DETERMINATION OF "BRINELL" HARDNESS OF TONEWOOD

A new portable hardness test has been developed for wood by modifying a machinist's automatic centre punch. Preliminary results on tonewood, i.e. spruce and maple, suggest that maple is twice the hardness of spruce and that the "dynamic" hardness is twenty times the "static" value. Further work on a variety of species is needed. Also needed is a statistical correlation with other wood properties to assess its usefulness.

INTRODUCTION

The measurement of hardness in Timber Technology [1] is done by recording the load required to cause a ball to be forced into the timber to a depth of half the diameter. The steel ball has a diameter of 11.5 mm giving the projected area at the diameter of 1 cm^2. This test does not appear to be an important one in the timber industry except for comparative purposes. Published values indicate that the hardness is similar on the radial (RL) and tangential (LT) surfaces and higher on the end surface (RT).

Brinell Hardness [2] is an arbitrary test widely applied in Metals Technology and has been empirically correlated with the properties and behaviour of metals and alloys and is used with great confidence. It is defined as the resistance to penetration of a 10 mm diameter (D) hardened steel ball under a load of 3000 Kg (500 kg for soft metals) applied for 15-30 seconds. The diameter (d) of the impression made is measured and the load divided by the indentation surface area gives the Brinell

Hardness Number in Kg/mm^2. It is more rigorous to use the projected area but usage has prevented this being adopted in this case. The test is a static one and the d/D ratio usually falls between 0.25 and 0.5. The modern standard laboratory test which implies use on steels, uses a load of 30 Kg and a ball diameter of 2 mm. Changes in load and ball diameter are allowed to suit the soft metals. The test was developed in the steel industry in Sheffield, England.

For metals there is an approximate relationship between BHN and the yield strength i.e. BHN = 3.1 x Yield Strength. The yield strength is that stress beyond which the metal does not fully recover the imposed deformation i.e. there is some permanent change in shape on removal of the load. Metals at room temperatures, except lead, do not show visco-elastic behaviour as do wood and some plastics and PVA glues. Speed of testing, within limits, therefore has no effect. Visco-elastic materials will have a "static" or "relaxed" value of hardness and a "dynamic" or "unrelaxed" value. The latter will be higher and the difference will be an indication of the degree of the visco-elastic effect.

It was thought that a less robust test than that used in the timber industry, and one that makes the test quantitative, might allow correlation with other tone wood properties with some benefit to makers. A "Brinell" type test is thought to be a useful addition. Once understood, the test is easily applied.

EXPERIMENTAL

A method was developed for the determination of the indentation hardness of wood modelled on the method used for metals. This was done to minimise the damage to the wood surface and allow the object of the test to be used e.g. a bridge. Both the static and the dynamic aspect of the test were considered.

The static loading system consisted of a hardened steel ball i.e. a ball bearing 11.115 mm dia. (actually 0.4375 ins.) mounted in an aluminium block attached to a steel stirrup from which weights could be suspended. In this case a total of 13.921 Kg (including the weight of the stirrup) was applied to the specimen.

The dynamic loading system consisted of the same size steel ball supported at the end of the redesigned shaft of an "Eclipse" No 171 automatic centre punch. (an American equivalent with the same specification appears in the Doall catalogue, No 606555) The ball in this case was left free but it could be attached with superglue. The impact could be changed by varying the tension in the punch spring; maximum tension was used in these trials.

Sample preparation and indentation measurement was the same for both methods. The wood surface was planed flat and smoothed with 15um abrasive paper to a fine finish, which in this case amounted to a polish. The indentation diameter was measured with a millimeter scale divided in 1/10 ths. viewed through a magnifier avoiding parallax errors. Suitable small folding magnifiers are made for inspecting textiles and stamp perforations. An accurate scale is needed. The edge of the indentation was made visible by rubbing the surface of the sample with typewriter carbon paper (not pencil carbon) supported on a flat block. This implies that the sample has been planed flat on the surface to be tested. Only round impressions are accepted and usually the average of the nearest two out of three for any one determination.

The "Brinell" hardness is calculated using the formula:

$$H_B = 2F / [\pi D^2(1- \sqrt{1-(d/D)^2})] \qquad [1]$$

where F is the load applied, Kg,

D is the ball indenter diameter, mm,

d is the indentation diameter, mm.

Another formula using the projected area and giving a slightly different value is:

$$H_M = 4F / \pi d^2 \qquad [2]$$

This formula is used to express another hardness, the Meyer Hardness, used in metal studies. No parallel can be drawn between hardness measurements on metals and those on wood. If hardness measurements are to be useful, a convenient method is required that is sensitive to perceived differences within and between wood species. This would be helped if a correlation could be established between indentation hardness and other wood properties. It has been mentioned in general and it is to be expected that hardness would increase with rise in density.

The Static Test.

The ball indenter attached to the stirrup and weights was gently lowered onto the specimen supported on a stout plank clamped to the bench and left for 30 minutes for most of the relaxation to occur. The weights and indenter were carefully removed and the diameter measured as described above. A distorted indentation is discarded and the test repeated. Where the orthotropic nature of the wood has given an elliptical impression an average of the major and minor diameters should be taken. This effect has not been noticed so far in the tests done here. It must be admitted that only a few samples have so far been studied to establish the method. The hardness was calculated using equation [1].

