THE HARDNESS TEST BY STATIC BALL INDENTATION FOR WOOD, ESPECIALLY FOR NARA-WOOD UNDER VARIOUS MOISTURE CONDITIONS

By

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木材，特にナラの生材，氣乾材および全乾材の硬さ試驗

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INTRODUCTION

It is well known that the hardness is an important property in connection with wood working and using. But there are various methods for measuring the hardness of wood which are being argued even now. As the standard testing procedure, the two methods of JANKA and of BRINELL are generally used.[1),2),3),10)]

The test of JANKA hardness involves the determination of the force required by static loading to embed a steel hemisphere 11.284 mm in

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diameter completely in the wood. About this method, F. SEKIYA[9] has stated: "It is quite natural that the fracture takes place on the surface of indentation. Pictures in his work, evidently show the line of fracture due to excessive penetration, in other words, these pictures show that his hardness test was not carried out rationally."

In the BRINELL method, a hard steel ball, usually 10 mm in diameter, is pressed under a known load into the specimen, and the hardness number is taken as the stress per unit of spherical area. The testing procedure (1949) determined in "Japanese Engineering Standard" is based on this method; the load is 30 kg as standard—10 kg for a very soft material and 50 or 100 kg for a very hard one. N. PARRAY's[7] critical observation upon this method is the following: "The application of the various loads for measurement of impression makes the method uncertain and does not give unifying comparative basis." F. SEKIYA[9] has stated too: "It is evident that hardness numbers obtained by means of different applied loads are not comparable with each other."

In this report, by using specimens of Nara-wood (*Quercus crispula* BL.) in various moisture conditions, the deformation of wood due to static ball indentation was observed; relations of the BRINELL hardness number to the applied load, width of annual ring, specific gravity and moisture content were also carefully studied.

The work reported here was done under the direction of Professor Masayuki OHSAWA, to whom the author owes thanks for his invaluable advice and encouragement.

MATERIAL AND METHOD

The material used was Nara-wood grown in Ashibetsu district in Hokkaido. The test blocks were made from disks, 15 cm in thickness, which were taken from four Nara-trees at 4 m height above the ground in each case. The numbers of annual rings of the disks were 180 to 360. The dimensions of the test block are 5 by 5 by 2.5 cm as shown in figure 1.

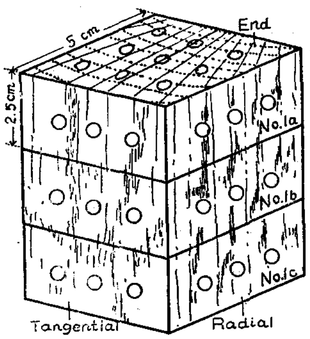

Fig. 1. One group of hardness test blocks. *No. 1a* was tested in green condition, *No. 1b* being air-dried and *No. 1c* oven-dried.

Twenty-one tests were made on each specimen, nine in one end, three on each of its radial faces and three on each of its tangential faces.

One-third of the individual specimens were tested in green condition (above the fiber saturation point), another one-third were air-dried and the remainder oven-dried.

The testing machine used in the present study was "*Mokuzai-Katasa-Shikenki*" (machine for testing hardness of wood) made by *Tokyo Koki Seizojo.* This machine, as shown in figure 2, consists of an anvil A for supporting the specimen S, and elevating screw E, a handwheel H and handle M (miniature) for raising the specimen to the desired height, a hard steel ball B 10 mm in diameter, a dial gage (1/100 mm) D for measuring the indentation depth during the test, and a lever system for applying a load by a weight W at the end of it. The range of loads is from 10 to 150 kg and by a special method the application of 5 kg load is possible too. A load of fixed amount is applied to the specimen through the ball B by weight W.

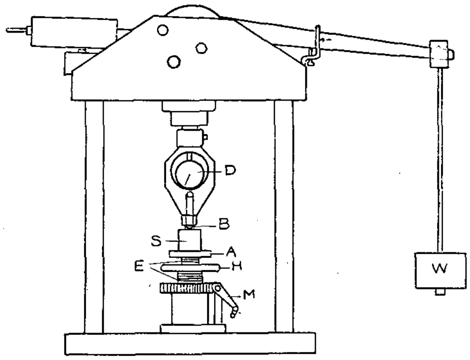

Fig. 2. Machine for testing hardness of wood.

In this test, the depth of indentation was measured when variation of the dial indicator under a dead load in one minute became unrecognizable by the naked eye. If the rate of variation of the depth of indentation resulting from a dead load decreases during successive equal intervals of time, it may be assumed that further variation will eventually cease: under such condition, the depth keeps stability. The method described above was used for the purpose of measuring the depth under such condition. In this test, the time during which a load was applied were approximately 5, 10 and 15 minutes in oven-dried, air-dried and green wood blocks, respectively.

The Brinell hardness number (H_B) is thus

$$H_B = \frac{P}{\pi D h} \quad \text{kg/mm}^2$$

where P, D and h are the load in kilograms, the diameter of the ball 10 mm, and the depth of the impression stated in millimeters, respectively.

When the green or oven-dried wood blocks were tested, in order to prevent evaporation of moisture in the wood or absorption of room humidity during the test, the anvil, the specimen, the steel ball and the dial gage were covered with a sheet of transparent polyvinyl film.

EXPERIMENTAL RESULTS AND DISCUSSION

1) Relations of the Indentation Depth and the BRINELL Hardness Number to the Applied Load.

