correlation and p-values) for variables 51-58.

	Loose Low 3rd Max.Min.	Latewood Width (in)	Earlywood Width (in)	Growth Rings per Inch	Earlywood/ Latewood Ratio	Load vs. Deflection Slope (lb./in.)	Failure Load (lbs.)	Percent Wood Failure
Loose RMS Max.Min.	0.424	0.387	0.480	-0.360	0.193	0.336	0.171	-0.259
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.	0.545	0.538	0.673	-0.516	0.282	0.501	0.236	-0.255
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Average	0.533	0.529	0.668	-0.514	0.288	0.483	0.223	-0.253
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Range Max.Min	0.430	0.404	0.474	-0.357	0.167	0.406	0.208	-0.217
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Skewness Average	-0.059	0.030	-0.066	0.018	-0.103	0.057	0.037	-0.019
	0.211	0.522	0.161	0.702	0.028	0.230	0.435	0.688
Loose Skewness Max.Min.	-0.199	-0.170	-0.241	0.224	-0.143	-0.122	-0.061	0.081
	0.000	0.000	0.000	0.000	0.002	0.009	0.196	0.088
Loose Kurtosis Average	-0.157	-0.132	-0.193	0.169	-0.110	-0.070	-0.041	0.014
	0.001	0.005	0.000	0.000	0.020	0.141	0.383	0.767
Loose Kurtosis Max.Min.	-0.171	-0.154	-0.203	0.195	-0.116	-0.119	-0.065	0.082
	0.000	0.001	0.000	0.000	0.014	0.011	0.169	0.083
Loose High 3rd Max.	0.451	0.483	0.609	-0.484	0.265	0.418	0.193	-0.242
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose High 3rd Max.Min.	0.477	0.477	0.508	-0.410	0.155	0.457	0.150	-0.252
	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000
Loose Low 3rd Min.	-0.575	-0.483	-0.628	0.481	-0.281	-0.426	-0.173	0.238
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Loose Low 3rd Max.Min.	1.000	0.470	0.571	-0.431	0.255	0.465	0.176	-0.315
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Latewood Width (in)	0.470	1.000	0.710	-0.723	-0.121	0.557	0.283	-0.290
	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000

Table C-8 (Continued). Cross correlation table (correlation and p-values) for variables 51-58.

	Loose Low 3rd Max.Min.	Latewood Width (in)	Earlywood Width (in)	Growth Rings per Inch	Earlywood/ Latewood Ratio	Load vs. Deflection Slope (lb./in.)	Failure Load (lbs.)	Percent Wood Failure
Earlywood Width (in)	0.571	0.710	1.000	-0.742	0.537	0.456	0.240	-0.278
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Growth Rings per Inch	-0.431	-0.723	-0.742	1.000	-0.324	-0.451	-0.325	0.299
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Earlywood/ Latewood Ratio	0.255	-0.121	0.537	-0.324	1.000	-0.053	0.080	-0.099
	0.000	0.010	0.000	0.000	0.000	0.261	0.089	0.037
Load vs. DeflectionSlope (lb./in.)	0.496	0.557	0.456	-0.451	-0.053	1.000	0.470	-0.427
	0.000	0.000	0.000	0.000	0.261	0.000	0.000	0.000
Failure Load (lbs.)	0.261	0.283	0.240	-0.325	0.080	0.470	1.000	-0.386
	0.000	0.000	0.000	0.000	0.089	0.000	0.000	0.000
Percent Wood Failure	-0.423	-0.290	-0.278	0.299	-0.099	-0.427	-0.386	1.000
	0.000	0.000	0.000	0.000	0.037	0.000	0.000	0.000

Appendix D. Non-significant Measures and Their P-values

Table D-1. Veneer measures found non-significant from stepwise regression in influencing load at failure and their corresponding p-values.

Variable	P-value	Variable	P-value
Percent of latewood at loose-side glue-line	0.0724	Latewood angle at saw kerf 1 (0)	0.3907
Number of latewood bands in test area	0.0957	Latewood angle at saw kerf 2 (0)	0.3932
Tight skewness max.min.	0.1025	Angle lathe check #2 (0)	0.3986
Percent of latewood at tight-side glueline	0.1154	Lathe check#1 origin dist. to saw kerf (in.)	0.4450
Tight high3rd maximum	0.1298	Tight high 3rd max.min.	0.5678
Loose range maximum	0.1427	Tight skewness average	0.6032
Latewood width (in.)	0.1815	Length lathe check #1 (in.)	0.6293
Loose range average	0.1920	Tight range average	0.6331
Tight CLA avg.	0.1938	Lathe check #1 tip dist. to saw kerf 1 (in.)	0.6585
Loose range max.min.	0.1955	Tight low 3rd max.min.	0.6974
Tight kurtosis max.min.	0.1969	Loose skewness max.min.	0.7108
Loose RMS max.min.	0.2216	Loose kurtosis max.min.	0.7768
Loose high 3rd maximum	0.2221	Tight range maximum	0.7898
Average lathe check angle to glue-line (0)	0.2286	Depth lathe check #1 (in.)	0.7962
Depth lathe check #2 (in.)	0.2370	Lathe check #2 tip dist. to saw kerf 1 (in.)	0.8140
Loose RMS average	0.2470	Loose high 3rd max.min.	0.8165
Loose CLA average	0.2645	Earlywood width (in.)	0.8470
Loose skewness average	0.2871	Average lathe check depth (in.)	0.8551
Tight RMS average	0.3016	Tight RMS max.min.	0.8740
Loose CLA max.min.	0.3085	Loose low 3rd minimum	0.9188
Average latewood angle (0)	0.3757	Loose kurtosis average	0.9311
Average latewood angle (absolute) (0)	0.3874	Angle lathe check #1 (0)	0.9354
Length lathe check #2 (in.)	0.3879	Tight kurtosis average	0.9734
Tight CLA max.min.	0.3899	Loose low 3rd max.min.	0.9925

Table D-2. Veneer measures found non-significant from stepwise regression in influencing percent wood failure and their corresponding p-values.

