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ACCURACY OF STANDARD BLOCKS FOR HARDNESS AND UNCERTAINTY OF HARDNESS

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Abstract – The authors numerically discuss the accuracy of the hardness values of standard hardness blocks by evaluating the uniformity of hardness blocks and the resolution of hardness values according to test method. As a result of reviewing the results of this evaluation and the reasonability of the currently proposed method for evaluating the uncertainty of hardness values, it is revealed that the variance of hardness values of popular standard blocks for hardness—Rockwell and Vickers—is extremely small ($\sigma \leqq 0.05$ HRC, including the variance attributable to the tester). It is also found that the depth-measuring Rockwell test method shows higher resolution of hardness values than the Vickers test method using microscopic measurements.

Regarding the uncertainty of hardness, it is technically impossible to have discussions on the accuracy of uncertainty. Prior to discussing the uncertainty of hardness testing, we believe more efforts should be directed to studying ways to improve the accuracy and reliability of the testing method itself.

Keywords: Hardness, Uniformity, Uncertainty

1. INTRODUCTION

Obviously the uniformity of hardness is the most important feature of standard blocks. In this context, the issue of hardness uncertainty has been attracting increased attention recently, besides studies on ways to increase the accuracy of hardness testing methods. However, it is not well known that there is little correlation between the uncertainty of hardness values and the hardness uniformity of standard hardness blocks, or the variance of hardness values. The confusion between the two often leads to serious misconceptions. The authors estimated the uniformity of hardness blocks, or representative values of hardness variance, from the results of tests to determine reference values for a large quantity of hardness blocks. These estimates were made to evaluate the hardness uniformity of hardness standard blocks with Rockwell tests, which is representative of depth-measuring hardness tests, and with Vickers tests, which is representative of microscopic measuring hardness tests.

The results of this evaluation were compared to the much-debated uncertainty of hardness values to help dispel a misconception about the uniformity of hardness blocks, or the variance of hardness values, and the uncertainty of hardness values.

2. METHODS OF EVALUATING THE HARDNESS UNIFORMITY OF HARDNESS STANDARD BLOCKS

Sales of standard blocks for hardness on the Japanese market amount to around 30,000 units a year, and they are available in nearly 140 types, including those for nanoindentation, Brinell, and Leep testing as shown in Table 1. These blocks differ in material, shape, and dimensions according to the purpose of the hardness tests for which they are used. However, they share three important attributes: uniformity of hardness, reliability of reference values, and stability of hardness values [1]. Above all, uniformity of hardness is the most important attribute, but discussing it based on test results for a small number of hardness blocks cannot present a realistic picture of the issue.

To get a precise picture of the uniformity of hardness, or the variance of hardness values, the authors used the advantage a test block manufacturer has of easy access to the results of tests for determining the reference values of a large quantity of hardness blocks, including the results for blocks that have been rejected. The uniformity of Rockwell blocks was investigated to evaluate a depth-measuring hardness test, whereas the uniformity of Vickers blocks was investigated to evaluate a microscopic measuring hardness test, as described in the following paragraphs.

2.1. Method for evaluating the hardness uniformity of Rockwell test blocks

The Rockwell hardness test [2] is the most popular method for industrial applications. In particular, demand for Rockwell C Scale accounts for almost half of demand for all hardness blocks.

For recently produced 24 lots, or 480 blocks, each of our 60 HRC and 30 HRC blocks, we estimated the standard deviation from the variance (range: R) of results of tests for determining the reference values of these blocks. Likewise, we also estimated the standard deviation of hardness, σ_H from allowances of variation ($D_4\overline{R}$, JIS Z 9021) determined from our 60 years of experience of test block production by (1).

$$\sigma'_H = \overline{R}/d_2 = D_4\overline{R}/D_4 d_2 \quad (1)$$

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Table 1 Varieties and specifications of standard blocks for hardness

