COLORIMETRIC ANALYSIS IN GRADING BLACK WALNUT VENEER[1]

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ABSTRACT

Colorimetry techniques and automated data collection instrumentation were used to evaluate grade of black walnut veneer on the basis of sheet color and to identify and classify defects by size. Although color measurement readily quantifies veneer color, relatively large differences in color within sheets and between sheets within a veneer grade make the usefulness of overall color values in grading black walnut veneer doubtful under current grading practices. Differentiation between sapwood and heartwood is easily determined and may have commercial application in veneer clipping operations. Colorimetry techniques can detect defects with reasonable consistency, but accurate size classification needs more study.

Keywords: Colorimetry, black walnut veneer, defect detection, veneer grading.

INTRODUCTION

Hardwood veneer grading is based primarily upon the appearance of the veneer. This is especially true for black walnut (*Juglans nigra*, L.) veneer. The grade of walnut veneer and, consequently, its value are based upon many appearance factors. The major factors include color, uniformity of color, grain patterns, presence of defects (type, size, number, and location), amount of sapwood, and veneer sheet size. Visual veneer grading is limited by the fact that a grader can inspect only for features that he has been trained to recognize. Also, accuracy and consistency of grading vary with the grader's perception of these features, ex-

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perience, and other factors such as lighting and fatigue. Thus, walnut veneer grading is subjective and may vary widely from one grader to the next as well as between veneer companies. The process seems to work well enough on an industry-wide basis; however, it is nonstandardized, time-consuming, cumbersome, and produces variable results.

In any attempt to improve the current walnut veneer grading process, some means of removing the subjectivity from the current grading process must be sought. Ideally, such a process would be automated and would provide a numerical basis for comparing veneer flitch grades and the grades of various sheets of veneer within a flitch. An improved process would allow grades between companies to be compared and, perhaps more importantly, the subjectivity of attempting to select a set of similar grades of flitches for a customer from a warehouse of flitches or of attempting to color match the veneer from a previous order could be reduced.

Although automatic defect detection and grading systems have been developed for the lumber industry (Conners et al. 1983; Juvonen 1985; Thunell 1985), investigation of these systems showed that none are particularly suitable for use in the veneer industry because they do not analyze color, the most important walnut grading criterion. Color differences between defects and clear wood, between earlywood and latewood, and between sapwood and heartwood in walnut suggest that color analysis equipment may be suitable in the grading process. Color analysis equipment is presently available and in use in the paint and textile industries. Similar techniques to remove human subjectivity by quantifying color measurement may be able to satisfactorily analyze the grading criteria to determine walnut veneer grades.

COLOR ANALYSIS

A HunterLab D25A colorimeter and an interfacing computer for data recording and analysis were used to measure color variables of samples of various grades of veneer. To determine the feasibility of quantitative color analysis to effectively evaluate and distinguish between the various walnut veneer grading criteria, this system utilized what is known as the *L, a, b* color system. The *L, a, b* system is an opponent-type color system based on human perception of color as light-dark, red-green, and yellow-blue signals (Billmeyer and Saltzman 1981; HunterLab Process Monitoring and Control Division 1985; Kowlek 1982; Moslemi 1969). Opponent-type color systems presume that a color cannot contain two opponent colors simultaneously. For example, a color cannot appear red and green at the same time.

The lightness-darkness of a color is designated by an *L* value, where *L* ranges from 0, for black, to 100, for white. The *a* value represents redness (positive *a* values), or greenness (negative *a* values). Yellowness-blueness is shown by the *b* value, positive for yellowness and negative for blueness. The *L, a, b* color system has been used to analyze wood color and color differences (Moslemi 1967, 1969). It has been shown that the *L* scale is particularly useful for increasing the precision of measurements of dark colors (Billmeyer 1969), which makes the system appear to be suitable for black walnut analysis. The *L, a, b* system was used in this study to obtain quantitative color measurements.