Variable	P-value	Variable	P-value
Loose CLA max.min.	0.0659	Latewood angle at saw kerf 2 (0)	0.4842
Loose-side RMS average	0.0840	Loose kurtosis max.min.	0.4875
Lathe check #2 origin dist. to saw kerf (in.)	0.0885	Loose skewness average	0.4929
Lathe check #2 tip dist. to saw kerf 1 (in.)	0.0990	Angle lathe check #1 (0)	0.5144
Lathe check #1 tip dist. to saw kerf 1 (in.)	0.1100	Length lathe check #2 (in.)	0.5396
Loose high 3rd max.min.	0.1257	Angle lathe check #2 (0)	0.5874
Loose RMS max.min.	0.1327	Average latewood angle (absolute) (0)	0.5909
Loose high 3rd maximum	0.1670	Loose skewness max.min.	0.5986
Tight high 3rd max.min.	0.1799	Tight CLA max.min.	0.6171
Tight skewness max.min.	0.2208	Loose low 3rd minimum	0.6250
Percent of latewood at loose-side glue-line	0.2281	Tight kurtosis max.min.	0.6328
Average lathe check depth (in.)	0.2867	Average lathe check angle to glue-line (0)	0.6404
Loose range average	0.3129	Number of latewood bands in test area	0.6597
Loose kurtosis average	0.3185	Tight RMS max.min.	0.6853
Depth lathe check #1 (in.)	0.3266	Earlywood width (in.)	0.6980
Lathe check #1 origin dist. to saw kerf (in.)	0.3700	Latewood width (in.)	0.7268
Tight skewness average	0.3762	Loose range max.min.	0.7321
Tight range average	0.4084	Average latewood angle	0.8191
Tight RMS average	0.4202	Depth lathe check #2 (in.)	0.8217
Check frequency (checks/inch)	0.4252	Latewood angle at saw kerf 1 (0)	0.8306
Tight low 3rd max.min.	0.4324	Tight range max.min.	0.8653
Tight range maximum	0.4420	Loose range maximum	0.9188
Tight high 3rd maximum	0.4432	Tight kurtosis average	0.9464
Tight CLA Average	0.4451	Length lathe check #1 (in.)	0.9975

Appendix E. All Possible Combinations Best-fit Regression Models

All Possible Combinations Best-fit Regression Variable Identification Letters

A – Check frequency
B – Average lathe check depth
C – Average lathe check angle to glue-line
D – Crack tip distance to saw kerf of lathe check #1
E – Crack tip distance to saw kerf of lathe check #2
F – Lathe check origin distance to saw kerf of lathe check #1
G – Lathe check origin distance to saw kerf of lathe check #2
H – Length of lathe check #1
I – Length of lathe check #2
J – Depth of lathe check #1
K – Depth of lathe check #2
L – Angle of lathe check #1
M – Angle of lathe check #2
N – Percent latewood at tight-side glue-line
O – Percent latewood at loose-side glue-line
P – Latewood band angle at saw kerf #1 to glue-line
Q – Latewood band angle at saw kerf #2 to glue-line
R – Average latewood band angle to glue-line
S – Average latewood band angle (absolute) to glue-line
T – Number of latewood bands in test area
U – Percent latewood in test area
V – Tight-side CLA average
W – Tight-side CLA maximum-minimum
X – Tight-side RMS average
Y – Tight-side RMS maximum-minimum
Z – Tight-side Range maximum
AA – Tight-side Range average
AB – Tight-side Range maximum-minimum
AC – Tight-side Skewness average
AD – Tight-side Skewness maximum-minimum
AE – Tight-side Kurtosis average
AF – Tight-side Kurtosis maximum minimum
AG – Tight-side high 3rd maximum
AH – Tight-side high 3rd maximum minimum
AI – Tight-side low 3rd minimum
AJ – Tight-side low 3rd maximum-minimum
AK – Loose-side CLA average
AL – Loose-side CLA maximum-minimum
AM – Loose-side RMS average
AN– Loose-side RMS maximum-minimum
AO – Loose-side Range maximum
AP – Loose-side Range average
AQ – Loose-side Range maximum-minimum
AR – Loose-side Skewness average
AS – Loose-side Skewness maximum-minimum
AT – Loose-side Kurtosis average
AU – Loose-side Kurtosis maximum minimum

AV – Loose-side high 3rd maximum
AW – Loose-side high 3rd maximum minimum
AX – Loose-side low 3rd minimum
AY – Loose-side low 3rd maximum-minimum
AZ – Latewood width
BA – Earlywood width
BB – Growth rings per inch
BC – Ratio earlywood/latewood width

Load at Failure Best-fit Model for the Specified Number of Variables Included

R-Square Selection Method

Number in Model	R-Square	Variables in Model
1	0.1458	A
2	0.2128	A BB
3	0.2528	A U BB
4	0.2700	A U AB BB
5	0.2847	A G U AB BB
6	0.2963	A G U AB BB BC
7	0.3044	A G U AB AI BB BC
8	0.3146	A G S T U AB BB BC
9	0.3267	A G S T U AB AZ BB BC
10	0.3344	A G S T U AB AZ BA BB BC
11	0.3408	A E I K S T U AB AZ BB BC
12	0.3501	A C E I K S T U AB AZ BB BC
13	0.3578	A E I K M S T U AB AZ BA BB BC
14	0.3630	A C E I K S T U AB AI AZ BA BB BC
15	0.3677	A C E I K N S T U AB AI AZ BA BB BC
16	0.3721	A C E I K S T U V Z AB AI AZ BA BB BC
17	0.3768	A C E I K N S T U V Z AB AI AZ BA BB BC
18	0.3796	A C E I K S T U V X AB AE AF AI AZ BA BB BC
19	0.3844	A C E I K N S T U V X AB AE AF AI AZ BA BB BC
20	0.3873	A C E I K N S T U V AA AB AE AF AG AI AZ BA BB BC
21	0.3910	A C E I K N S T U V AA AB AE AF AG AI AR AZ BA BB BC
22	0.3934	A C E I K N O S T U V AA AB AE AF AG AI AR AZ BA BB BC
23	0.3962	A C E I K N O S T U V AA AB AE AF AG AI AP AX AZ BA BB BC
24	0.3981	A C E I K N O S T U V AA AB AE AF AG AI AM AP AX AZ BA BB BC
25	0.4007	A C E I K N O S T U V W Y Z AB AE AF AG AI AP AX AZ BA BB BC
26	0.4022	A C E G I K N O S T U V AA AB AE AF AG AI AK AM AP AR AZ BA BB BC
27	0.4041	A C E I K N O S T U V W Y AA AB AE AF AG AI AK AM AP AX AZ BA BB BC
28	0.4060	A C E G I K N O S T U V W Y AA AB AE AF AG AI AK AM AP AR AZ BA BB BC
28	0.4058	A C E G I K N O S T U V W Y AA AB AE AF AG AI AK AM AP AX AZ BA BB BC
29	0.4076	A C E G I K N O S T U V W Y AA AB AE AF AG AI AK AM AP AR AS AZ BA BB BC
30	0.4090	A C E G I K N O S T U V W Y Z AA AB AE AF AG AI AK AM AP AR AS AZ BA BB BC
31	0.4102	A C E G I K N O S T U V W Y Z AA AB AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
32	0.4111	A C E G I K N O S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
33	0.4117	A C E G I J K N O S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
34	0.4124	A C D E F G I K N O S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
35	0.4132	A C D E F G I K N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
36	0.4135	A B C D E F G I K N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
37	0.4140	A C D E F G H I J K N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
38	0.4144	A C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
39	0.4145	A B C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AP AR AS AX AZ BA BB BC
40	0.4147	A C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AN AP AQ AR AS AX AZ BA BB BC
41	0.4149	A C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AN AO AP AQ AR AS AX AZ BA BB BC
42	0.4150	A B C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AI AK AM AN AO AP AQ AR AS AX AZ BA BB BC
43	0.4152	A B C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AH AI AK AM AN AP AQ AR AS AW AX AZ BA BB BC
44	0.4153	A B C D E F G H I J K M N O Q S T U V W Y Z AA AB AD AE AF AG AH AI AK AM AN AO AP AQ AR AS AW AX AZ BA BB BC
45	0.4154	A B C D E F G H I J K M N O P R S T U V W Y Z AA AB AD AE AF AG AH AI AK AM AN AO AP AQ AR AS AW AX AZ BA BB BC
46	0.4155	A B C D E F G H I J K M N O P R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AM AN AO AP AQ AR AS AW AX AZ BA BB BC
47	0.4156	A B C D E F G H I J K M N O P R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AW AX AZ BA BB BC