Assortment	Hardness value	Tolerance	Calibration number(n)	Variation (R=Max.-Min)	Materials (JIS notation)	Dimention (mm)	Finished surface	Standard based
HMV (1, 0.1)	1650	±10%	4 (2×2)	2% (HV1)	Si_3N_4	□10×5	□	JIS B 7735
HMV (1,0.1,0.01)	900, 800, **700**, 600, **500**	±15	6 (3×2)	5% (HV0.1)	SK85	φ25×6	□	JIS B 7735
〃	400, 300, **200** (Be Copper)	±15	〃	〃	C1720P	φ25×6(2)	□	〃
〃	100(C2600P), 40(C1020P),	±10	〃	7 (100HV0.1), 4 (40HV0.1)	←	φ25×5 ※	□	〃
HMV (0.1,0.01,0.001)	30(AU)	±10	〃	4 (HV0.1)	Au	φ25×5(0.8)	□	〃
UMV (0.01, 0.002)	900, 700 (Berkovich 9.8mN tested)	±20%	6 (3×2)	10% (HV0.01)	SK85	φ25×6	■	JIS B 7735
〃 (0.01, 0.001)	500, 200 (〃)	〃	〃	〃	SK85,C1720P	φ25×6(2)	■	〃
★Nano indentation Hardness Blocks (HV0.01, 0.001 Berkovich 9.8mN tested)		APPROX430 HV0.001	6 (3×2 HV, Nano)		Single Crystal Tungsten	φ25×6 (W: φ9×3)	■	JIS B 7735
HV (30, 1)	1000(SK120), 900, 800, **700**	±15	10 (5×2)/HV30,10	1.5%	SKS3	φ64×15	○	JIS B 7735
HV (10,1)	600, **500**, 400, 300, **200** (SK85), 150 (S45C)	〃	6 (3×2)/HV1	〃	←	〃	○	〃
〃	100(C2600P), 40 (C1020P)	±10		(150HV and below 2.2%)	←	φ64×10	○	〃
HS	100(SK120), 95, **90**, 80, 70, **60**, 50, 40, **30**	±2	HV10 (5×2)	R VHS≦1.5(70HS and below 1.2)	SK85	φ64×15	○	JIS B 7731
〃	20 (S20C), 7 (C1020P φ64×10)	〃	HS10 (5×2)	⊿HS(HS−VHS) ≦0.5	←	〃	○	〃
HL	HLE (Dia) 850, 800, 700, 600, 500	±15	(HV Calibration)		SK85	φ115×33	○	JIS B 7731
	HLD (WC) 880, 830, 730, 630, 520	〃			〃	〃	○	Related
HR C	70 (SK120), 67, 64, 62, **60**	±1	10 (5×2)	0.2	SKS3	φ64×15	○	JIS B 7730
〃	57, 55, **50**, 45, **40**, 35, **30**, 25, 20, 10	〃	〃	(40RC and below 0.3)	SK85	〃	○	〃
HR A	87, 85, 83, **81**, 78, 75, 71, **65**, 56	〃	〃	0.3	Same as HRC	〃	○	〃
HR 30N	83, **81**, 78, 73, **67**, 60, 55, 50, 41	〃	〃	0.6	〃	〃	○	〃
HR 15N (45N)	92, **90**, 87, 85, **80**, 75 (43) (23)	〃	〃	〃	〃	〃	○	〃
HR B	100, 95, **90**	±2	10 (5×2)	0.8	SK85	φ64×10	△	JIS B 7730
〃	**82**, 72, **62**, 52, **42**, 32	〃	〃	(50RB and below 1.0)	C2600P	〃	△	〃
HR 30 T	78, 72, 62, **52**, 42, 38, 32	〃	〃	1.0	Same as HRB	〃	○	〃
HR 15 T	87, 82, **78**	〃	〃	〃	〃	〃	○	〃
HR (E·M·L·R·F·S)	HRE**90** HRM107 HRL118 HRR123 HRF90	〃	〃	〃	(100HV)	〃	○	JIS K 7202
〃	HRM67 HRL92 HRR**105** HRS90	〃	〃	〃	(40HV)	〃	○	〃
HBW (10/3000)	600, 550, 500, 450, **400**, 350	±15	6 (3×2)	1.5%	SK85	φ115×18	●	JIS B 7736
HB (10/3000)	**300**, 250, 229 (d=4mm), **200**, 180	〃	〃	〃	〃	〃	●	〃
	HB (10/3000) 150, HB (10/500) 125	〃	〃	2.5%	S45C	〃	●	〃
	HB (10/500) 100	〃	〃	3%	S10C	〃	●	〃

Finished test surface; ●Fine grinding, △plate lapping, ○Buffing, □Super finish, ■Super finish(fine), ※φ25×6

New Test Blocks (N. T. B.)※(for Spot Anvil)◇Export only

HRC	67, 64, 62, 60	±1	6 (3×2)	φ50.8×6.4 (φ2'×1/4')	(ASTM E-18)
HRC	55, 50, 45, 40, 35, 30, 25, 20				

where d_2 and D_4 are coefficients required to estimate standard deviation σ from range R (=Max.−Min.) in JIS Z 9021which depend on measurement number n.

