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Variation in Lightness of White Oak Dimension Stock

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Abstract (summary)

A set of sample parameters for the lightness of planed white oak dimension stock is generated. The effect of grain angle of lightness values is investigated. The level of sampling needed to color match white oak dimension stock on the basis of lightness or darkness as quantified by the parameter L* (psychometric lightness) is determined. Color measurements were obtained with a portable spectrophotometer interfaced with a notebook computer. The lightness values of these defect-free white oak dimension parts have a normal distribution, suggesting that lighter colored material could be sorted for higher priced markets where this attribute is favorable. This suggests an opportunity to explore raw material sourcing for desired color attributed. There is very little variation of lightness within each board. Because of this, sufficient data for color matching of parts using lightness as the color criterion can be obtained by taking one reading on each board, as long as the readings are collected with the same grain orientation. Lightness readings are significantly different along grain versus across the grain.

Full Text

Subtle changes in consumer preferences often provide the impetus for incremental improvements in manufacturing processes. In the case of hardwood dimension manufacturing, the current preference is toward lighter, more uniformly colored panels for use in products such as kitchen cabinets. As a result, many hardwood producers are seeking ways to improve product quality by more accurately matching the color of boards that comprise edge-glued panels. The current industrial practice is for human operators to visually color and grain match boards on a piece-by-piece basis. Evaluation with instruments may be useful during manufacturing. This decision-making process could be aided by quantitative color measurements.

Previous research has shown that the color of wood may be quantified, but the utility of such quantification depends upon the application. The area of color matching of defect-free white oak dimension stock lends itself to this approach. Therefore, the objectives of this research were to generate a set of sample parameters for the lightness of planed white oak dimension stock, to determine the level of sampling needed to match white oak dimension stock on the basis of lightness or darkness as quantified by the parameter L* (psychometric lightness), and to investigate the effect of grain angle on lightness values. This information is important to determine the feasibility of using a low-cost instrumental evaluation of color in a production setting and its potential impact on raw material sourcing and product pricing.

INSTRUMENTAL EVALUATION OF WOOD COLOR

The instrumental evaluation of wood color has been the subject of much research. Like any research concerning the quantification of color, research concerned with wood color is complicated because color perception by humans is a psychophysical phenomenon that escapes exact measurement. Nevertheless, the quantification of color in general has been accomplished with sufficient success to provide useful tools for the textile, paint, automotive, and other industries. The adoption of color quantification within the wood products industry, however, has been limited. A number of previous and current development efforts in the wood products industry have been thoroughly reviewed by Brunner et al. (7). More recent research using increasingly sophisticated models are described by Maristany et al. (12).

Color evaluation of wood may be applied for a variety of objectives such as defect detection, sorting of species, and grading of veneer, etc. In the case of defect detection, multiple criteria such as size, shape, color, or statistical parameters derived from such measurements are needed for accurate detection (8-10). Color criteria may have potential for sorting species by using "chromaticity coordinates," but the most satisfactory quantification of color differences may be limited to differences in brightness (4,5). Vetter et al. (21) suggested that a visual color matching system, such as the Munsell color charts, would be sufficient to provide simple descriptions of wood color, but instrumental evaluation would provide better results for assessing color variation and change. In the case of veneer grading, it has been shown that despite the significance of color in determining the value of decorative hardwood veneer, color cannot be used as an accurate indicator of black walnut veneer grade due to the confounding influence of factors such as knots, splits, insect damage, and heartwood/sapwood variations (6).

In the examples just discussed, it is evident that the application of color analysis is currently limited, primarily by the variability introduced by factors such as defects, species variations, and heartwood/sapwood differences. In situations in which such confounding factors are minimized, there does appear to be an opportunity to use currently available technology to quantify color parameters of wood products.

One such situation is in manufacturing edge-glued panel stock from single species input. In this case, species variation is minimized and variation due to defects can be reduced by measuring color after the dimension stock has been planed and the defects removed. Alternatively, color measurement could be taken concurrently with optical scanning for defect removal, as long as the measurements are taken from clear, planed wood. Furthermore, if the objective is to match the dimension stock according to a single criterion such as lightness, the choice of color-quantifying parameters is greatly simplified.