It is obvious that, when a steel ball is pressed into the flat surface of the test block, the depth of indentation is increased by increasing the applied load. An example of relation between the depth and load when the ball is penetrated into the wood surface until its maximum section as in JANKA's method is shown in figure 3. This test was carried out on the end surface of air-dried Nara-wood by using the Universal Testing Machine for Wood with a ball 10 mm in diameter. The relation varies with the rate of ball indentation as shown by (*A*) or (*B*) in figure 3.

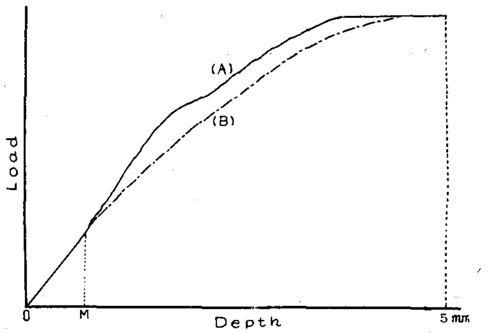

Fig. 3. Relationship between depth of indentation and load. Rate of ball indentation, (*A*): 0.5 mm per min., (*B*): 5 mm per min.

In the diagram, within the range of *O*-*M* the relations between them are shown as a straight line. In view of the present experiments, it seems that the point *M* was generally about 0.7 mm in depth of indentation.

In order to find the relation of the depth of indentation to the corresponding applied load within the range described above, a series of experiments was carried out as follows. A steel ball was pressed into the surface of the test block, and the depth of ball indentation was noted at every 10 kg of applied load on the end surface, and at every 5 kg on the side surfaces.

The moisture conditions of the materials were green, air-dry and oven-dry. The depth and the hardness number corresponding to the applied load are shown in table 1; the relations of the depth to the applied load are shown in figure 4, and the relations of the hardness number to the applied load are shown in figure 5. Each point in the diagrams was obtained from the average of 27 impressions in the end surface and from the average of 18 impressions in the side surfaces.

In table 1, h is the depth of indentation in 1/100 mm, Δh is the difference of the depth h between successive equal increases in the applied load, and H_B is the BRINELL hardness number in kilograms per square millimeter. If Δh is constant, relation between load and depth h is given in a straight line. Table 1 shows that the average Δh is very nearly constant in each case, and figure 4 indicates the approximately linear

Table 1. Relations of the indentation depth and the hardness number to the applied load

1) In green condition

Average width of annual rings mm			Specific gravity in oven-dry			Moisture contents %		
Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
0.9	1.3	0.6	0.52	0.60	0.44	56	77	52

Load kg	h 1/100 mm			Δh 1/100 mm			H_B kg/mm²		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
(A) End surface (27 impressions)									
10	18.4	24.0	9.0	18.4	24.0	9.0	1.77	3.54	1.33
20	36.6	47.5	25.5	18.2	23.5	14.5	1.74	2.50	1.34
30	54.7	68.0	41.3	18.1	22.5	15.0	1.75	2.31	1.41
40	72.8	91.0	56.8	18.1	22.0	14.0	1.75	2.24	1.40
50	92.5	116.0	74.3	19.7	29.0	11.7	1.72	2.14	1.37
(B) Radial surface (18 impressions)									
5	23.1	29.3	16.5	23.1	29.3	16.5	0.69	0.96	0.54
10	46.3	56.0	35.5	23.2	28.7	19.0	0.69	0.90	0.57
15	69.1	83.5	53.5	22.8	29.5	18.0	0.69	0.89	0.57
20	91.6	108.0	71.0	22.5	25.5	15.5	0.69	0.90	0.59
(C) Tangential surface (18 impressions)									
5	20.1	25.0	11.5	20.1	25.0	11.5	0.79	1.38	0.64
10	39.4	46.0	29.5	19.3	22.5	17.0	0.81	1.08	0.69
15	59.4	68.0	52.0	20.0	24.0	16.0	0.80	0.92	0.70
20	79.1	87.5	73.5	19.7	25.5	15.2	0.81	0.87	0.73

2) In air-dry condition

Average width of annual rings mm			Specific gravity in oven-dry			Moisture content %		
Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
0.9	1.2	0.7	0.55	0.62	0.48	16.6	16.7	16.4

(A) End surface (27 impressions)

Load kg	h 1/100 mm			Δh 1/100 mm			H_B kg/mm^2		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
10	10.6	15.0	7.3	10.6	15.0	7.3	3.00	4.36	2.12
20	21.9	29.7	15.0	11.3	15.8	8.0	2.91	4.25	2.14
30	34.0	46.0	24.2	12.1	16.0	8.8	2.81	3.95	2.08
40	45.1	58.5	33.0	11.1	13.0	7.7	2.82	3.86	2.18
50	56.8	74.5	42.5	11.7	16.0	8.0	2.80	3.75	2.14
(B) Radial surface (18 impressions)									
5	16.0	21.0	11.5	16.0	21.0	11.5	1.00	1.38	0.76
10	32.6	39.5	23.0	16.6	21.3	10.5	0.98	1.38	0.81
15	49.0	58.5	34.0	16.4	21.5	11.0	0.98	1.41	0.82
20	63.5	76.0	43.0	14.5	19.5	9.0	1.00	1.48	0.84
(C) Tangential surface (18 impressions)									
5	10.9	16.8	4.5	10.9	16.8	4.5	1.46	3.54	0.95
10	23.5	33.3	13.5	12.6	17.9	7.0	1.36	2.36	0.96
15	36.2	48.0	24.0	12.7	17.7	8.0	1.32	1.99	0.99
20	49.7	73.3	33.0	13.5	23.5	9.0	1.28	1.93	0.87

