THREE METHODS OF DETERMINING HARDNESS OF INCREMENT CORE SEGMENTS[1]

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ABSTRACT

Three methods were devised to measure the hardness of small wood samples: a sanding test, a diamond point indentation test, and a saw blade tooth deformity test. Based on stepwise multiple regression analysis with 19 and with five important independent variables, the sanding test was best, followed by the indentation test. The saw blade test gave poor results and was discarded. The order of important independent variables among the four plots analyzed individually showed a nearly perfect relationship with the sanding test, but no consistent order of the variables among plots for the indentation test. Again this indicated that the sanding test was best.

Additional keywords: *Quercus rubra*, hardness tests, sanding, tool wear, sawing, machining.

Observations on the U. S. Forest Service's Fernow Experimental Forest at Parsons, West Virginia, indicated that lumber sawn from trees grown on limestone soils dulled saws faster than did lumber from trees grown on sandstone soils. This observation set in motion a project to learn if wood from limestone soils actually had properties that dulled saw blade teeth faster than wood from sandstone soils, and if so, to learn what wood properties were responsible.

Preliminary to the main study, a method had to be selected, or developed, to test the "hardness" of wood. The method would need to be suitable for testing small wood samples because increment cores would be used rather than lumber due to the relatively large number of trees needed and the difficulty of obtaining lumber from trees from the sites selected.

The purpose of this paper is to present the procedure used in developing a method for testing the "hardness" of small wood samples.

EXPERIMENTAL

Four areas in northern West Virginia were selected for study. They were in even-aged hardwood stands with abundant

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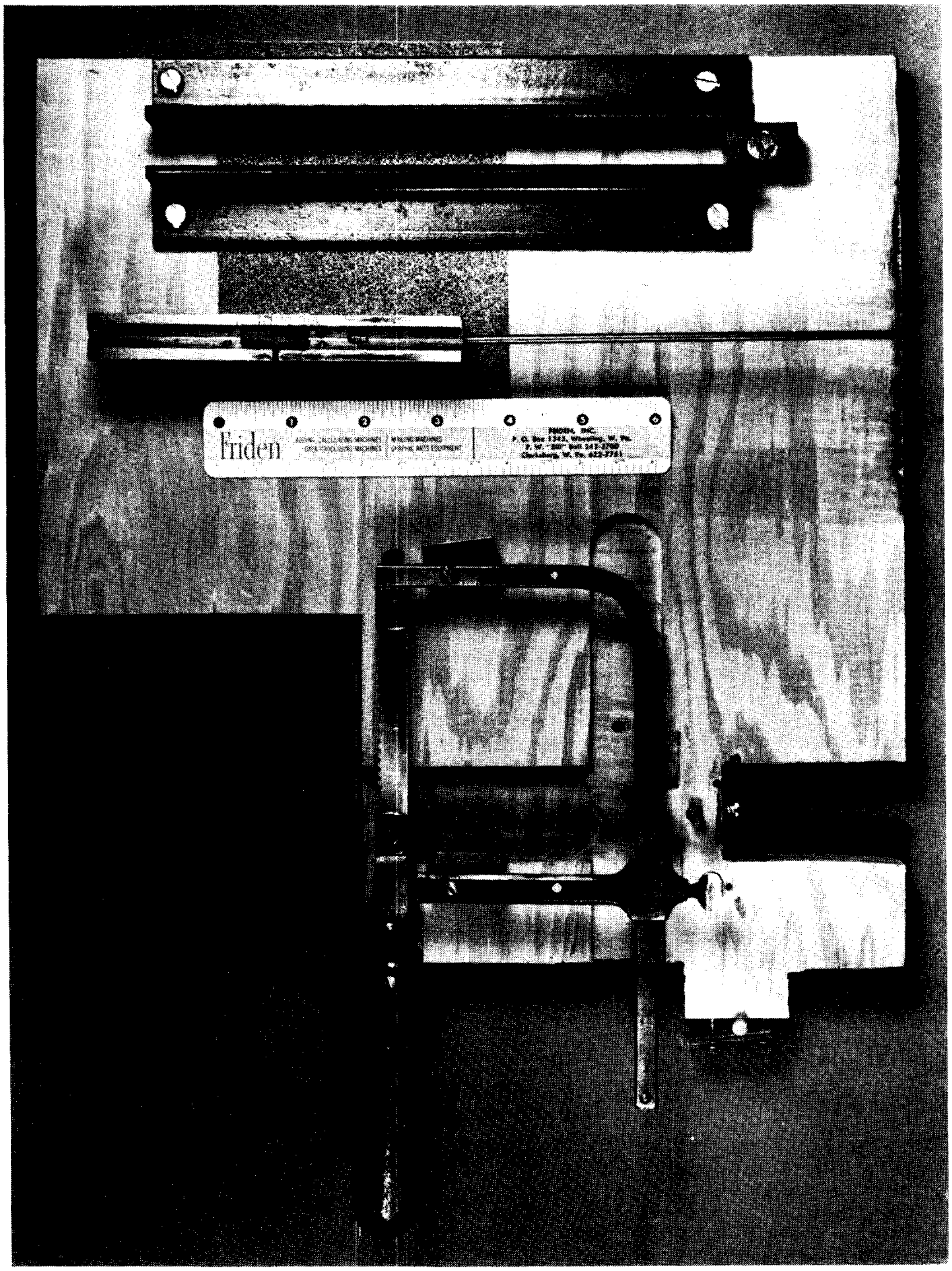