48	0.4156	A B C D E F G H I J K M N O P Q R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AW AX AZ BA BB BC
49	0.4157	A B C D E F G H I J K M N O P Q R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AM AN AO AP AQ AR AS AT AU AW AX AZ BA BB BC
50	0.4157	A B C D E F G H I J K M N O P Q R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AW AX AZ BA BB BC
51	0.4157	A B C D E F G H I J K M N O P Q R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AW AX AY AZ BA BB BC
52	0.4157	A B C D E F G H I J K M N O P Q R S T U V W Y Z AA AB AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
53	0.4157	A B C D E F G H I J K M N O P Q R S T U V W Y Z AA AB AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
54	0.4157	A B C D E F G H I J K M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
55	0.4157	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC

Load at Failure All Possible Combinations Best-fit Model for One Through Eight Variables Included

Number in Model	R-Square	Variables in Model
1	0.1458	A
1	0.1059	BB
1	0.0794	AZ
1	0.0665	AB
1	0.0582	Y
1	0.0576	BA
1	0.0557	AO
1	0.0542	W
1	0.0498	AP
1	0.0482	Z
1	0.0445	AG
1	0.0431	AQ
1	0.0402	AH
1	0.0393	AM
1	0.0384	AA
1	0.0381	AJ
1	0.0373	AV
1	0.0363	AK
1	0.0341	X
1	0.0319	V
1	0.0312	AI
1	0.0311	AY
1	0.0306	S
1	0.0298	AX
1	0.0294	AN
1	0.0228	AL
1	0.0224	AW
1	0.0166	O
1	0.0126	E
1	0.0106	P
1	0.0106	R
1	0.0093	Q
1	0.0089	D
1	0.0082	G
1	0.0064	BC
1	0.0057	U
1	0.0052	C
1	0.0051	AC
1	0.0042	AU
1	0.0037	I
1	0.0037	AS
1	0.0037	AE
1	0.0028	AD
1	0.0026	K
1	0.0018	B
1	0.0017	AT
1	0.0014	AR
1	0.0013	H
1	0.0011	F
1	0.0006	AF
1	0.0002	N
1	0.0002	L
1	0.0001	J
1	0.0000	M
1	0.0000	T
2	0.2128	A BB
2	0.2017	A AZ
2	0.1831	A AB
2	0.1774	A Y
2	0.1764	A W
2	0.1755	A BA
2	0.1708	A AO
2	0.1681	A AQ
2	0.1679	A AP
2	0.1657	A AN
2	0.1656	A Z
2	0.1652	A G
2	0.1651	A AH
2	0.1650	A AG

2	0.1636	A AM
2	0.1635	A AV
2	0.1626	A AL
2	0.1621	A AK
2	0.1607	A O
2	0.1602	A AA
2	0.1599	A E
2	0.1591	A AX
2	0.1586	A F
2	0.1580	A AY
2	0.1579	A X
2	0.1577	A U
2	0.1570	A AJ
2	0.1569	A V
2	0.1569	A S
2	0.1559	A AW
2	0.1543	A AI
2	0.1525	A P
2	0.1523	A H
2	0.1522	A K
2	0.1520	A R
2	0.1518	A AE
2	0.1507	A Q
2	0.1488	A I
2	0.1483	A AR
2	0.1477	A D
2	0.1476	A AC
2	0.1476	A AU
2	0.1475	A AS
2	0.1469	A T
2	0.1469	A C
2	0.1467	A J
2	0.1465	A AD
2	0.1464	A BC
2	0.1463	A AT
2	0.1460	A L
2	0.1460	A M
2	0.1459	A B
2	0.1458	A N
2	0.1458	A AF
2	0.1427	T BB
3	0.2528	A U BB
3	0.2345	A O BB
3	0.2322	A G BB
3	0.2295	A T BB
3	0.2250	A AB BB
3	0.2246	A E BB
3	0.2242	A F BB
3	0.2218	A Y BB
3	0.2207	A U BA
3	0.2206	A W BB
3	0.2184	A K BB
3	0.2182	A AE BB
3	0.2181	A AZ BB
3	0.2176	A H BB
3	0.2171	A AQ BB
3	0.2170	A G AZ
3	0.2160	A BB BC
3	0.2159	A AB AZ
3	0.2157	A AN BB
3	0.2156	A AR BB
3	0.2153	A D BB
3	0.2152	A AH BB
3	0.2150	A I BB
3	0.2143	A J BB
3	0.2143	A AF BB
3	0.2142	A AL BB
3	0.2141	A AD BB
3	0.2140	A AO BB
3	0.2138	A AI BB
3	0.2136	A B BB
3	0.2136	A U AZ
3	0.2135	A V BB
3	0.2135	A X BB
3	0.2135	A M BB
3	0.2134	A BA BB
3	0.2134	A AG BB

3	0.2134	A AP BB
3	0.2133	A AA BB
3	0.2132	A AT BB
3	0.2132	A S BB
3	0.2131	A AJ BB
3	0.2131	A AS BB
3	0.2130	A AM BB
3	0.2130	A AV BB
3	0.2130	A L BB
3	0.2130	A Q BB
3	0.2130	A O AZ
3	0.2130	A AK BB
3	0.2129	A C BB
3	0.2129	A AC BB
3	0.2129	A R BB
3	0.2128	A AU BB
3	0.2128	A AX BB
3	0.2128	A F AZ
3	0.2128	A AY BB