MATERIAL PREPARATION AND PROCEDURE

Hardwood veneer is graded visually by a grader who generally selects three sheets at one-fourth intervals throughout the flitch. The sheets are chosen to represent the average veneer characteristics of the entire flitch. Thus, a flitch grade is assigned based upon observation of three somewhat randomly selected sheets. An automated grading process could ostensibly grade every sheet and produce a realistic profile of the flitch. However, for this study only the three-sheet samples were used. Sample sets of black walnut veneer provided by an Indiana veneer company permitted color information to be collected on the same material that the grader used to determine flitch grade. Each veneer sheet was graded at the time of manufacture and after drying. The material provided a good representation of the black walnut veneer grades recognized by this particular manufacturer and provided a close link between industry practice and research objectives.

Four flitch grades were sampled; each flitch grade had several subgrades. Except for the lowest grade (for which only one veneer sheet was studied), each flitch grade was represented by four sheets, two from a flitch at the high end of the grade and two from the low end of the grade; thus, thirteen veneer sheets from a total of seven flitches were chosen for study to represent the gamut of color shades and defects present in black walnut veneer of commercial quality. Since moisture content can affect the color of veneer (Brauner and Loos 1968), all of the specimens were equalized to a moisture content of approximately 7%. In addition, to prevent possible color change due to ultraviolet light, all specimens were kept covered when not being color processed.

For ease of handling, each sheet was cut into 6-inch-long specimens along the grain. The specimens of each veneer sheet were adhered to a stiff, plain white cardboard backing that could be firmly held onto an x-y coordinate table to provide precise point location over the colorimeter for data reproducibility. The colorimeter had a standard light source, C.I.E. illuminant C, and a C.I.E. two degree standard observer for consistent color measurement (HunterLab Process Monitoring and Control Division 1987).

Two colorimeter viewing port sizes were used in the study, ¼-inch square and ½-inch square; the latter was used for the majority of the data collection, and the former was used as a comparative check on accuracy and for defect assessment. The colorimeter was systematically moved in ¼- or ½-inch increments (matching port size) over each 6-inch veneer specimen to obtain L, a, and b values for an entire sheet. In this manner, color measurements could be used to reproduce the entire sample. All data were automatically recorded on computer disk files for subsequent analysis. The number of data point locations for each specimen ranged from 110 to 396, depending upon sheet width and nearness to the end of the veneer sheet (less than 6-inch specimen). A total of over 70,000 individual colorimeter (L, a, and b) readings were recorded and analyzed from 262 6-inch veneer specimens.

Repeatability of measurement was tested by collecting data on all locations within a sample and then repeating the measurements on the initial data location to see if time lapse or equipment shift had an effect on the readings. Overall, repeatability was very good; paired t-tests indicated that percent change was not significant for any color value. The L values exhibited the best repeatability over time, showing a maximum change of 2.5% from first reading to repeated end-of-test reading.

RESULTS AND DISCUSSION

Statistical analyses (primarily standard, computerized ANOVA statistical routines) and discriminate analysis techniques (Netter et al. 1982, 1985) were conducted to answer the following specific questions about colorimetric grading of black walnut veneer:

1) Are various veneer sheets within a veneer grade similar in color, and are there significant differences in mean color between the several veneer grades?
2) Can colorimetry techniques consistently distinguish sapwood areas from heartwood areas?
3) Can colorimetry techniques correctly identify defects in veneer, and, if so, how accurate is the identification with regard to defect type (knot, hole, or split) and size?

Comparison of within and between veneer grade color

The importance of heartwood color in walnut veneer suggests that colorimetry measurements should provide a means of veneer grade separation. Veneer sheets within a grade should have a similar color, and all areas within a sheet should likewise have a similar color. Mean color should be alike among sheets within a grade and different between grades. An analysis of variance was performed to examine three sources of color variability for each of the three color readings (*L*, *a*, and *b*). The three sources of variation are (1) grade, (2) sheets within grade, and (3) individual specimens taken from each sheet. For this analysis subgrades were used in place of the actual flitch grades, giving seven different subgrade values (one for the lowest flitch grade and both a high end and a low end subgrade for each of the other three flitch grades).

The analysis presented in Table 1 shows statistically significant sheet to sheet variation and specimen to specimen variation for all three color values. A consequence of the large sheet to sheet variation (within grade) is that the flitch grades are not distinguishable on the basis of these color values. Stated another way, the samples making up a veneer sheet do not have the same average color, and hence color differences between grades are not significant, i.e., not discernible.