3) In oven-dry condition

Average width of annual rings mm			Specific gravity in oven-dry			Moisture content %		
Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
0.8	0.9	0.7	0.53	0.58	0.50	0.5	0.6	0.5

(A) End surface (27 impressions)

Load kg	h 1/100 mm			Δh 1/100 mm			H_B kg/mm^2		
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
10	5.1	8.0	3.3	5.1	8.0	3.3	6.25	9.65	3.98
20	10.3	12.8	7.3	5.2	6.7	4.0	6.19	8.23	4.98
30	15.6	18.5	12.3	5.3	6.8	3.4	6.12	7.76	5.17
40	20.6	24.7	16.7	5.0	7.0	3.8	6.18	7.63	5.16
50	25.6	31.3	20.8	5.0	7.7	3.5	6.22	7.66	5.09

(B) Radial surface (18 impressions)

5	9.7	14.8	6.5	9.7	14.8	6.5	1.64	2.45	1.08
10	20.1	26.0	15.8	10.4	13.8	7.0	1.58	2.02	1.22
15	29.6	36.6	23.4	9.5	12.2	6.7	1.61	2.04	1.31
20	38.7	46.5	30.7	9.1	11.7	5.6	1.65	2.08	1.37

(C) Tangential surface (18 impressions)

5	7.8	12.5	3.1	7.8	12.5	3.1	2.04	5.13	1.27
10	15.5	23.5	8.0	7.7	12.2	4.0	2.06	3.98	1.36
15	22.4	30.5	14.5	6.9	10.0	5.0	2.13	3.30	1.57
20	29.1	39.1	22.0	6.7	8.6	3.8	2.19	2.90	1.63

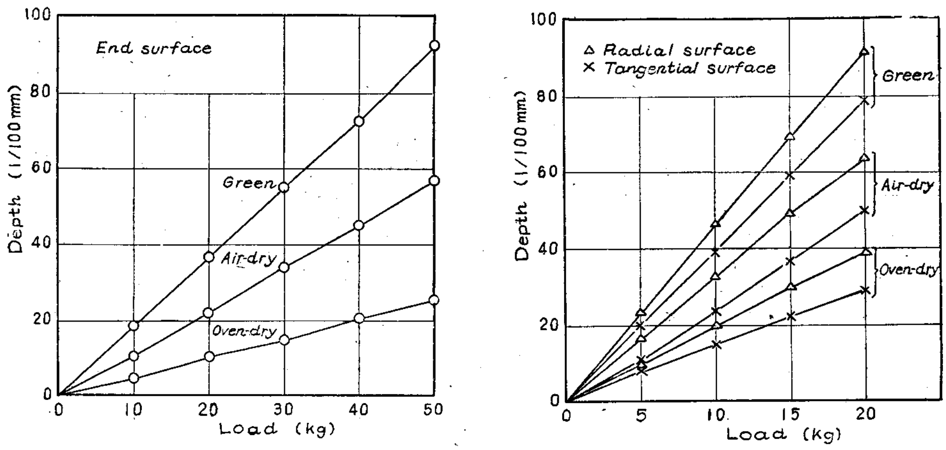

Fig. 4. Relation between depth of indentation and load.

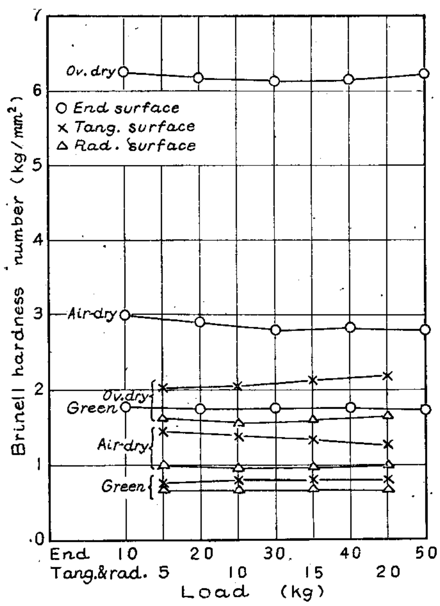

Fig. 5. Relation between load and BRINELL hardness number.

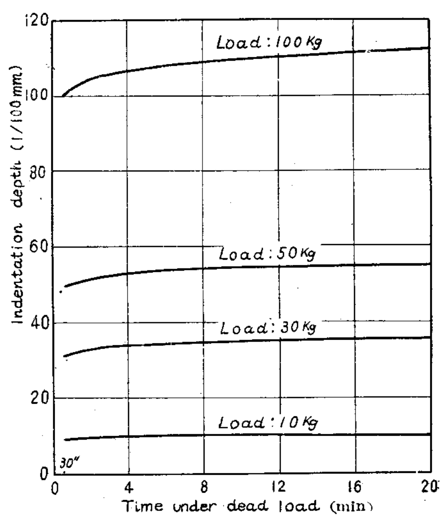

Fig. 6. Creep under dead load. Tested on the end surface of air-dried Nara-wood.

relations between load and depth.

If the depth of indentation increases in proportion to increasing the applied load, the BRINELL hardness number indicates the constant value according to the equation $H_B = P/\pi Dh$.