The Dynamic Test

The modified "Eclipse" punch was set to give maximum impact and placed on the ball indenter resting on the sample surface. An indentation was made by depressing the punch and the indentation diameter measured as described above. The calculation of hardness was not possible until the load applied by the punch was known. This was found by a calibration procedure.

Punch Calibration

The punch was calibrated by using an aluminium test bar. An aluminium bar was used because it would show no relaxation effect in this test and the impression diameter would be easily read. The hardness of the bar was determined with a standard Vickers Hardness machine using a standard method for this metal which was a load of 20 Kg and a ball diameter of 2 mm. The impression diameter was found with a measuring microscope which is part of the machine. The hardness of the aluminium bar was read from prepared charts. Having established the hardness of the aluminium bar with several indentations, impressions were made with the punch and the diameters recorded. The carbon paper was not needed in this case as the edge of the impression was clearly defined. The measurement method above was used although the microscope on the Vickers machine would have been more accurate. It was thought that the precision of this work did not demand a greater accuracy. The indentation made by the 2 mm ball, however, had to be measured accurately. With the knowledge of the hardness of the aluminium and the diameter of the indentation made by the punch the load being applied was found by rearranging equation [1]. The average indentation diameter for the aluminium (18 determinations) was 0.556 mm giving a hardness of 80.80 Kg/mm^2 using equation [1]. The indentation diameter using the punch was 2.10 + 0.05 mm (16 determinations) and from equation [1] the load was found to be 282.40 Kg. The load at other settings of the punch could be found in this way. The punch would have to be marked appropriately. This load value was used on subsequent tests on wood samples.

RESULTS

By happy coincidence, with these parameters, indentation diameters fell within the range of the equipment assembled, between 3 and 6 mm. Table [1] gives some preliminary results of tests on samples of spruce and maple, taken on the LR plane.

Table [1]

Test	Spruce sample No	Density Kg/m^3	H_B Kg/mm^2	Maple sample No	Density Kg/m^3	H_B Kg/mm^2
Static	3	414	0.643	2	564	1.108
	4	400	0.608	3	650	1.029
Dynamic	3		10.6	2		20.6
	4		10.8	3		21.1

Differences are to be expected on the three principal planes. An example of this difference for dynamic hardness is shown in Table [2].

Table [2]

Sample	Density	Plane LR	LT	RT
Spruce	?	12.26	14.28	21.66 Kg/mm^2
Maple	672 Kg/m^3	17.98	22.76	33.44 Kg/mm^2

The values in these two tables were calculated using equation [2]. An extensive program of tests needs to be undertaken to find the correlation with density, ratio of early to late wood, pore density, etc. and whether a modified test would be more appropriate. The dynamic test was the easier to apply.

DISCUSSION

The hardness test does not seem to be much used in the timber industry; in fact the "thumbnail" test would seem to have been as much used. Among the questions requiring answers would be the usefulness of the test to the violin maker. This could only be answered after extensive work establishing useful correlations. Instrumental considerations such as the most appropriate load or loads for the range of hardnesses encountered would need to be dealt with. Tests need to be done on sufficiently thick pieces, ribs would be too thin, bridges and bassbars would be suitable; and at least one indent diameter away from an edge or another indentation. It is not expected that the damage extends far from the impression. It is not known how important the d/D ratio is for tests on timber. The constancy of results on one specimen with different d/D ratios would determine the acceptable range. A very uniform sample would be required for this. The size of the indentation is important in that it must cover a number of annual rings in soft woods. It may not be so important in hard woods.

Calibration of the "Eclipse" punch presents a potential problem. Aquiring a calibration bar of known hardness is probably the best way of determining the impact load for a given punch and ball setup. If an "Eclipse" punch and ball as used here, is adopted the value above would serve to a first approximation. Only the spring constant and length of the loading spring would have to be within close limits. The design of the modified shaft would not be critical but the weight would have to be 9.105 gms which includes the circlip but not the ball, as used in these experiments. The actuating spring weighs 0.355 gms, 1/3 rd, of which contributes to the impulse. The shaft should be hardened to 62 Rc. to prevent "mushrooming". The existing shaft could be used if a ball adapter were fitted to the taper on the lower end.

The hardness values obtained so far indicate that maple is twice as hard as spruce both in a static and a dynamic test; also that the dynamic value is twenty times the static value. No real conclusions can be drawn from the density values given. The hardness on the RT plane appears to be higher than the other two as is generally understood; the RT plane is preferred as the exposed surface in flooring. Of the other two, the hardness on the LT plane is higher than that on the LR plane.

REFERENCES

[1] Wangaard F.F., "The Mechanical Properties of Wood", (J.Wiley and Son, N.Y. 1950) pp312-315

[2] O'Neil H., "Hardness Measurement of Metals and Alloys", (Chapman and Hall, London 1967) 2nd Edition, Chap.3, p 47

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