Color is quantified by the use of parameters that define various "color spaces" (23). The Commission International de l'Eclairage (CIE) is generally recognized as an authoritative source for methodology for the evaluation of color. The CIE L*a*b* color space is one that is commonly applied to the evaluation of opaque materials, wherein L* specifies the psychometric lightness (i.e., related to the psychological phenomenon of human color perception) in a range from 0 = black to 100 = white, and a* and b* are positive/negative coordinates that define the hue (chroma, or dominant wavelength) and intensity (saturation) of the color.

In order to make meaningful color measurements, the conditions of illumination and specimen viewing must be standardized. The most commonly used standard illuminant is the D 65, which simulates average daylight (3). Similarly, the geometry of the illumination and viewing (collection of reflected light) conditions must be standardized (1). A common arrangement in commercially available instruments is a 45/0 geometry, wherein the specimen is illuminated from a standard illuminant at a 45-degree angle, and the reflected light is collected directly above the specimen. The color-matching functions then applied to the reflected light spectra are related to a so-called "standard observer," which is typically either 2 or 10 degrees. By definition, a 2- or 10-degree standard observer is an ideal colorimetric observer based on a field of 2 or 10 degrees on the retina, respectively (2). The point is, that in order for any color quantifying values to be used or compared in a meaningful way, these parameters must be known and specified.

Equipment is available commercially for the measurement of color. Generally, two types of instruments are used. The first, known as a tristimulus colorimeter, calculates colorspace coordinates (e.g., L*a*b* values) based on the integrated spectral response of the colors red, green, and blue. These instruments are mainly used for measuring color differences. The other type of instrument, a spectrophotometer, differs from a tristimulus colorimeter in that it measures the spectral reflectance of a specimen throughout the visible range of light and calculates the colorspace coordinates. Most portable instruments collect spectral data from 400 to 700 nm in 10-nm intervals. As a result, spectrophotometers provide more complete information (reflectance data for the visible spectrum) than tristimulus instruments, and are generally preferred for research purposes (7). The spectra themselves may also be analyzed, and it has been suggested that for certain applications to wood products, such as evaluating color changes due to environmental effects, this may be more suitable than the use of colorspace parameters (13).

The design differences in these instruments also lead to a difference in price, in that portable tristimulus colorimeters may be purchased for under $5,000 ($US), whereas comparable spectrophotometers will cost $8,000 to $15,000, including PC software used to manipulate the spectral data. Voss (22) lists some examples of portable instruments currently available. However, whether these instruments are rugged enough to be used in a hardwood dimension operation is questionable. Industrial systems developed for use in other industries cost several times more than the portable instruments.

Color evaluation (specifically lightness (L*)) of edge-glued white oak furniture dimension stock with a handheld portable spectrophotometer has previously shown statistical (and visual) differences within and between three panels assembled in an industrial operation (17). As a result, the present study was conducted to further investigate the feasibility of the concept.

MATERIALS AND METHODS

A set of 20 loose-assembled (i.e., unglued) white oak panels were selected for study at a dimension plant that obtains lumber from an 8-state area. Each panel measured 31.5 inches long, 12 inches wide, and 3/4 inches thick and contained from four to seven boards. The total number of boards in the sample was 113. On each board, spectral reflectance data were obtained using a handheld spectrophotometer at three locations, approximately 1/4, 1/2, and 3/4 of the distance from one end of each board along the centerline (Fig. 1). (All figures omitted) At each location, four readings were taken: two with the illumination directed along the grain but 180 degrees apart (readings 1 and 3 at each location), and two with the illumination directed across the grain, also 180 degrees from one another (readings 2 and 4). Thus, 1,356 (113 boards by 3 locations per board by 4 readings per location) readings were taken.

Readings were collected with a Colormet,(1) handheld spectrum analyzer interfaced with a notebook computer for storage and subsequent processing of spectral data. Each reading consisted of spectral data acquired from an elliptical central viewing area (Fig. 1) from 400 to 700 nm in 10-nm intervals. A D 65 standard illuminant, 45/0 illumination/viewing geometry, and 10-degree standard observer were used to calculate CIE L*a*b* parameters. The L* values were statistically analyzed using the SAS System for Windows 3.10 (19).