This fact is shown graphically in figure 5. From these results it will be seen that the BRINELL hardness number is constant to any applied load within the range employed in these tests. Therefore, it is quite possible to compare the BRINELL hardness number based on a certain load with the other based on a different one within a certain limit of applied load. But in the case of applying a lighter load, the hardness number is importantly affected by the experimental error. Furthermore, in the case of applying a heavier load, the creep under the dead load becomes conspicuous, and in consequence under such condition, it is difficult to measure the depth of indentation; this is shown in figure 6. In the BRINELL hardness test, therefore, the load should be selected as large as possible within the creep does not begin to appear distinctly. In this case, the depth of indentation is approximately 0.35–0.50 mm without regard to wood species, surface tested or moisture condition of test block.

About this problem, M. SAWADA[8] has advocated a new method, in which he proposes to measure the load (kg) required to indent a ball 10 mm in diameter into surface of wood block until 0.318 mm of depth is reached. In this case, the equation is

$$H_B = \frac{P}{\pi Dh} \doteqdot \frac{P}{10} \quad \text{kg/mm}^2.$$

On the other hand, the method, in which the diameter of the impression after the load is removed is measured by a micrometer microscope in order to determine a hardness, is used too. But this method has a fault as follows. When a steel ball is indented into the surface of material, the periphery of the impression does not always lie on the original surface. Sometimes the edge of the periphery extrudes or intrudes as indicated in figure 7. Especially on the longitudinal surface of wood, the edge of the ball impression which is left after loading, shows a remarkable intrusion and shows some what elliptic projection whose minor axis is in the direction parallel to the grain. In this case, the boundary of the impression is not distinct, consequently it is almost impossible to measure the diameter of an impression exactly.

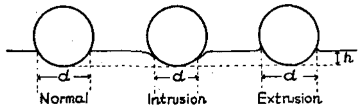

Fig. 7. Conditions of impressions.

In such a case as the above, computation of the hardness number should be based upon the depth of impression under a dead load instead of upon the diameter of the impression.

2) Relation between the Average Width of Annual Rings and the Hardness on the End Surface.

The width of growth rings, especially of ring-porous hardwoods, has frequently been suggested as a measure of the physical and mechanical properties of wood, on the supposition that it is correlated with density. For example, wide-ringed stock of a ring-porous wood is frequently characterized by high strength and stiffness in comparison with narrow-ringed stock[1].

This consideration may have connection with the hardness of Nara-wood too. In order to ascertain the relation between the ring width and hardness, the average width of annual rings was measured from each impression on the end surface. Number of impressions in each moisture condition is 180. The applied loads are 30 kg for green wood, 30 or 50 kg for air-dried wood, and 50 or 100 kg for oven-dried wood.

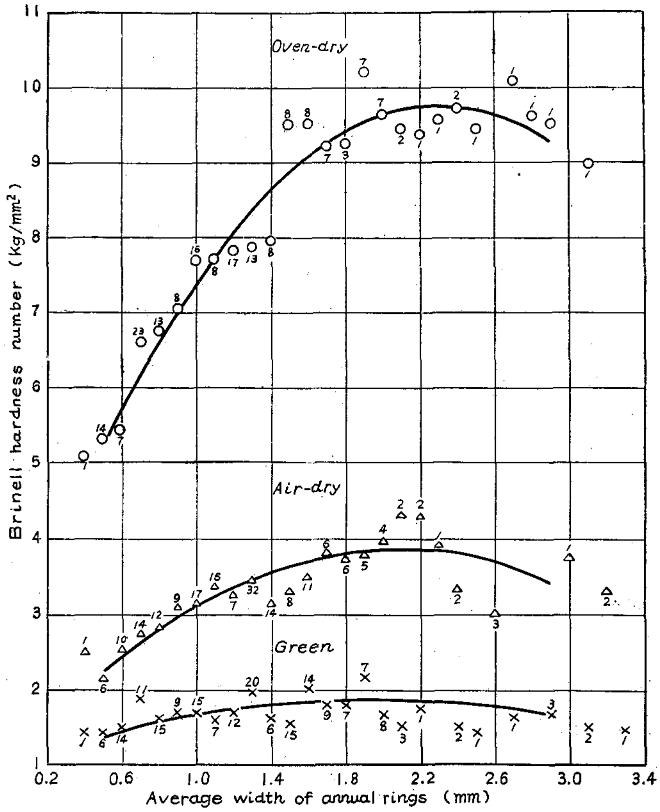

Fig. 8. Relationship between width of annual ring and end hardness.

The relations between the average width of annual rings and the end hardness are indicated by parabolic curves as shown in figure 8, and expressed in the form of a series of equations as follows:

In green condition

$$H_B = 1.05 + 0.874r - 0.23r^2$$

in air-dry condition

$$H_B = 1.10 + 2.62r - 0.623r^2$$

and, in oven-dry condition

$$H_B = 2.48 + 6.32r - 1.37r^2$$

where, H_B is the BRINELL hardness number of the end surface and r is the average width of annual rings in millimeters. In air-dry condition, the average moisture content of test blocks is 16.2 per cent of oven-dry weight.