FIG. 1. Sanding test apparatus (top) and saw blade test apparatus (bottom).

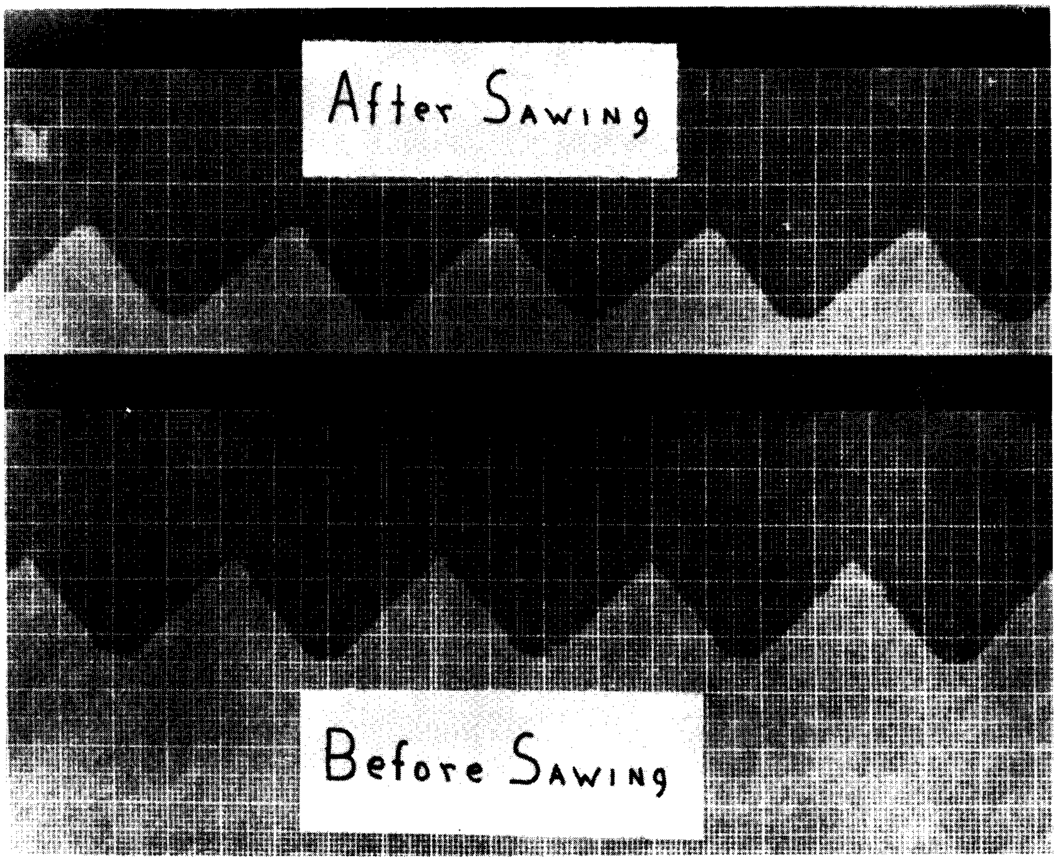

FIG. 2. Photograph of saw blade images taken before and after sawing. The smallest units are in millimeters.

northern red oak (*Quercus rubra* L.) ranging in age from 35 to 60 years. Two areas were on limestone-derived soils, and two were on sandstone-derived soils. On each rock type, one area was moist and the other dry.