The magnitude of the variation would indicate that colorimetry is not a satisfactory tool for use in grade discrimination. Also implied is the indication that perceived color differences between grades are not real, or that color is often overshadowed in grading by other factors. The color differences between the high end of one grade and the low end of the next higher veneer grade, as was measured in this study, are rather subtle. These results are similar to those shown by Moslemi (1967) and Phelps et al. (1983). Thus quantitative color measurements are of limited usefulness in grading black walnut veneer.

Delineation of sapwood and heartwood

Logically, heartwood color is more important than sapwood color in black walnut veneer; sapwood material is usually removed in secondary manufacture. The color difference between sapwood and heartwood (Anon. 1956; Brauner and Loos 1968; Kowlek 1982; Phelps et al. 1983), suggests that color information can delineate between the two. To test this hypothesis, sapwood and heartwood regions were visually delineated on each sheet. Color values measured on the samples with ½-inch viewing port were grouped into sapwood and heartwood for each sample based upon the initial visual evaluation. For each type, means and standard deviations were calculated for each of the *L*, *a*, and *b* color values. The mean color values were tested by a standard *t*-test, (Netter et al. 1982, 1985).

The results are shown in Table 2; all of the color values are significantly different between sapwood and heartwood at the 0.01 level of probability. Phelps et al. (1983) obtained similar success in delineating black walnut sapwood and heartwood. Naturally, sapwood is lighter in color than heartwood; its redness-greenness value is higher, implying that heartwood is more red than sapwood. Likewise, a higher yellowness-blueness value for sapwood attests to its being more yellow than heartwood. The color values coincided with the visual assessment quite well. The value of this result lies not with the fact that sapwood-heartwood delineation can be made by colorimetric tactics, since this is a rather easily performed visual process. The value lies rather in applying colorimetry to the grading of an entire flitch, or incorporating it into a manufacturing process whereby sapwood and heartwood can efficiently be identified and separated in an automated clipping process. In this way much more efficient evaluation and utilization of veneer could be made.

Ability of color information to detect and identify defects

Defect detection and identification are probably the most important criteria for grading black walnut veneer other than color. The location, type, and size of defects present in the veneer are major factors in determining veneer grades. In general, defects exhibit different colors than clear wood. Knots, checks, and splits tend to be darker than clear wood, whereas decay tends to be lighter and holes allow background material to be seen through the veneer (Conners et al. 1983; Juvonen 1985; Thunell 1985). These characteristics of defects suggest

TABLE 1. *ANOVA—of, between and within grade color.*

	Degrees of freedom	*F* values		
		L	*a*	*b*
Grade	6	0.819	0.402	0.750
Sheet	6	52.807**	2.633*	16.731
Specimens	249	144.17**	151.03**	147.58**

Note: Sheet is nested within Grade; Specimens are nested within Sheet within Grade.
** Significant at the 0.01 level; * Significant at the 0.05 level.

that color information can be used to determine the presence of defects. *L* values should be a preferred color measurement since the color values for knots and splits were expected to be lower, i.e., darker brown, than clear wood. The white background material was expected to cause *L* values for holes to be higher than those for clear wood and for *a* and *b* values to be approximately zero. The hypothesis that color values can be used to detect defects in walnut veneer was tested by comparing color values for clear wood areas to those for immediately adjacent areas containing various defects.

The ability to detect defects and identify their nature and size turned out to be a difficult task. Two port sizes were used, ½-inch square and ¼-inch square, for comparison. Logarithmic transformations of sums of squares and discriminate analyses were required to obtain meaningful results.

There was a large degree of color variation within the various veneer sheets, so much so that any between sheet variation was masked. As a result, even though areas containing defects, or the defects themselves, appear different in color than surrounding clear wood, the defected areas may not be significantly different in color from the color value determined from an analysis of an entire sheet. Thus, it was hypothesized that defect detection could be accomplished only by comparison of two closely adjacent areas, one with a defect and the other clear. Further, it was decided to use two different-sized areas for comparison. One size area contained data points that included the viewing-port-sized test point (containing either a defect or an area of clear wood) and one row and one column on each side of the test point, providing a 3 × 3 matrix of 9 data points for analysis. The second size area utilized data points that were within two rows and two columns of the test point, providing a 5 × 5 matrix of 25 data points for analysis. The two matrix sizes were studied since some defects are not clearly delineated by distinct color changes and a larger background area could enhance defect detection. Hypothetically, a defect centered within a matrix of evaluated points should appear markedly different in color from surrounding wood when compared to the color of a centered, nondefected point relative to its surrounding matrix of color evaluated points, regardless of localized color shades within a veneer sheet.