In the case of each moisture condition, there is a maximum value in the hardness number: when growth has been extremely fast, above

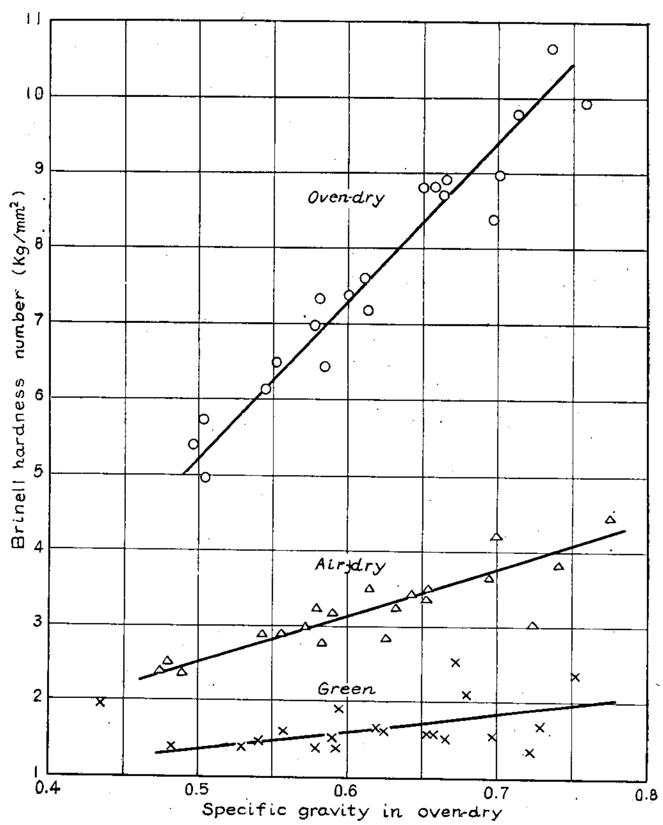

Fig. 9. Relationship between specific gravity and end hardness.

2.0–2.2 mm in ring width as shown in the figure, the curves show a decrease in the hardness number concommitant with increase the width of growth ring. The wide-ringed test blocks which showed such results were obtained from near the pith.

3) Relation between the Specific Gravity and the Hardness.

The hardness of wood varies with specific gravity: the relations between them for Nara-wood in green, air-dry and oven-dry conditions are shown in figure 9.

As this figure indicates, the relation of the end hardness to the specific gravity based on oven-dry weight and volume is given in an approximately straight line in each moisture condition, and expressed in the following equation:

In green condition

$$H_B = 2.44\,S_0 + 0.13$$

in air-dry condition

$$H_B = 6.20\,S_0 - 0.6$$

and, in oven-dry condition

$$H_B = 21.0\,S_0 - 5.3$$

where H_B is the Brinell hardness number of the end surface, and S_0 is the specific gravity based on oven-dry weight and volume.

4) Comparison of the Hardness of Nara-wood in Green, Air-dry and Oven-dry Conditions.

The results obtained from this test on the comparative hardness of twelve specimens in each moisture condition are shown in table 2. The loads applied to the end surface were 30 kg for green wood, 30 or 50 kg for air-dried and 50 or 100 kg for oven-dried wood; those applied to the side surfaces were 10 kg for green, 10 or 20 kg for air-dried and 20 or 30 kg for oven-dried wood.

At the time of testing, the moisture content of the air-dry specimens

Table 2. Results of hardness test for Nara-wood

Moisture condition	Brinell hardness number kg/mm²									r	S_0	u
	End			Radial			Tangential					
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.			
Green	1.68	3.32	1.17	0.66	1.65	0.46	0.79	2.20	0.44	1.2	0.62	63.1
Air-dry	3.21 (3.51)	4.75	2.08	1.07 (1.20)	1.79	0.73	1.40 (1.54)	2.54	0.75	1.2	0.62	16.2 (15.0)
Oven-dry	7.73	12.05	4.63	2.24	4.15	1.26	2.85	6.05	1.59	1.2	0.62	0.8

Notes: r is the average width of annual rings in millimeters, S_0 is the specific gravity in oven-dry, and u is the moisture content at time of test in per cent.

varied between 13.1 and 17.7 per cent, the average value being 16.2 per cent, therefore, the following equations to express the relationship between the moisture content and hardness were worked out based on the experimental data; for purposes of comparison the average results of the air-dry tests were adjusted to the values they would have at 15 per cent moisture content. The equations are

$$H_{eu} = 7.14 - 0.242u$$
$$H_{ru} = 2.70 - 0.100u$$
$$H_{tu} = 3.34 - 0.120u$$

where H_{eu}, H_{ru} and H_{tu} are the end, radial and tangential hardness, respectively, at u per cent moisture content. The hardness values adjusted to 15 per cent moisture content are given in parentheses in the table.

From table 2, it is clear that there is large increase in the hardness number of wood with a decrease in the moisture content.

The percentage ratios of the average hardness values of green and oven-dried wood in relation to those of air-dried wood are shown in table 3.

Table 3. Percentage ratios in the hardness of green, air-dried and oven-dried Nara-wood

Moisture condition	Hardness ratio		
	End	Radial	Tangential
Green	48	53	51
Air-dry*	100	100	100
Oven-dry	220	188	185

* Adjusted to 15 per cent moisture content.

As will be seen from the above table, the ratio in the hardness of green, air-dry (15 per cent) and oven-dry Nara-wood is approximately 0.5 : 1 : 2 on each surface.

Comparisons of the hardness of side surfaces and that of the end surface are given in table 4.

Table 4. Percentage ratios in the hardness of end, radial and tangential surfaces of Nara-wood

Moisture condition	Hardness ratio		
	End	Radial	Tangential
Green	100	39	47
Air-dry*	100	34	44
Oven-dry	100	29	37

* Adjusted to 15 per cent moisture content.

It may be seen that genenally the radial hardness is about 30–40 per cent of the end hardness while the tangential hardness is about 120–130 per cent of the radial hardness.