2.2. Method for evaluating the hardness uniformity of Vickers test blocks

The demand for Vickers hardness blocks is only about one fifth of that for Rockwell blocks. This is attributable to the slightly lower operability of Vickers testing. However, the industrial significance of Vickers hardness is extremely high in that there is little difference theoretically among the test results obtained with Vickers testers, provided test forces are applied accurately, and that Vickers is the only hardness testing method that covers microscopic to macroscopic fields [3].

Considering the great significance of Vickers blocks, we also estimated the uniformity of blocks, or the variance of hardness values σ_H, for Vickers testing as well, using the same procedures (equation (1)) as those for Rockwell testing.

2.3. Comparison of the uniformity of hardness between Rockwell and Vickers

The estimates of the uniformity of hardness blocks, or the variance of hardness values, made as per 2.1 and 2.2 above represent comparative results of hardness measurements on almost identical test blocks using different test methods: Rockwell and Vickers. However, as shown in Fig.1, it is not very meaningful to compare the variance of hardness values between Rockwell (Type A) and Vickers (Type C) because their measurement principles are fundamentally different.

Therefore, we decided to make the comparison by converting the uniformity of hardness blocks, or the variance of hardness values σ_H, into the variance of indentation depth measurements σ_S. If there is a significant difference between these variances, it is considered to stem from the difference in testing methods, not the hardness blocks tested. One can then draw the conclusion that the variance attributable to hardness blocks is less than the smaller of these variances.

For Rockwell hardness, σ_H can be converted into the variance of indentation depth Δh (Fig. 2) measurements σ_S.

$$\sigma'_S = 2\sigma'_H \ (\mu \text{m}) \tag{2}$$

and,

$$\sigma'_S \ \% = \sigma'_S \ / \ 2(100 - HRC) \times 100(\%) \tag{3}$$

For Vickers hardness, from the relationship of (4), σ'_s could be derived as shown in (5).

$$\frac{\Delta HV}{HV} = 2\frac{\Delta d}{d} \tag{4}$$

where ΔHV is difference of hardness occurred by difference of measured diagonal length of indentation Δd.

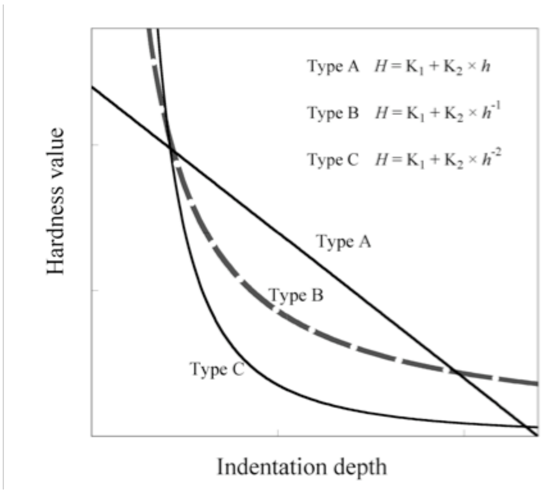

Fig. 1 Relationship between indentation depth and hardness value

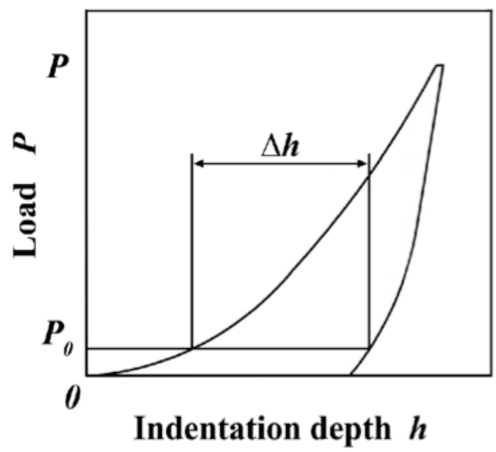

Fig. 2 Measurement of Δh in case of HRC test

Table 2 Assumed non-uniformity σ of hardness and indentation depth from hardness Range R of standard blocks for hardness. (R: Maximum permissible range of n =10 hardness measurements at YSTL)