To measure the variability of color around a defect, the median color value for the 9 or 25 test points was calculated. Then the sum of squares of the deviations of individual points from the median was computed. To stabilize the variability of these sums of squares, analysis was performed on the logarithms of these quantities.

Thus, sums of squares for *L*, *a*, and *b* values were calculated for the two sets of test points for each defect sample studied; one test point set contained a defect, while the other con-

TABLE 2. *Comparison of sapwood and heartwood color.*

Color value	Sapwood		Heartwood		*t* statistic
	Mean	Standard deviation	Mean	Standard deviation	
L	65.442	5.774	53.902	2.940	40.938**
a	3.141	4.126	3.428	3.228	−7.220**
b	13.383	2.533	11.709	1.642	27.383**

** Significant at the 0.01 level.

TABLE 3. *Classification of defects and clear wood with all transformed color values (using one row and one column around the test point, ½-inch port).*

Actual classification	Analysis classification			
	Defect		Clear wood	
	Number	Percentage	Number	Percentage
Defect	51	78.46	14	21.54
Clear wood	10	15.38	55	84.62

tained clear wood for comparison. The test points were selected such that all of the surrounding, contiguous data points contained only clear wood. The sums of squares calculated for test points with a defect were expected to be significantly higher than the sums of squares of test points with clear wood due to the differences in color between defects and clear wood. If the sums of squares could be shown to be consistently different, it was reasoned that defects could be detected by colorimetric techniques. Paired *t*-tests of the log transformations were performed. The means of the logs of the sums of squares were significantly higher (significant at the 0.01 level of probability) than those for clear wood for all color values. Although these calculations are rather complex, the procedure does permit the detection of defects and can readily be programmed for a PC.

Discriminate analyses were performed on the logarithms of the sums of squares to evaluate not only the ability of the above procedure to consistently detect defects, but to evaluate the accuracy of detection as well. Discriminate analysis is a statistical technique that provides a numerical evaluation of the percentage of defects actually identified correctly as defects and, also, the percentage of nondefect areas properly classified as clear areas. Thus, the ability of the technique to correctly, or incorrectly, spot a defect when one exists and to not spot a defect when there is none present can be assessed. The analyses were performed using lightness-darkness, redness-greenness, yellowness-blueness, and the combination of all three values as variables.

Table 3 shows the results of the discriminate analyses for the three color values calculated using one row and one column data around the test point. The table presents the number of "defect" areas properly identified (for example, 51 defects; i.e., 78%) and the number of "defect" areas improperly identified as clear wood (for example, 14 defects; i.e., 22%). The results are satisfactory for individual color variables, but the combination of all three color variables (Table 3) exhibits the best results, correctly identifying 78% of the defects and 85% of the clear wood areas. Transformed yellowness-blueness values are able to distinguish defects as well as using all three variables but are slightly less useful in consistently identifying clear areas. Transformed lightness-darkness and redness-greenness values give similar results. Both correctly identified defects 69% of the time and clear areas somewhat over 70% of the time. These results show that transformed color values can be used to detect defects in black walnut veneer and that the combination of all three transformed values produces the best results, correctly classifying more defects and clear wood areas than any of the individual color values. A lacking, but interesting and valuable, piece of information would be a similar analysis of defect detection using the present visual grading system. One would like to think that the visual graders are keen-eyed; however, studies of dimension lumber mill graders (Huber et al. 1985) indicate that accurate defect detection and assessment over time are not as good as desired and are very similar to the results found in this study.

Discriminate analyses were also performed on transformed color values calculated using two rows and two columns around the test point. Overall, results for classification using these data were not as good as results calculated with only one row and column.

Defect detection by defect type and defect size

Although colorimetric techniques can be developed to detect defects and consistently discriminate between clear wood and defects, it