4	0.2700	A U AB BB
4	0.2688	A G U BB
4	0.2672	A U BB BC
4	0.2648	A U Y BB
4	0.2642	A F U BB
4	0.2641	A U W BB
4	0.2639	A E U BB
4	0.2600	A T U BB
4	0.2597	A H U BB
4	0.2596	A U AQ BB
4	0.2587	A N U BB
4	0.2578	A U AZ BC
4	0.2578	A U AH BB
4	0.2578	A U AN BB
4	0.2572	A U AO BB
4	0.2571	A U AG BB
4	0.2563	A U AL BB
4	0.2562	A O U BB
4	0.2560	A J U BB
4	0.2560	A U AP BB
4	0.2557	A U AE BB
4	0.2557	A I U BB
4	0.2554	A C U BB
4	0.2553	A K U BB
4	0.2553	A U Z BB
4	0.2553	A D U BB
4	0.2553	A U BA BB
4	0.2549	A U AM BB
4	0.2547	A U AK BB
4	0.2546	A U AV BB
4	0.2540	A U AY BB
4	0.2537	A U AR BB
4	0.2535	A M U BB
4	0.2534	A L U BB
4	0.2534	A U AA BB
4	0.2533	A U AX BB
4	0.2533	A U AJ BB
4	0.2532	A U X BB
4	0.2531	A U V BB
4	0.2531	A U AW BB
4	0.2530	A U AC BB
4	0.2529	A U AT BB
4	0.2529	A S U BB
4	0.2529	A Q U BB
4	0.2529	A U AD BB
4	0.2529	A U AF BB
4	0.2528	A B U BB
4	0.2528	A U AZ BB
4	0.2528	A R U BB
4	0.2528	A U AU BB
4	0.2528	A U AI BB
4	0.2528	A G O BB
4	0.2528	A P U BB
4	0.2528	A U AS BB
4	0.2484	A O AB BB

5	0.2847	A G U AB BB
5	0.2829	A F U AB BB
5	0.2828	A U AB BB BC
5	0.2818	A G U BB BC
5	0.2801	A E U AB BB
5	0.2790	A G U Y BB
5	0.2781	A G U W BB
5	0.2771	A E U BB BC
5	0.2770	A U AB AI BB
5	0.2770	A U Y BB BC
5	0.2762	A U W BB BC
5	0.2762	A F U BB BC
5	0.2757	A G T U BB
5	0.2757	A H U AB BB
5	0.2756	A F U Y BB
5	0.2750	A N U AB BB
5	0.2746	A E U Y BB
5	0.2746	A G N U BB
5	0.2744	A T U BB BC
5	0.2743	A U AQ BB BC
5	0.2742	A F U W BB
5	0.2739	A E U W BB
5	0.2737	A D U AB BB
5	0.2736	A T U AB BB
5	0.2735	A O U AB BB
5	0.2734	A U AB AJ BB
5	0.2730	A G U AH BB
5	0.2730	A J U AB BB
5	0.2729	A S U AB BB
5	0.2728	A I U AB BB
5	0.2727	A K U AB BB
5	0.2726	A G U AQ BB
5	0.2723	A C G U BB
5	0.2723	A O U BB BC
5	0.2723	A H U BB BC
5	0.2722	A G O U BB
5	0.2722	A U Z AB BB
5	0.2721	A U Y AI BB
5	0.2721	A F T U BB
5	0.2720	A G K U BB
5	0.2720	A G U AG BB
5	0.2719	A U AB AQ BB
5	0.2719	A U AZ BB BC
5	0.2719	A U W AI BB
5	0.2718	A U AB AC BB
5	0.2718	A U AA AB BB
5	0.2717	A G U AE BB
5	0.2716	A G U AN BB
5	0.2716	A U AN BB BC
5	0.2714	A U AH BB BC
5	0.2714	A U AB AN BB
5	0.2712	A U AO BB BC
5	0.2712	A Q U AB BB
5	0.2712	A G U AO BB
5	0.2712	A U X AB BB

6	0.2963	A G U AB BB BC
6	0.2932	A F U AB BB BC
6	0.2919	A E U AB BB BC
6	0.2917	A G U AB AI BB
6	0.2909	A U AB AI BB BC
6	0.2903	A G U Y BB BC
6	0.2902	A F U AB AI BB
6	0.2896	A G N U AB BB
6	0.2893	A G U W BB BC
6	0.2888	A G T U BB BC
6	0.2886	A G U AB AJ BB
6	0.2883	A G S U AB BB
6	0.2882	A G T U AB BB
6	0.2882	A G O U AB BB
6	0.2881	A G K U AB BB
6	0.2878	A O U AB BB BC
6	0.2877	A S T U AB BB
6	0.2876	A G U Z AB BB

6	0.2872	A F N U AB BB
6	0.2871	A E U AB AI BB
6	0.2870	A G U AA AB BB
6	0.2869	A G O U BB BC
6	0.2869	A H U AB BB BC
6	0.2868	A F O U AB BB
6	0.2868	A F T U AB BB
6	0.2865	A I U AB BB BC
6	0.2865	A T U AB BB BC
6	0.2865	A F U AB AJ BB
6	0.2864	A G Q U AB BB
6	0.2863	A G U X AB BB
6	0.2863	A F G U AB BB
6	0.2862	A U Z AB BB BC
6	0.2862	A C G U BB BC
6	0.2861	A G R U AB BB
6	0.2861	A G U AB AC BB
6	0.2861	A N U AB BB BC
6	0.2860	A U AB AJ BB BC
6	0.2860	A G U AQ BB BC
6	0.2860	A D F U AB BB
6	0.2859	A E U Y BB BC
6	0.2859	A G U V AB BB
6	0.2859	A I K U AB BB
6	0.2859	A G U Y AI BB
6	0.2858	A C G U AB BB
6	0.2858	A F U Y BB BC
6	0.2858	A U AA AB BB BC
6	0.2857	A G N U BB BC
6	0.2857	A G P U AB BB
6	0.2856	A G U AB AZ BB
6	0.2856	A D U AB BB BC
6	0.2855	A F U Z AB BB
6	0.2855	A F S U AB BB
6	0.2855	A G U AB AW BB
6	0.2855	A G U AB AE BB
6	0.2854	A G U AB AX BB

