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On Shore Hardness Tester (Scleroscope) of Type D*

— Motion of Hammer —

By Takeo YOSHIKAWA** and Saburo SEKIYA***

This research concerns the investigation on the behaviour of the hammer in the scleroscope of type D before it is clamped with the ball clutch the effect of the changeable action of the clutch on the rebound of the hammer and the hardness values measured. Then we compared the hardness values indicated on the hardness dial of the scleroscope with the hardness values which were calculated with the height of rebound of the hammer measured by the optical method. We also discussed the relation between the height of rebound of the hammer and the shape of its diamond tip.

1. Foreword

It seems that the action of the ball clutch in Shore scleroscope of type D affects the repeatability of hardness values measured. Fig. 1 shows the hammer which is clamped with steel balls inside the conical seat of the clutch. Such a position is a little lower than the highest position of rebound of the hammer, (because the hammer should fall a certain height before it is clamped with the clutch), and the height of such fall and consequently the hardness values measured seem to vary in every measurement on the same specimen due to the unreliable action of clamping.

This research was made to investigate the behaviour of the hammer by the optical method until it is clamped with the clutch, and to determine the height of the clamped hammer measured from the surface of the specimen and the height of the fall. Then the hardness values corresponding to the former and to the maximum height of rebound of the hammer for each test

specimen were calculated and compared with the values indicated on the hardness dial of the scleroscope.

We also discussed the relation of the height of rebound of the hammer and the shape of its diamond tip.

2. Method of measurement

The scleroscope used in this investigation is home made, and has been used for our research on Shore hardness of metallic materials since 1945, but is now a little modified so as to measure the height of the hammer; i. e. one hole was drilled horizontally through the hammer and a wire of

Fig. 1 Ball clutch

Fig. 2 Modified main part of scleroscope

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** Professor, Faculty of Engineering, University of Tokyo, Bunkyo-ku, Tokyo.

*** Assistant, Faculty of Engineering, University of Tokyo.

Fig. 3 Arrangement (mm unit)

about 0.01 mm dia. was soldered across the hole (Fig. 2). The change of the weight of the hammer due to the machining is about 0.9 %. And large holes were also made across the cylindrical wall. The return spring in the operating knob was removed, so that it might be turned back by the hand until it stopped, when the hardness dial was used to measure the indicated hardness.

Fig. 3 shows the skeleton of the arrangement to measure the behaviour of the hammer. A is the main part of the scleroscope, through which large holes B are made. C is the hammer which is clamped with the ball clutch D. E is the anvil of the specimen F, and G is the table to adjust the height of the scleroscope, the vertical displacement of which is measured with the dial gauge I. H is the hardness dial which indicates the hardness value corresponding to the height of the clamped hammer. The light from the light source J passes through lenses (K, L, M, and N) and the hole of the hammer, and then the shadow of wire is projected on the recording drum O through the slit P. Q is the switch which acts to drop the hammer and to open the shutter of the recording apparatus a little later. A datum line is marked on the surface of the slit to measure the height of the clamped hammer, with the dial gauge I.

In every measurement of hardness, each specimen was forced on the anvil under about 20 kg force.

Measured and calculated values are as follows :

h : height of the hammer clamped with the ball clutch, which is measured as the difference between the height of the hammer when it contacts with the test specimen and its height when it is clamped, by means of putting the shadow of fine wire on the datum line of the slit. H_s' : Shore hardness calculated with h by the next formula which was adopted in JIS B 7776 (Standard of Shore Hardness Testers)-1952,

$$H_s' = \frac{10000}{65} \times \frac{h}{h_0} = \frac{h}{1.193} \quad (1)$$

where

h_0 : initial height of the hammer which is 18.36 mm in our scleroscope,

H_s : Shore hardness indicated, which is measured by the pointer on the hardness dial after the operating knob is completely turned back,

Δh : height of fall of the hammer clamped after it reaches the highest position of rebound, which is measured on the height-time curve concerning the behaviour of the hammer (Fig. 4),

ΔH_s : change of Shore hardness calculated with Δh by the formula (1),

$h + \Delta h$: height of the highest position of rebound of the hammer,

H_{sm}' : Shore hardness calculated with $h + \Delta h$ by the formula (1),

and

Fig. 5 Histogram of ΔH

Fig. 4 Record of behaviour of hammer

Table 1 Result of 1st measurement (Standard deviations in parentheses)