CONCLUSIONS AND SUMMARY

In the case of measuring the hardness of wood by the static ball indentation method, the matter of amount of the load to be applied is still under argument. For example, N. PARRAY[7] has said that the BRINELL hardness number based on a certain load is not to be compared with the other one based on a different load. Furthermore, F. SEKIYA[9] has stated a similar view to that. But, the present author[5] has already expressed his opinion that it is indicated by an approximately linear relation between load and depth of ball indentation within a certain limit of the depth, and consequently, that the BRINELL hardness number is constant to any applied load within the range.

In the present study, by using a machine for testing hardness of wood with lever system, the depth of static ball indentation was measured under the following conditions: (1) A load of known amount was applied to the specimen and maintained for sufficiently long to enable removing the influence of creeping due to loading time. (2) The depth of indentation was measured under a sustained loading.

The results obtained by using specimens of Nara-wood in green, air-dry and oven-dry conditions are briefly stated as follows:

1) Within a certain limit the relationship between load and depth of indentation is indicated by a straight line, and the BRINELL hardness number is constant to any load regardless of the surface to which it was applied and of the moisture content of the wood.

2) Relation of the end hardness to the width of annual ring is graphed as a parabolic curve; the wood with about 2.0–2.2 mm ring widths shows the maximum value in the hardness number in each moisture condition.

3) Relation between the specific gravity and the hardness number is shown in straight line under each moisture condition.

4) Hardness ratio of green, air-dry and oven-dry wood is about 0.5 : 1 : 2 on each surface.

5) The radial hardness is 30–40 per cent of the end hardness, and the tangential hardness is about 120–130 per cent of the radial hardness.

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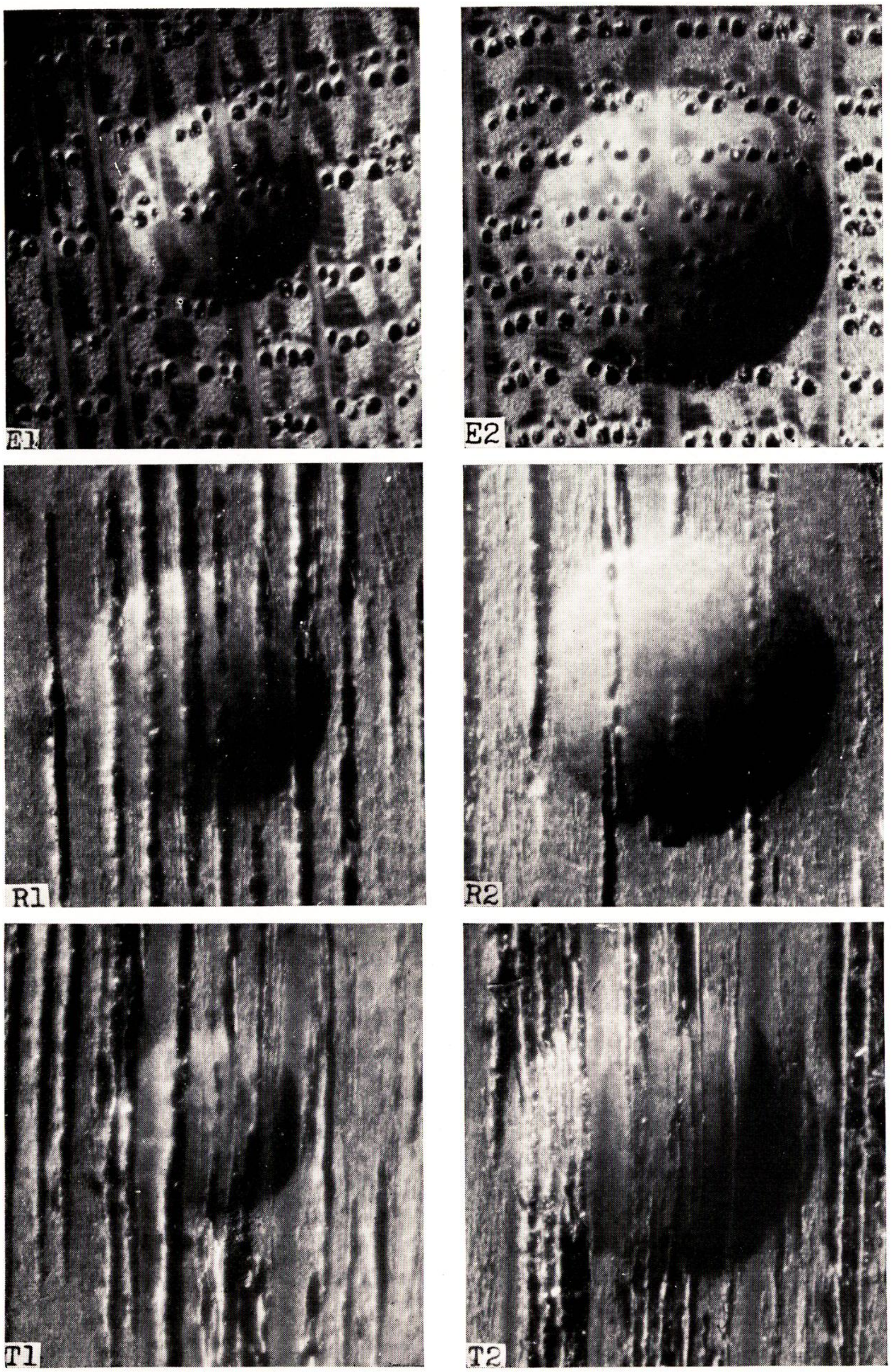
EXPLANATION OF PLATE