Twenty dominant red oaks were randomly selected on each of the four areas. Two increment cores, 5 mm in diameter, were taken near d.b.h. from each oak. The two cores extended to the pith, and were on the same radius about two inches apart vertically. One core was ashed for elemental analysis. From the other core, a six-ring segment, having uniform ring widths, and including the 20th to 25th annual rings from the pith was selected for testing for hardness.

Hardness and abrasive resistance were considered to have the greatest correlation with tooth wear. Hardness is defined as resistance to indentation and is commonly determined by the Janka test, involving resistance to indentation using a 0.444-inch-diameter steel ball (A.S.T.M. 1965; USDA Forest Products Lab. 1974). Abrasive resistance refers to the ability of a substance to resist the wearing away of a surface when rubbed across the surface of another substance (Hechtlinger 1959).

Three methods were finally devised to test the small wood samples: (1) a sanding test, (2) a diamond point indentation test, and (3) a saw blade test. The first one, sanding, was considered to measure abrasive resistance, and the others to measure hardness. However, all three will be called hardness tests for simplicity in presentation.

A *Sanding Test* was developed which used a four-inch width of aluminum oxide sanding paper, grit size 80 D, as the abrading surface, over which a weighed increment core segment was drawn. The placement of the sandpaper, a guide, and the specimen holding apparatus weighing 485 grams may be seen in Fig. 1. The increment core segment with wood fibers perpendicular to the sanding surface was pulled across the sandpaper 100 strokes per segment, or 400 inches of total abrasion. A fresh sanding surface was used for each stroke. The percentage of oven-dry weight loss by sanding was used as a measure of hardness. The greater the weight loss, the softer the wood was considered to be. This test, as well as the other two, was made with the samples at a uniform moisture content, oven-dry at the start of each test.

A *Diamond Point Indentation Test* was used which was considered to produce similar, but not identical, results as the standard Janka test for hardness. Each segment was mounted on a wooden block, sanded to obtain a smooth, flat surface, and brought to a uniform moisture content in a desiccator jar in the testing room. The sample was then placed on the Tukon Hardness Tester, Model M.O. (Freudenthal 1950), and with a 100-gram load, two diamond-shaped indentations were made in the transverse plane of the summer wood of each of the six annual rings of each segment. The distances from one apex to another across the indentations were measured using a vertical illumination system with a 40× objective and a 10× eyepiece. Indentation lengths could be measured from 5 to over 1,000 microns. The distance across the indentations should be inversely related to hardness.

A *Saw Blate Tooth Deformity Test* was devised using as a basis the fact that the harder the wood the greater would be the deformity imparted to the teeth when drawn across the wood. Saw blades were made from 0.012-inch-thick 1100 aluminum alloy (A.S.T.M. Standards) having 99% minimum aluminum. The teeth of the blades were formed by filing while being held in a form. The finished blades were tensioned as uniformly by hand as possible in a jeweler's saw frame, this assembly with weights weighing approximately 180 grams. The tests were made in the summer wood of the 25th ring from the pith for each sample. A device was made to hold the core segments and guide the saw (Fig. 1). A total of 150 strokes, pulled in one direction only by hand at a uniform velocity across the tangential surface of the 25th ring, was made using a separate blade for each sample. The length of each stroke was about 40 millimeters. The technique used to determine tooth deformation involved photographic double exposures before and after the test. These are shown in Fig. 2. The difference in the number of units representing teeth heights before and after the test indicates the amount of saw teeth displacement, or the hardness of the wood.

TABLE 1. *R^2 values used as a criteria in selecting usable hardness test for red oak increment core segments*

Test	R^2 of twenty variable equation	R^2 of five variable equation
Sanding	0.8491	0.8101
Indentation	0.4144	0.4002
Saw blade	0.3771	0.2301

Multiple regression analyses with the stepwise elimination of variables were used for evaluating the three hardness tests. Nineteen independent variables were involved in the testing. They included: rock type, site index, specific gravity, sample length, percent latewood of sample, percent latewood of 25th year, vigor index, rings per inch, width of 25th year; and the elemental constituents as percentages of the elemental ash analysis: SiO_2, Fe_2O_3, Al_2O_3, $CaCO_3$, $MgCo_3$, MnO, NiO, CuO, Cr_2O_3, and PbO.