Nominal hardness (HRC)	HRC						HV		
	Hardness			Size (Depth)			Hardness		Size (Diagonal)
	R (HRC) = D_4Rbar	σ'$_H$ (HRC)	σ'$_H$ % = σ'$_H$/HRC×100	Δh (μm) = (100−HRC)×2	σ'$_S$ (μm) = σ'$_H$×2	σ'$_S$ % = σ'$_S$/Δh×100	R % = D_4Rbar %	σ'$_H$ %	σ'$_S$ % = σ'$_H$ / 2
10	0.3	0.05	0.55 %	180	0.11	0.03 %	1.5 %	0.27 %	0.14 %
20			0.27 %	160		0.03 %			
30			0.18 %	140		0.04 %			
40			0.14 %	120		0.04 %			
45	0.2	0.04	0.08 %	110	0.07	0.05 %			
50			0.07 %	100		0.05 %			
55			0.07 %	90		0.06 %			
60			0.06 %	80		0.06 %			
64			0.06 %	72		0.07 %			
70			0.05 %	60		0.08 %			

Notice 1 For n = 10 , D_4 =1.78 , d_2 = 3.078 ,σ' = D_4Rbar/D_4d_2 = D_4Rbar/5.479 (JIS Z 9021)
Notice 2 Allowance of variation (R = Max.-Min. in n=10 measurements) is based on Table 1

$$\sigma'_S\ \% = \sigma'_H\ \% / 2\ (\%) \tag{5}$$

3. ESTIMATES OF THE HARDNESS UNIFORMITY OF HARDNESS STANDARD BLOCKS

Estimates of σ_H—the uniformity of hardness blocks or the variance of hardness values—made from the results of testing Rockwell blocks (60 HRC and 30 HRC) and their equivalent Vickers blocks (700 HV30 and 300 HV10) to determine their reference values are as follows: $\sigma_H \leqq$ 0.03 HRC for 60 HRC, $\sigma_H \leqq$ 0.05 HRC for 30 HRC, $\sigma_H \leqq$1.2 HV for 700 HV30, and $\sigma_H \leqq$ 0.8 HV for 300 HV10.

Meanwhile, estimates of σ_H—the uniformity of hardness blocks or the variance of hardness values—made from allowances of variation, based on many years of experience, appearing in the YSTL catalogue of standard blocks for hardness are as follows: $\sigma_H \leqq$ 0.04 HRC for 60 HRC, $\sigma_H \leqq$ 0.05 HRC for 30 HRC, $\sigma_H \leqq$1.9 HV for 700 HV30, and $\sigma_H \leqq$ 0.8 HV for 300 HV10 as shown in Table 2.

Although the estimates for 700 HV30 have about a 25% disparity, the other estimates did not show a significant disparity between the two estimation methods.

Therefore, we converted the estimates of σ_H made from the allowances of variation shown in the catalogue into σ_S., or the variance of indentation depth measurements, as mentioned in 2.3 above, to compare Rockwell and Vickers test blocks. The results are: $\sigma_S \leqq 0.06$ % for 60 HRC, $\sigma_S \leqq 0.04$ % for 30 HRC, and $\sigma_S \leqq 0.14\%$ for 700 HV30 and 300 HV10. These results show that the variance of indentation depth measurements σ_S differs by a factor of a few between Rockwell and Vickers methods, even when the same blocks are tested.

This fact shows not only the excellent hardness uniformity of these test blocks, but also that the depth-measuring type of hardness testing method excels over the microscopic measurement type in terms of the resolution of hardness measurements. This may be one of the reasons supporting the prevalence of the Rockwell test method in the industrial world.

It should be noted, however, that this is only limited to the aspect of resolution, and does not automatically apply to the reliability of absolute hardness measurements.

4. CONCLUSIONS

As a result of evaluating the hardness uniformity of test blocks using hardness values and depth of indentations, the hardness uniformity of test blocks was found to be extremely high, which can be translated into less than 0.05% in the variance of indentation depth measurements.

Another finding is that the variance of indentation depth measurements σ_S differs by a factor of a few between the Rockwell and Vickers methods, due to the difference in testing theory, even when the same blocks are tested. It should be noted that this difference only represents the difference in resolutions of measurements between the two methods, and that such a resolution hardly contributes to the reliability of absolute hardness measurements. It is a well-known fact that the reliability of hardness measurements is higher with the Vickers method, particularly because the Vickers method is virtually free from the problem of differences among testers attributable to indenters, and the method and theory of Vickers testing is more straightforward than that of Rockwell, which involves small indentation depth measurements. Considering these facts and the results of evaluating the hardness uniformity of test blocks discussed in this report, we believe that greater efforts should be directed to increasing the accuracy of testers and test methods than the argument over methods of calculating the uncertainty of hardness values.

REFERENCES

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