RESULTS

A histogram of L* values for all 1,356 readings, with a mean of 62.7, standard deviation of 4.42, and standard error of the mean of 0.120, resembles a normal distribution (Fig. 2). The approximate normality of the data is confirmed by skewness and kurtosis values of 0.0028 and -0.28, respectively (these measures would be zero for a perfectly normal distribution).

A preliminary analysis of variance (ANOVA) of the data (table not shown) showed there were significant differences in the average lightness between panels (F = 5.84; 19, 93 df; p > F = 0.0001) and between boards within panels (F = 5.12; 93, 1,243 df; p > F = 0.0001). This was expected based on our previous study (17) and upon visual inspection of the panels and boards, i.e., the statistics confirm that visually perceptible differences do exist.

The effect of location of measurement in a board and direction of measurement within location for the complete data set were analyzed with a nested design. The model was:

L* = li + dj(li) + eij

where:

L*= lightness

li = location (1/4, 1/2, or 3/4 of board length)

dj = direction (1, 2, 3, or 4)

eij = error term attributable to readings within direction

The results of this analysis are given in Table 1. (Table 1 omitted) Locations of measurement within a board (i.e., along its length) are not different from one another (p = 0.9866) but directions of measurement (along or across the grain) do differ (p = 0.0000).

Separate analyses of variance of L* for each direction (along or across the grain) show there are no significant differences between locations within boards. For L* measured along the grain, F = 0.907; 2, 675 df; p > F = 0.4042 and for L* measured across the grain, F = 1.244; 2, 675 df; p > F = 0.2890 (ANOVA table not shown, but variance components are given in Table 2). (Table 2 omitted)

We also wanted to determine if there was any difference in the lightness values obtained 180 degrees apart because we have observed that a board may appear to be light or dark when viewed along the grain, but if the board is turned 180 degrees, it may look quite different. Therefore, a subsequent analysis of only the readings taken along the grain (two readings 180 degrees apart at each location) and a similar analysis of only the readings across the grain were performed. The analysis showed that there were no significant differences in the lightness values obtained when the instrument was turned 180 degrees. Specifically, for readings along the grain, F = 0.58; 1, 676 df; p > F = 0.4471 and for readings across the grain, F = 0.00; 1, 676 df; p > F = 0.9719 (ANOVA table not shown).

Finally, correlations between lightness readings taken along and across the grain could have practical significance for material that is color matched by viewing the pieces along the grain; but in the final product the view from a side angle (say, of a kitchen cabinet) may make the product appear to be poorly color matched. A plot of lightness values obtained along the grain (LAL) versus lightness across the grain (LAC) is shown in Figure 3. LAL had an average lightness of 60.4 (standard deviation 3.81). The average LAC lightness was 64.9 (standard deviation 3.82). A simple linear regression of LAL on LAC yields an equation of LAL = 20.4 + 0.61 LAC, with an r sup 2 of 0.382. A Pearson Correlation analysis produced a coefficient of 0.618 with a probability of a greater r of 0.0001 under the null hypothesis of r = 0.

PRACTICAL IMPLICATIONS

The key results in this study consist of a further description of the sample parameters for L* of white oak dimension, and various measures and analyses of variability of L* within boards. These results have some practical implications for producers.

The normal distribution of L* values has importance for pricing of lighter colored boards and the panels made from them. From the histogram in Figure 2, it is apparent that the proportion of light-colored boards (i.e., those having high L* values) is limited and, thus, these boards may have a higher value in a marketplace where this attribute is desirable. According to Philip E. Bins, company buyer for the Next Dimension Company of Scunthorpe, England,(2) panels with high lightness (approximately L* >= 65) are preferred by European consumers. In the sample evaluated in this study, 34.5 percent (468/1,356) of the readings were >= 65.

If this is representative of the population of white oak panel stock lightness, a price differential could be expected for this material. In addition, dimension mills could conceivably better source their material by identifying lumber producers who generate lighter colored material. Thus, an opportunity exists for processors to derive greater economic returns by focusing on this particular market demand at several stages of manufacture.