In addition, plot-by-plot stepwise multiple regression analyses were run to help evaluate the three testing methods. The percentage of variability explained (R^2) by an individual multiple regression equation was used to evaluate the reliability of the

TABLE 2. *Sanding test statistical data of the plot-by-plot multiple regression analyses used as a criteria in hardness testing*

Plot	R^2	Order of importance of variables[a] Most			Least
Sandstone, dry site	0.9518	R**	S**	V	Ca
Sandstone, moist site	0.8366	R**	S**	V	Ca
Limestone, dry site	0.8565	R**	S*	Ca	V
Limestone, moist site	0.7028	R**	S	V	Ca

[a] R = rings per inch
S = specific gravity
V = vigor index
Ca = percent $CaCO_3$

** = significant at 1% level
* = significant at 5% level

three hardness tests, with the greatest R^2 value used to indicate the best method. An R^2 value of 0.50 was considered an acceptable minimum, as is commonly used in testing biological data. Also, the order of importance of the strongest independent variables and their similarity among plots for each test was used to complement the results of the initial multiple regression analyses. The basis for such a comparison is the Friedman nonparametric test (Siegel 1956); however, because of the highly significant nature of the order of the variables, the actual tests were not necessary.

RESULTS AND DISCUSSION

The results of the multiple regression tests for the original 20-variable and the five-most-important-variable equations are presented in Table 1. The sanding test clearly had the greatest R^2 in both equations, exceeding 0.8 in both instances, and was well above the 0.5 R^2 requirement for an acceptable hardness testing method. The indentation test with R^2 values of 0.4144 and 0.4002 was considered marginal, but the saw blade test with values of 0.3771 and 0.2301 indicated such poor reliability that it was dropped from further consideration.

Plot-by-plot multiple regression analyses were run for the sanding and indentation tests (Tables 2 and 3). The R^2 values for the sanding test remained high, ranging from 0.7028 to 0.9518. Also, the R^2 values for the indentation test were below the arbitrary 0.5 requirement, ranging from 0.3489 to 0.4366. Thus the plot-by-plot and initial multiple regression analyses were in close agreement.

Finally, the individual variables were studied to determine consistency in order of importance from plot to plot. Table 2 shows close agreement of the important variables for the sanding test. The same four variables were most important in each of the four plots, and in three of the four plots the order was exactly the same. In studying the order of important variables in the indentation test, the five explaining the greatest percentages of variability were used (Table 3). The same five variables were most important in each of the four plots, but there was no uniformity of the arrangement of the variables from plot to plot. The greater uniformity of order of importance of variables in the sanding test as compared with the indentation test, again points to the sanding test as the better method of determining wood hardness.

TABLE 3. *Indentation test statistical data of the plot-by-plot multiple regression analyses used as a criteria in hardness testing*

Plot	R^2	Order of importance of variables[a] Most				Least
Sandstone, dry site	0.3551	L	S	Ca	Ni	Pb
Sandstone, moist site	0.4016	S**	Ni	Pb	Ca	L
Limestone, dry site	0.4366	Ca	Pb	S	Ni	L
Limestone, moist site	0.3489	Ni	S	L	Pb	Ca

[a] L = percent latewood
S = specific gravity
Ca = percent $CaCO_3$
Ni = percent NiO
Pb = percent PbO

** = significant at 1 percent level

Originally the length of the increment core segments was not included in the sanding test analysis. However, a curvilinear relationship developed because of a constant weight load and varying sample lengths. Therefore length was included as an independent variable. The sanding test could perhaps be improved by using samples of equal length, and square in cross section rather than round.

CONCLUSIONS

Methods for assessing hardness were devised for use with small wood samples. The most appropriate test was a sanding test which, on the basis of stepwise multiple regression analysis and ranking of independent variables, appeared to be a better method than either an indentation or saw blade deformation test. Possible improvements in the method could include using wood specimens of equal length rather than having equal numbers of annual rings, and square in cross section instead of round as are increment cores.

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