These figures show impressions due to ball (10 mm in diameter) indentation on the surfaces of air-dried Nara-wood, and conditions of the ball indentation are as follows:

No.	Surface	Load kg	Depth of indentation 1/100 mm	Creep
E1	End	50	35.0	
E2	End	100	86.0	Distinct
R1	Radial	20	67.0	
R2	Radial	50	101.0	Distinct
T1	Tangential	20	37.3	
T2	Tangential	50	88.8	Distinct

Plate 1



(8×)

APPENDIX

No. : Test piece No.
Hardness : BRINELL hardness number kg/mm²
r : Average width of annual rings mm
S_0 : Specific gravity based on oven-dry volume and weight 100×
u : Moisture contents at time of test in per cent of oven-dry weight

1) In green condition

No.	End hardness			Radial hardness			Tangential hardness			r	S_0	u
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.			
1	1.40	1.52	1.34	0.53	0.57	0.50	0.70	0.95	0.55	0.6	48.4	79.9
2	1.63	1.79	1.54	0.60	0.65	0.55	0.76	0.93	0.64	1.3	62.6	69.5
3	1.68	1.77	1.59	0.68	0.74	0.61	0.72	0.86	0.56	2.0	73.0	59.8
4	1.96	2.31	1.71	0.75	0.90	0.70	0.76	0.84	0.69	0.7	43.5	51.5
5	1.90	2.02	1.77	0.70	0.77	0.64	0.82	0.91	0.76	0.9	59.5	51.9
6	2.10	2.48	1.91	0.70	0.76	0.63	0.83	1.02	0.76	1.1	68.0	45.7
7	1.49	1.60	1.40	0.62	0.73	0.59	0.87	1.08	0.73	0.9	54.1	76.5
8	1.38	1.63	1.27	0.58	0.63	0.55	0.69	0.76	0.63	1.3	59.3	70.9
9	1.56	1.66	1.47	0.62	0.68	0.58	0.69	0.74	0.63	1.5	65.9	57.7
10	1.39	1.52	1.31	0.55	0.60	0.51	0.69	0.76	0.57	1.0	57.9	72.1
11	1.52	1.63	1.31	0.64	0.72	0.57	0.69	0.85	0.61	1.5	66.6	67.4
12	1.37	1.53	1.17	0.52	0.56	0.50	0.54	0.64	0.44	1.8	72.4	60.0
13	1.52	1.59	1.43	0.56	0.62	0.50	0.68	0.78	0.61	1.1	59.0	61.9
14	1.57	1.68	1.50	0.59	0.64	0.55	0.69	0.86	0.62	1.7	65.5	60.0
15	1.58	1.86	1.44	0.59	0.62	0.57	0.65	0.69	0.57	2.1	69.8	52.7
16	1.46	1.63	1.41	0.56	0.75	0.46	0.81	0.86	0.66	0.6	53.0	71.4
17	1.61	1.77	1.46	0.62	0.65	0.53	0.73	0.92	0.53	0.8	55.8	76.0
18	1.67	1.75	1.62	0.58	0.68	0.51	0.74	0.86	0.65	0.8	62.0	70.5
19	2.54	2.77	2.38	0.95	1.14	0.72	1.43	1.85	1.06	1.4	67.4	54.4
20	2.36	3.32	2.58	1.33	1.65	1.00	1.47	2.20	1.09	1.8	75.3	52.9
Avg.	1.68	3.32	1.17	0.66	1.65	0.46	0.79	2.20	0.44	1.2	61.9	63.1

2) In air-dry condition

No.	End hardness			Radial hardness			Tangential hardness			r	S_0	u
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.			
1	2.51	2.66	2.29	0.79	0.81	0.73	1.04	1.26	0.75	0.6	48.0	15.7
2	2.84	2.99	2.45	0.93	1.03	0.82	1.25	1.55	1.04	1.3	62.6	17.7
3	3.02	3.24	2.68	1.10	1.39	0.97	1.36	1.93	1.03	1.9	72.4	16.7
4	2.39	2.75	2.08	0.85	1.00	0.82	1.12	1.27	0.96	0.7	47.7	16.7
5	3.23	3.45	3.06	1.03	1.14	0.96	1.24	1.55	1.02	0.9	58.0	17.0
6	3.50	3.94	2.96	1.21	1.38	1.10	1.83	2.36	1.55	1.2	61.7	16.6
7	2.88	3.43	2.39	0.94	1.06	0.81	1.38	1.55	1.24	0.9	54.3	16.4
8	2.78	3.39	2.48	0.91	0.98	0.86	1.24	1.68	1.06	1.2	58.3	16.7
9	3.50	3.67	3.30	1.16	1.17	1.14	1.46	1.69	1.14	1.5	65.5	16.5
10	2.97	3.18	2.79	0.89	0.97	0.81	1.28	1.48	1.03	0.9	57.3	16.7
11	3.43	3.74	3.08	1.18	1.27	1.10	1.43	1.49	1.36	1.5	64.4	15.5
12	3.82	4.18	3.54	1.26	1.71	1.07	1.47	1.75	1.37	1.7	74.0	14.9
13	3.18	3.36	2.88	0.98	1.00	0.95	1.14	1.20	1.10	1.1	59.1	16.4
14	3.38	3.94	3.20	1.11	1.23	0.97	1.62	2.06	1.07	1.6	65.3	16.0
15	3.68	3.81	3.54	1.31	1.38	1.24	1.42	1.59	1.29	2.0	69.8	15.8
16	2.37	2.62	2.19	0.78	0.83	0.76	1.17	1.25	1.06	0.6	49.0	17.4
17	2.91	3.24	2.50	0.90	1.03	0.84	1.30	1.77	1.06	0.8	55.6	16.1
18	3.23	3.60	2.71	0.91	1.10	0.83	1.50	1.99	1.19	0.8	63.3	15.9
19	4.21	4.57	3.70	1.55	1.79	1.38	1.89	2.50	1.61	1.5	70.0	16.7
20	4.43	4.75	4.15	1.56	1.77	1.37	1.93	2.54	1.63	1.7	77.8	13.1
Avg.	3.21	4.75	2.08	1.07	1.79	0.73	1.40	2.54	0.75	1.2	61.7	16.2

