

# The Present and Future of Hardness Standard Blocks

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## Abstract

Looking at the current status of hardness standards, we occasionally come across the view that it is sufficient that hardness measurements can be matched somewhat forcibly to the hardness values of standard blocks. However, if the direct accuracy of a hardness tester and indenter and loading conditions are well managed and appropriate testing procedures are taken, the measurement of hardness should naturally agree with the value indicated on a standard block, and “hardness” should be an industrial quantity obtained in that way. Therefore, we should recognize anew the original purpose of a hardness standard block as a standard tool, such as the daily inspection (indirect verification) of a tester and/or whether testing practices are under proper management, as well as to make a comparison between testers and/or between indenters. From this standpoint, we, in the capacity of a dedicated test-block manufacturer, discuss the principles of hardness test methods, the uniformity, durability and trends of hardness standard blocks, and future hardness standards relative to the ISO standards, based on our past results from testing and experiments with a number of standard blocks.

**Keywords:** ISO, Standard blocks, Indentation hardness

## 1. Overview of Hardness Tests

The present hardness testing originates from the quantification of hardness by Brinell in 1900, which was followed by Vickers, who established a way of measuring higher hardness, and Rockwell who developed a means of measuring hardness in a way that met the needs of the modern industrial world. In Japan, domestic production of hardness standard blocks started in 1939, which accelerated the introduction of hardness tests into the industrial world<sup>1)</sup>. Recently, machinery industries have been replaced by electronic industries. Accordingly, there is a growing need for micro hardness tests, such as Micro Vickers. The basics of hardness testing are unchangeable, but other changes do have a considerable significance for studies concerning a hardness standard.

The issue of a hardness standard should be discussed after categorizing hardness tests according to such factors as test force, indenter shape, and testing cycle, Tables 1 and 2. In terms of test force—the most important factor—hardness tests can be divided into Type A fixed-load tests, such as Brinell and Rockwell, which are independent of the similarity rule of hardness, and Type B variable-load tests, such as Vickers and Micro Vickers, to which the similarity rule of hardness applies. There are three indenter shapes: ball (Brinell, Rockwell Scale B), pyramidal (Vickers, Knoop, Berkovich), and conical (Rockwell diamond indenter, which has a spherical tip). Testing cycles have two conditions: general industrial conditions as stipulated in ASTM and absolute conditions where velocity and duration of penetration are constant. Although differences in hardness measurements attributable to differences between these two testing cycles are limited, a hardness standard established using general industrial conditions is required to make hardness values relevant to industrial applications.

## 2. The Present Situation of Hardness Standard Blocks

Strictly, the standard values of hardness blocks cannot be determined until the three factors mentioned above are standardized, although measurements of force and length—among the factors constituting a hardness standard—are explicitly traceable to international standards. Accordingly, it may be necessary to address difficulties with such standardization in a realistic manner by recognizing a certain amount of uncertainty<sup>2)</sup>. With this in mind, I would like to discuss the present and the future of hardness standard blocks in the following.

**Table 1 Examples of Hardness Tests Based on Measuring the Area of an Indentation**

Hardness Test Method	Symbol	Method of Measuring the Dimensions of an Indentation		Definition of Hardness = Test Force / Area of Indentation			Indenter			Conceptual Category			Year of Invention	
		Depth measurement	Microscopic	Surface Area	Projected Area	Unit System when Invented	Material	Indenter Shape	Indentation Shape	Macro	Micro	Nano		
Brinell	HB	●	● After load is removed	●		CGS	Carbide (Hard Steel)	Ball	Not similar	●			1900	
Meyer					●		Carbide only for HB Standard						1908	
Vickers	HV			●			●	Diamond	Regular Square Pyramid Angle between opposite faces: 136°	Analogous	●	●		1925
Knoop	HK				●				Quadrangular Pyramid Angle between opposite edges: 172.5 and 130°					1939
Berkovich				●	*				Berkovich Triangular Pyramid Angle between indenter axis and face: 65.03°					1951
Instrumented Indentation (Nano-indentation included)	HM HIT	● When load is applied		●		SI			●	●	●	ISO 14577 - 2002		

\* E. S. Berkovich defines hardness  $H$ , which is determined from the surface area of an indentation ( $H$ ) and the hardness  $H'$ , which is determined from the projected area of an indentation.

**Table 2 Examples of Hardness Tests Based on Measuring the Depth of an Indentation (Rockwell and Rockwell Superficial)**

Hardness Test Method	Symbol	Procedure for Measuring the Dimensions of an Indentation	Definition of Hardness Based on Depth "h"		Indenter			Conceptual Category	Year of Invention
			Formula for Defining Hardness (Initial test force kgf / Full test force kgf)	Unit System When Invented	Material	Indenter Shape	Indentation Shape		
Relatively hard metals	Rockwell	HRC	(1) Apply the initial test force to determine the origin of depth measurement.	Hardness = 100 - 500 h (10 / 150)	CGS	Diamond	Spherical Tip R 0.2 mm Cone Angle 120°	Not Analogous	Macro
	Rockwell Superficial	HR30N		Hardness = 100 - 1000 h (3 / 30)					Macro ( Light test load )
Relatively soft metals	Rockwell	HRB	(2) Increase the load until the full test force is reached.	Hardness = 130 - 500 h (10 / 100)	CGS	Hard Steel Carbide	Ball	Not Analogous	Macro
	Rockwell Superficial	HR30T		Hardness = 100 - 1000 h (3 / 30)					Macro ( Light test load )
			(3) Remove the test force until the initial test force is reached. Then obtain the difference h (mm) in depth between (2) and (1).						