7	0.3044	A G U AB AI BB BC
7	0.3040	A G S T U AB BB
7	0.3015	A F U AB AI BB BC
7	0.3014	A G O U AB BB BC
7	0.3008	A S T U AZ BB BC
7	0.3006	A F S T U AB BB
7	0.3005	A G U Z AB BB BC
7	0.3001	A G U AB AJ BB BC
7	0.3000	A G T U AB BB BC
7	0.2999	A G U AA AB BB BC
7	0.2999	A E U AB AI BB BC
7	0.2999	A E I K U AB BB
7	0.2996	A G N U AB BB BC
7	0.2994	A S T U AB BB BC
7	0.2994	A G S U AB BB BC
7	0.2991	A E S T U AB BB
7	0.2990	A G U X AB BB BC
7	0.2986	A F O U AB BB BC
7	0.2986	A G Q U AB BB BC
7	0.2985	A G R U AB BB BC
7	0.2985	A G K U AB BB BC
7	0.2984	A G U V AB BB BC
7	0.2982	A G P U AB BB BC
7	0.2979	A C G U AB BB BC
7	0.2978	A G U Z AB AG BB
7	0.2976	A G U Y AI BB BC
7	0.2976	A G I U AB BB BC
7	0.2975	A I K U AB BB BC
7	0.2975	A G U AB BA BB BC
7	0.2974	A E I U AB BB BC
7	0.2974	A G N U AB AI BB
7	0.2974	A G M U AB BB BC
7	0.2973	A G S T U BB BC
7	0.2973	A G U AB AX BB BC
7	0.2973	A G U AB AC BB BC
7	0.2972	A G S T U Y BB
7	0.2972	A F T U AB BB BC
7	0.2972	A G U AB AG AI BB
7	0.2972	A F G U AB BB BC
7	0.2972	A G U AB AQ BB BC

7	0.2971	A G U AB AE BB BC
7	0.2971	A F U Z AB BB BC
7	0.2970	A G U AB AZ BB BC
7	0.2970	A G U Y AB BB BC
7	0.2969	A G U AB AR BB BC
7	0.2967	A U AB AI AO BB BC
7	0.2967	A G U AB AN BB BC
7	0.2967	A D G U AB BB BC
7	0.2967	A G U AB AT BB BC
7	0.2966	A F U AB AJ BB BC
7	0.2966	A G U AB AW BB BC
7	0.2966	A G U W AI BB BC
7	0.2966	A G U AB AD BB BC
7	0.2966	A G U AB AD AI BB
7	0.2966	A E O U AB BB BC

8	0.3146	A G S T U AB BB BC
8	0.3141	A S T U AB AZ BB BC
8	0.3136	A G S T U AZ BB BC
8	0.3111	A G N S T U AB BB
8	0.3104	A E I K U AB BB BC
8	0.3100	A F S T U AB BB BC
8	0.3100	A E S T U AZ BB BC
8	0.3097	A E S T U AB BB BC
8	0.3096	A E I K M U BB BC
8	0.3095	A G O U AB AI BB BC
8	0.3089	A G U Z AB AG BB BC
8	0.3088	A G T U AB AI BB BC
8	0.3086	A G S T U AB BA BB
8	0.3086	A C E I K U BB BC
8	0.3086	A G U AB AD AI BB BC
8	0.3084	A S T U Y AZ BB BC
8	0.3083	A G N U AB AI BB BC
8	0.3080	A G U AB AG AI BB BC
8	0.3078	A S T U W AZ BB BC
8	0.3078	A G U AB AI AO BB BC
8	0.3075	A E I K M U AB BB
8	0.3075	A G U AB AZ BA BB BC
8	0.3075	A F S T U AZ BB BC
8	0.3074	A G S T U Y BB BC
8	0.3073	A G S T U AB AI BB
8	0.3072	A G K S T U AB BB
8	0.3071	A C G S T U AB BB
8	0.3071	A G U AB AI AP BB BC
8	0.3070	A G U V AB AI BB BC
8	0.3070	A F O U AB AI BB BC
8	0.3070	A G U AB AI AZ BB BC
8	0.3070	A G U AB AI AQ BB BC
8	0.3070	A G U AB AF AI BB BC
8	0.3070	A I K M U AB BB BC
8	0.3069	A F N S T U AB BB
8	0.3069	A E I K U AB AI BB
8	0.3069	A S T U AZ BA BB BC
8	0.3068	A G I K M U BB BC
8	0.3068	A G U AA AB AG BB BC
8	0.3067	A G U AB AI AN BB BC
8	0.3067	A G U AB AI AV BB BC
8	0.3067	A C E I K U AB BB
8	0.3067	A C G U AB AI BB BC
8	0.3066	A G K U AB AI BB BC
8	0.3065	A G S T U W BB BC
8	0.3065	A G U AB AI AM BB BC
8	0.3064	A F T U AB AI BB BC
8	0.3063	A G U AB AI AK BB BC
8	0.3062	A G U AB AI AR BB BC
8	0.3062	A F U Z AB AG BB BC
8	0.3061	A N S T U AZ BB BC
8	0.3061	A G U X AB AI BB BC
8	0.3061	A G I K U AB BB BC
8	0.3060	A E N S T U AB BB
8	0.3060	A G U AB AI AL BB BC

Percent Wood Failure Best-fit Model for the Specified Number of Variables Included