Hardness of specimens	h mm	H_s'	H_s	Δh mm	ΔH_s	$h + \Delta h$ mm	H_{sm}'	$H_s' - H_s$	$H_{sm}' - H_s$
22.0~22.7	2.479	20.77 (1.06)	22.80 (0.99)	0.062	0.51	2.541	21.28 (1.02)	- 1.99 (0.16)	- 1.49 (0.20)
31.4~31.8	3.546	29.71 (2.02)	30.90 (1.79)	0.065	0.55	3.611	30.26 (2.01)	- 1.15 (0.32)	- 0.61 (0.29)
50.5~51.2	6.385	53.50 (0.87)	52.50 (0.73)	0.062	0.52	6.446	53.93 (0.88)	+ 1.01 (0.26)	+ 1.55 (0.26)
69.9~70.3	8.485	71.11 (2.49)	68.16 (2.33)	0.055	0.46	8.540	71.57 (2.48)	+ 2.93 (0.25)	+ 3.40 (0.27)
89.4~89.9	11.426	95.72 (0.97)	90.36 (0.81)	0.056	0.47	11.482	96.27 (1.00)	+ 5.39 (0.28)	+ 5.86 (0.27)

Table 2 Measured values of Δh and ΔH_s (1st measurement)

Hardness of specimens	Δh mm			ΔH_s			
	Max	Min	Mean	Max	Min	Mean	Standard deviation
22.0~22.7	0.081	0.043	0.062	0.67	0.36	0.51	0.09
31.4~31.8	0.080	0.050	0.065	0.67	0.42	0.55	0.07
50.5~51.2	0.086	0.033	0.062	0.72	0.28	0.52	0.10
69.9~70.3	0.081	0.031	0.055	0.68	0.26	0.46	0.09
89.4~89.9	0.106	0.037	0.056	0.89	0.31	0.47	0.16

Table 3 Result of 2nd measurement (Standard deviations in parentheses)

Hardness of specimens	h mm	H_s'	H_s	H_{sm}'	$H_s' - H_s$	$H_{sm}' - H_s$
22.0~22.7	2.690	22.54 (0.23)	24.57 (0.24)	23.05	- 2.03 (0.25)	- 1.51
31.4~31.8	3.804	31.88 (0.29)	33.16 (0.20)	32.43	- 1.28 (0.21)	- 0.73
50.5~51.2	6.444	53.99 (0.52)	53.12 (0.48)	54.51	+ 0.87 (0.16)	+ 1.39
69.9~70.3	8.993	75.35 (0.35)	72.66 (0.34)	75.81	+ 2.69 (0.28)	+ 3.15
89.4~89.9	11.444	95.89 (0.79)	91.02 (0.80)	96.36	+ 4.87 (0.31)	+ 5.34

Table 4 Measured values of Δh and ΔH_s (3rd measurement)

Hardness of specimens	Δh mm			ΔH_s			
	Max	Min	Mean	Max	Min	Mean	Standard deviations
22.0~22.7	0.077	0.045	0.064	0.64	0.37	0.53	0.09
31.4~31.8	0.079	0.050	0.061	0.66	0.42	0.51	0.07
50.5~51.2	0.083	0.044	0.063	0.70	0.37	0.53	0.11
69.9~70.3	0.083	0.034	0.059	0.70	0.28	0.49	0.13
89.4~89.9	0.095	0.031	0.053	0.80	0.26	0.44	0.15

Table 5 Theoretical values of Shore hardness

Hardness of specimens	H_s	H_{sm}'	Theoretical values of Shore hardness	
	2nd measurement	2nd measurement	$h_0 = 18.36$ mm	
			$H_s'' (R=1.0)$	$H_s'' (R=1.7)$
22.0~22.7(22.4)	24.57	23.05	23.04	30.13
31.4~31.8(31.6)	33.16	32.43	32.10	39.63
50.5~51.2(50.9)	53.12	54.51	50.10	60.61
69.9~70.3(70.1)	72.66	75.81	70.15	80.22
89.4~89.9(89.7)	91.02	96.36	85.50	96.76

Fig. 6 Measured values of H_s Fig. 7 Calculated values of H_s'

Fig. 8 Relation between the rebound of the hammer and the indicated hardness values

$H_s' - H_s$, $H_{sm}' - H_s$: difference of hardness values.

The measurement was made first in the ordinary condition of the scleroscope and then after dusting of its main part. The third measurement was made to ascertain the values of Δh and ΔH_s after the ball clutch was substituted by a new one.