There are two important practical implications of the results shown in Table 1. First, it is unnecessary to take several readings on each board in order to obtain a reliable estimate of board lightness. In our previous study (17) we observed that within-board coefficients of variation were low (generally < 2%), suggesting that few locations per board would need to be sampled for color matching purposes using L* as the matching criterion. Results from the larger sample population in this study confirm this suggestion. Second, it is important to be consistent in taking measurements either along or across the grain. Previous investigations have found differences in along- grain versus across-grain color parameters (11,12,16), but one investigator found no significant differences at the alpha = 0.01 level(15). However, because such differences are generally found, most investigators tend to take readings in one direction or the other, or they average the two (7).

We stated previously that few measurements per board are needed to obtain an adequate sample for color matching based on lightness as quantified by L*. The estimation of the level of sampling necessary may be further evaluated by examination of the variance components (Table 1). The calculated variance component for location within board is - 4.97. A negative estimate of variance of a random effects variable is customarily set to zero (20). The SAS VARCOMP algorithm will set negative estimates to zero (18), and the NESTED procedure used here gives the negative estimate but reports the percentage of the total variance as zero as shown in Table 1. In their discussion of the use of variance components for wood products research, Mize and Winistorfer (14) state that it may be assumed that the variance is small when a negative variance component is estimated from a large sample. Another alternative is that the sample size is too small. Using data from our previous study (17), and also based on the low coefficients of variation for wood color parameters reported in the literature (7), we conclude that the former is the case, i.e., the sample size was large so L* does, in fact, have low within-board variance for this nearly defect-free, planed white oak dimension stock. The variation in these data is thus attributable to direction of measurement (experimental error = 40.8 and sampling error among readings within directions (59.2%). Furthermore, the variance components for the data partitioned into readings either along or across the grain (Table 2) also show that the variation attributable to locations is zero. Thus, it is again confirmed that for these single-species, defect-free dimension parts, the variation of L* within each board is low, such that an adequate sample for the purpose of color matching may be obtained with a single measurement on each piece. Thus, data acquisition in an industrial application could be minimized. Statistical analyses clearly demonstrate that location of measurement within boards is not important, but direction of measurement (along or across the grain) is important and should be consistent. However, human operators provide a key function in making critical decisions concerning grain and color matching, particularly at the edges of adjacent boards. As a result, we suggest that a portable spectrophotometer would be useful to assist human operators in making color matching decisions, but the spectrophotometer in and of itself cannot completely supplant skilled workers. Probably the best use of the instrument would be to presort the dimension stock into groups of material, perhaps as tightly as intervals of one L* unit. We have conducted limited presorting tests with the spectrophotometer in a production setting in which we were able to keep pace with a production of approximately 20 pieces per minute when taking one reading on each piece. The presorted material was then used by experienced industrial personnel to assemble edge-glued panels, resulting in panels plant managers found to be highly satisfactory.(3)

While we have stressed the importance of being consistent in making readings along or across the grain due to statistical differences, it should be recognized there is some correlation between the readings obtained from different directions of measurement at a given location on a board. Whether these correlations are sufficient to result in panels that appear to be color matched regardless of the angle at which a consumer views the final product remains to be seen.

CONCLUSIONS

Lightness values of planed, defect-free white oak dimension parts have a normal distribution, suggesting that lighter colored material could be sorted for higher priced markets where this attribute is desired. There is very low variation of lightness within each board, the practical implication of which is that sufficient data for the purpose of color matching of parts using lightness as the color criterion can be obtained by taking one reading on each board, as long as the readings are collected with the same grain orientation. There is, however, some correlation between lightness values along and across the grain.

Further uses or investigations of color matching of edge-glued panels using portable instruments would include customer acceptance of the concept and implementation for quality assurance programs, sourcing of lumber having desirable color characteristics, consumer preferences for greater color uniformity in the final product, better marketing of the darker colored material which makes up the majority of the raw material, presorting of material, and improved visual sorting techniques.

1 The Colormet handheld spectrum analyzer is no longer manufactured. For a list of comparable instruments. see (22).

2 Personal communication with the authors, Feb. 25, 1993.

3 Darrell Rich, personal communication with A. Pugel, Feb. 28, 1993.

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