R-Square Selection Method

Number in Model	R-Square	Variables in Model
1	0.1549	AI
2	0.1768	AI AY
3	0.1919	U AI AY
4	0.2045	U AI AY BB
5	0.2178	N U AI AY BB
6	0.2300	N U AI AK AY BB
7	0.2358	N U AI AK AL AY BB
8	0.2424	G N U AI AK AL AY BB
9	0.2502	N U AI AK AL AM AO AY BB
10	0.2566	E N U AI AK AL AM AO AY BB
11	0.2610	E N U AH AI AK AL AM AO AY BB
12	0.2640	E N U V AD AI AK AL AM AO AY BB
13	0.2668	B E N U V AD AI AK AL AM AO AY BB
14	0.2702	E N U AH AI AK AL AM AO AY AZ BA BB BC
15	0.2743	E N U V AD AI AK AL AM AO AY AZ BA BB BC
16	0.2772	E N U V AD AH AI AK AL AM AO AY AZ BA BB BC
17	0.2801	B E N O U V AD AI AK AL AM AO AY AZ BA BB BC
18	0.2825	B E N U V W AD AH AI AK AL AM AO AY AZ BA BB BC
19	0.2853	B E N O U V W AD AH AI AK AL AM AO AY AZ BA BB BC
20	0.2877	B E N O U V W AD AH AI AK AL AM AO AR AV AY AZ BA BC
21	0.2905	B E N O U V W AD AH AI AK AL AM AO AR AV AY AZ BA BB BC
22	0.2930	B E N O U W X AD AE AH AI AK AL AM AO AR AV AY AZ BA BB BC
23	0.2954	B E N O U V W AD AH AI AK AL AM AN AO AQ AR AV AY AZ BA BB BC
24	0.2975	B E N O U W X AD AE AH AI AK AL AM AN AO AQ AR AV AY AZ BA BB BC
25	0.2999	G H J N O U W X AD AE AH AI AK AL AM AO AR AS AT AV AY AZ BA BB BC
26	0.3026	B E N O U W X AD AE AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
27	0.3055	G H J N O U W X AD AE AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
28	0.3080	G H J N O U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
29	0.3094	B G H J N O U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
30	0.3112	B G H J K N O U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
31	0.3125	B E H I J K N O U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
32	0.3139	B C G H J K M N O U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
33	0.3151	B C E H I J K M N O U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
34	0.3164	B C E H I J K M N O S U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
35	0.3180	B C E H I J K M N O Q S U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
36	0.3192	B C E H I J K M N O Q S T U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
37	0.3204	B C D E F I J K M N O Q S T U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AV AY AZ BA BB BC
38	0.3210	B C D E F I J K M N O Q S T U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AU AV AY AZ BA BB BC
39	0.3214	B C D E F H I J K M N O Q S T U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AU AV AY AZ BA BB BC
40	0.3220	B C D E F H I J K M N O P R S T U W X AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AU AV AY AZ BA BB BC
41	0.3224	B C D E F H I J K M N O P R S T U W X AC AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AU AV AY AZ BA BB BC
42	0.3227	B C D E F H I J K M N O P R S T U W X AA AC AD AE AG AH AI AK AL AM AN AO AQ AR AS AT AU AV AY AZ BA BB BC
43	0.3229	B C D E F H I J K M N O P R S T U W X AC AD AE AG AH AI AJ AK AL AM AN AO AQ AR AS AT AU AV AW AY AZ BA BB BC
44	0.3232	B C D E F H I J K M N O P R S T U W X AC AD AE AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AY AZ BA BB BC
45	0.3234	B C D E F H I J K M N O P R S T U W X AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AY AZ BA BB BC
46	0.3235	B C D E F H I J K M N O P Q R S T U W X AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AY AZ BA BB BC
47	0.3236	B C D E F H I J K M N O P Q R S T U V W X AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AY AZ BA BB BC

48	0.3236	B C D E F H I J K L M N O P Q R S T U V W X AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AY AZ BA BB BC
49	0.3237	B C D E F H I J K L M N O P Q R S T U V W X Y AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AY AZ BA BB BC
50	0.3237	B C D E F H I J K L M N O P Q R S T U V W X Y AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
51	0.3237	A B C D E F H I J K L M N O P Q R S T U V W X Y AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
52	0.3237	A B C D E F G H I J K L M N O P Q R S T U V W X Y AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
53	0.3237	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
54	0.3237	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC
55	0.3237	A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL AM AN AO AP AQ AR AS AT AU AV AW AX AY AZ BA BB BC

Percent Wood Failure All Possible Combinations Best-fit Model for One Through Eight Variables Included

R-Square Selection Method

Number in Model	R-Square	Variables in Model
1	0.1549	AI
1	0.1406	Z
1	0.1363	AA
1	0.1290	X
1	0.1240	AJ
1	0.1218	V
1	0.0992	AY
1	0.0899	AG
1	0.0897	BB
1	0.0838	AZ
1	0.0786	AB
1	0.0771	BA
1	0.0763	Y
1	0.0756	AH
1	0.0753	W
1	0.0724	AL
1	0.0672	AN
1	0.0650	AO
1	0.0649	S
1	0.0641	AP
1	0.0635	AW
1	0.0586	AV
1	0.0568	AX
1	0.0510	Q
1	0.0496	AM
1	0.0472	AQ
1	0.0466	R
1	0.0431	AK
1	0.0376	P
1	0.0192	A
1	0.0164	D
1	0.0147	G
1	0.0129	C
1	0.0127	E
1	0.0125	AC
1	0.0121	N
1	0.0097	BC
1	0.0067	AU
1	0.0065	AS
1	0.0052	AD
1	0.0046	F
1	0.0042	T
1	0.0038	J
1	0.0034	AF
1	0.0020	O
1	0.0008	H
1	0.0005	M
1	0.0004	AR
1	0.0003	K
1	0.0003	I
1	0.0002	U
1	0.0002	B
1	0.0002	AT
1	0.0000	L
1	0.0000	AE
2	0.1768	AI AY
2	0.1700	AI BB
2	0.1687	AI AZ
2	0.1645	Q AI
2	0.1642	AI AJ
2	0.1642	U AI
2	0.1627	R AI
2	0.1619	O AI
2	0.1615	D AI
2	0.1607	AH AI
2	0.1606	G AI
2	0.1604	E AI
2	0.1602	P AI

2	0.1602	AI AN
2	0.1602	AI AL
2	0.1596	AD AI
2	0.1595	B AI
2	0.1593	J AI
2	0.1593	AI AW
2	0.1589	AI AT
2	0.1588	AI AK
2	0.1587	AA AJ
2	0.1583	S AI
2	0.1583	N AI
2	0.1582	L AI
2	0.1582	Z AJ
2	0.1577	Z AI
2	0.1576	AF AI
2	0.1575	AI BA
2	0.1574	AE AI
2	0.1574	A AI
2	0.1574	AB AI
2	0.1574	AI AM
2	0.1572	X AJ
2	0.1570	U Z
2	0.1568	AJ BB
2	0.1568	AA AI
2	0.1564	AI AR
2	0.1562	F AI
2	0.1561	AI AQ
2	0.1558	M AI
2	0.1555	Z AY
2	0.1554	AI AO
2	0.1554	AC AI
2	0.1554	AI AP
2	0.1554	I AI
2	0.1554	K AI
2	0.1553	V AJ
2	0.1552	AI BC
2	0.1552	Y AI
2	0.1551	AI AV
2	0.1551	X AI
2	0.1551	AI AU
2	0.1550	AG AI
2	0.1549	AI AS

3	0.1919	U AI AY
3	0.1867	AI AK AY
3	0.1863	U AI BB
3	0.1858	O AI AY
3	0.1849	AI AM AY
3	0.1844	AI AY BB
3	0.1831	AI AO AY
3	0.1830	D AI AY
3	0.1827	G AI AY
3	0.1825	AI AP AY
3	0.1824	AI AT AY
3	0.1824	E AI AY
3	0.1823	AI AY AZ
3	0.1817	L AI AY
3	0.1817	B AI AY
3	0.1814	J AI AY
3	0.1812	AD AI AY
3	0.1808	AI AX AY
3	0.1807	AI AJ AY
3	0.1800	Q AI AY
3	0.1795	N AI AY
3	0.1795	AF AI AY
3	0.1793	M AI AY
3	0.1792	AI AV AY
3	0.1792	R AI AY
3	0.1787	AI AK BB
3	0.1787	AI AJ BB
3	0.1785	AH AI AY
3	0.1785	F AI AY
3	0.1783	AI AY BC
3	0.1783	P AI AY
3	0.1783	AI AL AY
3	0.1783	A AI AY
3	0.1782	AI AN AY
3	0.1782	O AI BB