3. Results

Table 1 shows the results of the first measurement, in which each number is the mean of 16 ~ 23 values measured and their standard deviations are indicated in the parentheses under each mean value. Table 2 and Fig. 5 (a) show the results on the values of Δh and ΔH_s in the same

Fig. 9 Relation between Shore hardness and Vickers hardness

measurement, from which we can see that the values of Δh and ΔH_s are about 0.05 ~ 0.10 mm or 0.3 ~ 0.5 in Shore hardness unit, both of which are independent of hardness of specimens.

Table 3 shows the result of the second measurement after dusting, in which H_{sm}' are calculated with the mean values of Δh for the same specimens in the first measurement. From this result, we can see that the dusting improved the repeatability of the indicated hardness values H_s and also of the calculated values H_s' as shown in Fig. 6 and 7. We can also understand that, due to

Table 6 Diameter of indentations

Hardness of specimens	Diameter of indentations (mean) mm
22.0~22.7	0.55
31.4~31.8	0.45
50.5~51.2	0.40
69.9~70.3	0.35
89.4~89.9	0.30

Fig. 10 Profile of tip hammer

the decrement of frictional resistance, every mean value of hardness after dusting is nearly equal to the higher values among the values measured in the first measurement on the same specimen.

Table 4 and Fig. 5(b) show the results of Δh and ΔH_S in the third measurement. Their mean values are about 0.05 in mm or 0.5 in Shore hardness unit which are also independent of hardness of test specimens. The result is the same as in the first measurement.

Fig. 8 shows the relation between h and H_S , for which we get the next experimental formula ;
 $h = 0.131 \times (H_S - 3.7)$ in mm

In Table 5 and Fig. 9, $H_S''(R=1.0)$ and $H_S''(R=1.7)$ are the values calculated by Inobe's formula⁽¹⁾ adopted for the rebound of the hammer, where $h=18.36$ mm and the tip radius of the hammer is assumed as 1.0 or 1.7 mm, and they are compared with the values of H_S and H_{Sm}' in the second measurement, and also with the hardness relation specified in JIS B 7776. The profile of the tip of the hammer used (Fig. 10) and the dimension of indentations made with it (Table 6) tell us that these indentations on harder specimen are made with the tip point of about 1.7 mm radius and those on softer specimen are mainly made with the part of about 1.0 mm radius. This fact coincides with tendency of the results such as shown in Table 5 and Fig. 9.

4. Conclusion

(a) The action of the old and new ball clutches in the scleroscope is both almost stable, and the height of fall from the highest position of rebound of the hammer to that of the hammer clamped is about 0.5 in Shore hardness unit, which is independent of hardness of specimens.

(b) After dusting of the main part of the scleroscope, the repeatability of the hardness values indicated on the hardness dial and of the hardness values calculated by the formula (1) are both improved. It seems that the rebound of the hammer was not scattered due to the frictional resistance after dusting.

(c) The scattering of the hardness values measured before dusting of the main part of the scleroscope is due to the fact that the unnegligible frictional resistance acts on the rebound of the hammer very changeably, so that the mean value of the hardness measured after dusting seems to be nearly equal to the higher values among the values measured before dusting.

(d) In Fig. 8, the curve of H_{Sm}' calculated with $h + \Delta h$ are between the curves of $H_S''(R=1.0)$ and $H_S''(R=1.7)$ calculated by Inobe's formula⁽¹⁾, and the tendency of the former can be understood by considering the shape of the tip of the hammer. This fact certifies that Inobe's formula is sufficient to explain the rebound of the hammer in the scleroscope of type D.

Note (1) : the theoretical value of Shore hardness by Inobe's formula is as follows;

$${}_0H_S(R) = \frac{300\sqrt{2}}{13} (N+1)^{\frac{4N-1}{2(N+1)}} \phi^{\frac{5}{2(N+1)}} \times \left(\frac{R^3}{mgh_0} \right)^{\frac{3-2N}{2(N+1)}} \left(\frac{1-\mu_1^2}{E_1} + \frac{1-\mu_2^2}{E_2} \right)$$

where

ϕ and N : constant values concerning material of test specimen,

μ_1 and μ_2 : Poisson's ratio of material of test specimen and tip of hammer,

E_1 and E_2 : Young's modulus of material of test specimen and tip of hammer,

R : tip radius of hammer,

m : mass of hammer, and

h_0 : initial height of hammer.