3) In oven-dry condition

No.	End hardness			Radial hardness			Tangential hardness			r	S_0	u
	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.			
1	4.99	5.13	4.63	1.47	1.72	1.26	2.25	2.83	1.90	0.6	50.6	0.7
2	7.17	8.30	6.37	2.04	2.50	1.61	2.95	3.58	2.22	1.2	61.4	0.5
3	8.99	9.54	8.30	2.79	3.10	2.22	3.28	4.82	2.36	1.9	70.2	0.6
4	5.71	6.93	5.29	1.61	1.82	1.40	1.93	2.54	1.63	0.7	50.3	0.6
5	6.97	7.66	6.50	1.76	2.08	1.54	2.20	2.81	1.79	0.9	57.9	0.2
6	8.93	10.28	7.65	2.50	2.80	2.24	2.89	3.38	2.47	1.1	66.7	0.8
7	6.13	6.98	5.68	1.63	1.90	1.37	2.64	2.90	2.42	0.8	54.5	0.9
8	6.44	7.24	5.69	2.03	2.43	1.77	2.16	2.77	1.68	1.3	58.5	0.9
9	8.84	9.61	7.71	2.55	2.75	2.26	3.12	3.48	2.47	1.4	65.9	0.7
10	7.32	9.38	6.35	2.04	2.38	1.71	2.57	3.01	2.14	1.0	58.2	0.7
11	8.80	9.92	7.65	2.36	2.89	2.01	3.02	3.64	2.56	1.5	65.0	0.9
12	10.66	12.05	9.64	2.81	3.24	2.68	3.24	4.19	2.64	1.7	73.8	0.8
13	7.38	8.46	6.40	2.05	2.36	1.95	2.83	3.07	2.58	1.0	60.1	0.8
14	8.70	10.03	7.84	2.61	2.89	2.30	3.21	4.28	2.56	1.6	66.3	1.1
15	9.78	10.23	9.33	2.83	3.24	2.54	3.05	4.00	2.62	2.0	71.3	0.6
16	5.40	5.90	5.09	1.84	2.18	1.33	2.88	3.72	2.25	0.5	49.6	0.9
17	6.47	7.58	5.72	1.94	2.87	1.53	2.40	2.79	1.92	0.8	55.2	0.8
18	7.59	9.05	6.12	1.94	2.18	1.63	2.76	3.64	1.59	0.7	61.1	1.0
19	8.39	9.95	8.23	2.60	3.01	2.44	3.41	4.26	2.63	1.5	69.7	0.9
20	9.92	10.60	9.75	3.47	4.15	3.04	4.16	6.05	3.24	1.8	75.9	0.8
Avg.	7.73	12.05	4.63	2.24	4.15	1.26	2.85	6.05	1.59	1.2	62.1	0.8

木材，特にナラの生材，氣乾材および全乾材の硬さ試験

宮　島　　寛

要　　約

木材に対する硬さ試験，特に BRINELL の方法による場合，適用される荷重の種類およびその加圧時間について種々の議論があるが，この試験においては，鋼球を木材の表面に圧入してそこに生じたヘコミの深さを次の方法によつて測定した。(1) 決められた荷重をもつて鋼球を試験片に圧入し，加圧時間によるヘコミの深さの変化の影響を無視できるほど充分長くこの荷重を保持した。(2) ヘコミの深さの測定は荷重をかけたまま行つた。

表題のような含水状態にあるナラ材を用いて行つた試験結果の概要は次のとおりである。

(1) 鋼球を木材の表面に徐々に荷重を増しながら圧入するとき，そのヘコミの深さと荷重との関係は Fig. 3 に示すようになる。この場合最初の *O–M* の範囲ではヘコミの深さと荷重の関係は直線で表わされる。このことは更に荷重とヘコミの深さの関係を求めた実験によつて Table 1 および Fig. 4 に示すように確められた。荷重とヘコミの深さが直線的関係にあれば，BRINELL の方法では荷重を変えても硬さ数は一定値を示す。(Table 1 および Fig. 5)

(2) ナラ材において年輪幅と木口面の硬さ数の関係は抛物線で表わされ，各含水状態のときとも年輪幅 2.0～2.2 mm のものが硬さ数において最大値を示す。(Fig. 8)

(3) 比重が増せば硬さ数 (木口面) も直線的に増す。(Fig. 9)

(4) ナラの生材，気乾材および全乾材の硬さ数の比は各面ともおよそ 0.5 : 1 : 2 である。(Table 3)

(5) 各含水状態のときともまさ目面の硬さ数は木口面の 30～40%，板目面はまさ目面の 120～130% である。(Table 4)