3	0.1780	AE AI AY
3	0.1780	AI AK AZ
3	0.1779	I AI AY
3	0.1775	K AI AY
3	0.1775	C AI AY
3	0.1775	V AI AY
3	0.1774	AI AS AY
3	0.1772	X AI AY
3	0.1772	AI AW AY
3	0.1771	AB AI AY
3	0.1771	AC AI AY
3	0.1771	AI AR AY
3	0.1770	H AI AY
3	0.1770	W AI AY
3	0.1769	AG AI AY
3	0.1769	AI AY BA
3	0.1769	T AI AY
3	0.1769	AI AM BB
3	0.1768	AA AI AY
3	0.1768	Z AI AY

4	0.2045	U AI AY BB
4	0.2022	N U AI AY
4	0.1999	N U AI BB
4	0.1994	U AI AK AY
4	0.1993	G U AI AY
4	0.1981	D U AI AY
4	0.1981	AI AK AY BB
4	0.1979	E U AI AY
4	0.1979	U AI AM AY
4	0.1970	U AI AT AY
4	0.1965	U AI AY BC
4	0.1964	U AI AO AY
4	0.1963	AI AM AY BB
4	0.1960	AI AK AY AZ
4	0.1957	U AI AP AY
4	0.1955	O AI AK AY
4	0.1953	J U AI AY
4	0.1949	AI AK AM AY
4	0.1948	L U AI AY
4	0.1947	Q U AI AY
4	0.1947	U AI AX AY
4	0.1946	U AD AI AY
4	0.1945	AI AO AY BB
4	0.1945	T U AI AY
4	0.1944	U AI AY AZ
4	0.1943	B U AI AY
4	0.1942	AI AM AY AZ
4	0.1942	U AH AI AY
4	0.1941	U AI AJ AY
4	0.1941	R U AI AY
4	0.1940	O AI AY BB
4	0.1938	U AI AL AY
4	0.1937	AI AP AY BB
4	0.1937	O AI AM AY
4	0.1937	F U AI AY
4	0.1936	O U AI AY
4	0.1935	U AI AN AY
4	0.1935	A U AI AY
4	0.1933	U AF AI AY
4	0.1933	P U AI AY
4	0.1932	U AI AV AY
4	0.1932	U AI AY BA
4	0.1931	U AI AR AY
4	0.1930	AI AK AL AY
4	0.1929	U AI AJ BB
4	0.1929	U AI AK BB
4	0.1927	I U AI AY
4	0.1926	AI AO AY AZ
4	0.1925	U AI AW AY
4	0.1925	U AE AI AY
4	0.1924	M U AI AY
4	0.1924	D AI AK AY
4	0.1924	U Z AI AY
4	0.1923	U AB AI AY
4	0.1923	G U AI BB

5	0.2178	N U AI AY BB
5	0.2158	U AI AK AY BB
5	0.2143	U AI AM AY BB
5	0.2128	U AI AO AY BB
5	0.2120	U AI AP AY BB
5	0.2112	G U AI AY BB
5	0.2107	U AI AT AY BB
5	0.2103	D U AI AY BB
5	0.2102	E U AI AY BB
5	0.2100	N U AI AK AY
5	0.2099	G N U AI AY
5	0.2099	U AI AX AY BB
5	0.2086	E N U AI AY
5	0.2084	N U AI AM AY
5	0.2083	U AD AI AY BB
5	0.2081	U AI AV AY BB
5	0.2081	U AI AY BB BC
5	0.2079	D N U AI AY
5	0.2077	N U AI AT AY
5	0.2075	U AI AK AM AY
5	0.2075	O AI AK AY BB
5	0.2073	N U AI AJ BB
5	0.2072	N U AI AK BB
5	0.2071	J U AI AY BB
5	0.2070	B U AI AY BB
5	0.2069	U AI AJ AY BB
5	0.2068	N U AI AO AY
5	0.2062	N U AI AP AY
5	0.2062	F U AI AY BB
5	0.2061	G N U AI BB
5	0.2061	L U AI AY BB
5	0.2060	Q U AI AY BB
5	0.2059	U AH AI AY BB
5	0.2059	U AF AI AY BB
5	0.2059	U AI AY BA BB
5	0.2058	J N U AI AY
5	0.2058	U AI AK AL AY
5	0.2058	U AI AY AZ BB
5	0.2057	O U AI AY BB
5	0.2057	U AI AL AY BB
5	0.2057	N U AI AY AZ
5	0.2057	S U AI AY BB
5	0.2057	N U AI AT BB
5	0.2057	O AI AM AY BB
5	0.2056	U AI AT AU AY
5	0.2056	E N U AI BB
5	0.2056	A U AI AY BB
5	0.2055	N U AI AY BC
5	0.2055	N U AI AM BB
5	0.2055	U AI AN AY BB
5	0.2055	U AI AR AY BB
5	0.2054	R U AI AY BB
5	0.2054	G U AI AK AY
5	0.2054	I U AI AY BB
5	0.2054	N U AD AI BB
6	0.2300	N U AI AK AY BB
6	0.2283	N U AI AM AY BB
6	0.2268	N U AI AO AY BB
6	0.2260	N U AI AP AY BB
6	0.2247	N U AI AT AY BB
6	0.2247	G N U AI AY BB
6	0.2238	E N U AI AY BB
6	0.2235	N U AI AX AY BB
6	0.2229	D N U AI AY BB
6	0.2223	N U AD AI AY BB
6	0.2217	U AI AK AL AY BB
6	0.2216	N U AI AV AY BB
6	0.2211	U AI AK AM AY BB
6	0.2209	D U AI AK AY BB
6	0.2208	G U AI AK AY BB
6	0.2206	N U AI AJ AY BB
6	0.2205	J N U AI AY BB
6	0.2203	E U AI AK AY BB
6	0.2203	B N U AI AY BB
6	0.2199	N U AI AY BB BC
6	0.2199	N O U AI AY BB

6	0.2199	F N U AI AY BB
6	0.2198	U AI AK AN AY BB
6	0.2197	N U AI AY BA BB
6	0.2196	U AI AL AM AY BB
6	0.2195	D U AI AM AY BB
6	0.2194	U AI AK AW AY BB
6	0.2194	N U AH AI AY BB
6	0.2194	U AI AK AY BB BC
6	0.2193	G U AI AM AY BB
6	0.2192	N U AF AI AY BB
6	0.2192	U AI AN AO AY BB
6	0.2192	U AI AL AO AY BB
6	0.2191	N S U AI AY BB
6	0.2189	N U AI AL AY BB
6	0.2189	A N U AI AY BB
6	0.2189	I N U AI AY BB
6	0.2189	N U AI AY AZ BB
6	0.2189	E U AI AM AY BB
6	0.2188	N Q U AI AY BB
6	0.2188	U AI AK AV AY BB
6	0.2187	N U AI AN AY BB
6	0.2186	D U AI AO AY BB
6	0.2186	U AH AI AK AY BB
6	0.2185	N U AI AS AY BB
6	0.2185	L N U AI AY BB
6	0.2184	N U AI AR AY BB
6	0.2184	N U AI AK AM AY
6	0.2184	N R U AI AY BB
6	0.2183	M N U AI AY BB
6	0.2182	N U W AI AY BB
6	0.2182	N U V AI AY BB
6	0.2181	U AI AM AN AY BB
6	0.2181	N U AE AI AY BB
6	0.2181	G U AI AO AY BB
7	0.2358	N U AI AK AL AY BB
7	0.2351	N U AI AK AM AY BB
7	0.2350	G N U AI AK AY BB
7	0.2347	E N U AI AK AY BB
7	0.2344	D N U AI AK AY BB
7	0.2340	N U AI AK AW AY BB
7	0.2339	N U AI AK AN AY BB
7	0.2338	N U AI AL AM AY BB
7	0.2335	G N U AI AM AY BB
7	0.2333	N U AI AK AV AY BB
7	0.2332	N U AI AN AO AY BB
7	0.2332	N U AI AL AO AY BB
7	0.2331	E N U AI AM AY BB
7	0.2331	N U AH AI AK AY BB
7	0.2329	D N U AI AM AY BB
7	0.2326	N U AD AI AK AY BB
7	0.2325	N O U AI AK AY BB
7	0.2322	N U AI AM AW AY BB
7	0.2322	N U AI AM AN AY BB
7	0.2322	G N U AI AO AY BB
7	0.2321	N U AI AK AY BB BC
7	0.2320	N U AI AT AU AY BB
7	0.2319	B N U AI AK AY BB
7	0.2319	D N U AI AO AY BB
7	0.2319	N U AI AO AT AY BB
7	0.2317	N U AI AK AP AY BB
7	0.2317	E N U AI AO AY BB
7	0.2317	N U AI AK AT AY BB
7	0.2317	G N U AI AP AY BB
7	0.2316	J N U AI AK AY BB
7	0.2316	N U AI AO AW AY BB
7	0.2314	F N U AI AK AY BB
7	0.2313	N U AH AI AM AY BB
7	0.2313	N U AC AI AK AY BB
7	0.2311	N U AA AI AK AY BB
7	0.2311	G N U AI AT AY BB
7	0.2311	E N U AI AP AY BB
7	0.2311	N U X AI AK AY BB
7	0.2311	N U AD AI AM AY BB
7	0.2311	A N U AI AK AY BB
7	0.2310	N U AI AJ AK AY BB
7	0.2310	N U Z AI AK AY BB
7	0.2310	D N U AI AP AY BB

7	0.2310	N U AG AI AK AY BB
7	0.2310	N U V AI AK AY BB
7	0.2308	N Q U AI AK AY BB
7	0.2308	N U AI AK AU AY BB
7	0.2308	N O U AI AM AY BB
7	0.2308	N U AI AK AR AY BB
7	0.2308	N U AI AM AT AY BB
7	0.2308	N U AI AM AV AY BB
7	0.2307	L N U AI AK AY BB
7	0.2306	E N U AI AT AY BB
7	0.2306	I N U AI AK AY BB
7	0.2305	N U AI AL AP AY BB

8	0.2424	G N U AI AK AL AY BB
8	0.2420	E N U AI AK AL AY BB
8	0.2411	D N U AI AK AL AY BB
8	0.2409	N U AI AK AL AM AY BB
8	0.2405	G N U AI AL AM AY BB
8	0.2403	N U AI AO AP AQ AY BB
8	0.2402	G N U AI AL AO AY BB
8	0.2402	G N U AI AK AN AY BB
8	0.2402	G N U AI AN AO AY BB
8	0.2400	E N U AI AL AM AY BB
8	0.2399	G N U AI AK AM AY BB
8	0.2399	E N U AI AK AM AY BB
8	0.2397	E N U AI AK AN AY BB
8	0.2396	E N U AI AL AO AY BB
8	0.2396	E N U AI AN AO AY BB
8	0.2395	G N U AI AK AW AY BB
8	0.2395	D N U AI AL AO AY BB
8	0.2395	N U AI AK AM AO AY BB
8	0.2395	D N U AI AN AO AY BB
8	0.2393	E N U AI AK AW AY BB
8	0.2392	D N U AI AL AM AY BB
8	0.2392	N U AI AK AT AU AY BB
8	0.2390	D N U AI AK AM AY BB
8	0.2389	D N U AI AK AN AY BB
8	0.2389	N U AI AO AT AU AY BB
8	0.2389	N U AI AL AO AT AY BB
8	0.2387	G N U AI AM AN AY BB
8	0.2386	N U AI AM AT AU AY BB
8	0.2385	N U AI AP AT AU AY BB
8	0.2384	N U AH AI AK AL AY BB
8	0.2383	D N U AI AK AW AY BB
8	0.2382	N U AH AI AK AM AY BB
8	0.2381	E N U AI AM AN AY BB
8	0.2381	N U AI AK AL AV AY BB
8	0.2381	G N U AH AI AK AY BB
8	0.2380	F N U AI AK AL AY BB
8	0.2380	N U AI AK AR AV AY BB
8	0.2380	N O U AI AK AM AY BB
8	0.2380	N U AI AK AL AY BB BC
8	0.2379	G N U AI AK AV AY BB
8	0.2379	G N U AI AM AW AY BB
8	0.2379	N O U AI AK AL AY BB
8	0.2379	G N U AD AI AK AY BB
8	0.2378	N U AI AK AM AN AY BB
8	0.2378	N U AI AK AM AW AY BB
8	0.2378	G N U AI AL AP AY BB
8	0.2377	B N U AI AK AL AY BB
8	0.2377	N U AI AK AL AW AY BB
8	0.2377	J N U AI AK AL AY BB
8	0.2377	G N U AI AT AU AY BB
8	0.2377	E N U AH AI AK AY BB
8	0.2377	N U AD AI AK AL AY BB
8	0.2376	A N U AI AK AL AY BB
8	0.2376	E N U AI AK AV AY BB
8	0.2376	D N U AI AK AV AY BB