**Fig.1 Appearance of Standard Blocks (Rockwell and Micro-Vickers type)**

**2.1 High-accuracy Hardness Standard Blocks in Compliance with ISO and JIS**

Around 30,000 high-accuracy hardness standard blocks of about 130 different kinds are produced per year in Japan. Fig.1 shows some of these blocks, which have the specifications given in Table 3. Demand for blocks is highest at 40% for Rockwell C Scale, followed by 30% for other Rockwell scales, and the remaining 30% for Brinell, Shore, and Micro Vickers. To maintain the validity of hardness tests, factors concerning the measurement of hardness values, such as indenter,

load—either static or dynamic—measurement of indentations, and test specimen, must be monitored for each type of hardness test. As a standardized test piece, a hardness standard block is designed to reflect these factors in an integrated manner at the site of hardness measurements. Accordingly, a hardness standard block should give uniform hardness measurements, its measurements should not change with time, and preferably its material properties should be identical to those of the test piece to be actually measured. Yamamoto Scientific Tool Laboratory was established in 1939, inheriting the expertise of Shoichi Yamamoto, the founder and the first president of YSTL, who initiated the production of hardness blocks in Japan. Since then the Company has engaged in the development and the production of hardness standard blocks to repay the trust and patronage of its customers worldwide<sup>3), 4).</sup>

## 2.2 Quality System ISO 9001

To prove that YSTL's manufacturing processes for hardness standard blocks are compliant with the standards for hardness standard blocks, we constructed a quality management system to meet the ISO 9001 international standard for quality assurance. This system was certified in 1997 by Japan Quality Assurance Organization. The registration number is JQA-2078 ISO 9001-2000 / JIS 9001-2000.

Table 3 Specification of Standard Blocks

Y.S.T.L.'03

Assortment	Hardness value	Tolerance	Calibration number(n)	Variation (R=Max.-Min)	Materials (JIS notation)	Dimension (mm)	Finished surface	Standard based
HMV (1, 0.1)	1650	±10%	4 (4×2)	2% (HV1)	Si <sub>3</sub> N <sub>4</sub>	□10×5	□	JIS B 7735 <sup>new</sup>
HMV (1, 0.1, 0.01)	900, 800, 700, 600, 500	±15	6 (4×2)	5% (HV0.1)	SK5	φ25×5※	□	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※	□	∕
∕	30 (Gold)	±10	∕	4 (HV0.1)	Au	φ25×5 (0.8)	□	∕
HV (30, 1)	1000(SK2), 900, 800, 700	±15	10 (5×2)/30, 10	1.5%	SKS3	φ64×15	○	JIS B 7735
HV (10, 1)	600, 500, 400, 300, 200(SK5), 150(S45C)	∕	6 (3×2)/1	∕	←	∕	○	∕
∕	100(C2600P), 40(C1020P)	±10	∕	(150HV and below 2.2%)	←	φ64×10	○	∕
Semi HV (5, 0.3)	900, 800, 700, 600, 500, 400, 300, 200	±15	6 (3×2)/5, 0.3	2% (HV0.3)	SK5	φ50×6	○	JIS B 7735
∕	100(C2600P), 40(C1020P)	±10	6 (3×2)/5, 0.1	3% (HV0.3)	←	φ64×10	○	∕
HS	100(SK2), 95, 90, 80, 70, 60, 50, 40, 30±2	∕	HV10 (5×2)	R VHS ≤1.5 <sup>(70HS and below 12)</sup>	SK5	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	∕	∕	SK5	φ115×33	○	JIS B 7731
∕	HLD(WC)880, 830, 730, 630, 520	∕	(HV Calibration)	∕	∕	∕	○	Related
HR C	70(SK2), 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)	SK5	∕	○	∕
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)	∕	∕	∕	∕	∕	○	∕
HR B	100, 95, 90	±2	10 (5×2)	0.8	SK5	φ64×10	△	JIS B 7730
∕	82, 72, 62, 52, 42, 32	∕	∕	(50RB and below 1.0)	C2600P	∕	△	∕
HR 30T	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 HRM 107 HRL118 HRR123 HRF90	∕	∕	∕	(100HV)	∕	○	JIS B 7202
∕	HRM 67 HRL 92 HRR 105 HRS 90	∕	∕	∕	(40HV)	∕	○	∕
HBW(10/3000)	600, 550, 500, 450, 400, 350	±15	6 (3×2)	1.5%	SK5	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: ○Buffing, △plate lapping, □Super finish, ■Fine grinding, ※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, 35, 30, 25, 20	∕	∕	∕	∕	∕	∕

## 2.3 Materials and Manufacturing Methods

We carefully select materials to produce hardness blocks that are suitable for hardness tests for which the blocks are used, and that give uniform hardness measurements. We use a flat material to avoid the influence of central segregation. Materials are machined into different shapes of block, which then undergo carefully controlled heat treatment processes until their microstructure is stabilized, attaining the required level of hardness. For HV-convertible Shore hardness blocks in compliance with a standard that is effective only in Japan, carefully treated eutectoid carbon steel is used to ensure an acceptable relationship for conversion. (See Fig. 2.) After heat treatment, the block is finished by grinding, lapping, wet buffing, or any other appropriate means to increase the accuracy of measurements. During this process, particular attention is paid not to affect the block material, and, micro structure is inspected whenever it is required. (See Fig. 3) The hardness

uniformity of standard block depends on the blocks' material and microstructure. Therefore, the material and the heat treatment process must be examined carefully in accordance with the different purposes of hardness tests, such as HRC HRB, HB, and HVM. The hardness uniformity of our 60 HRC blocks, for example, achieves a value as high as  $\sigma \approx 0.03$  as shown in Table 4. <sup>5)</sup>

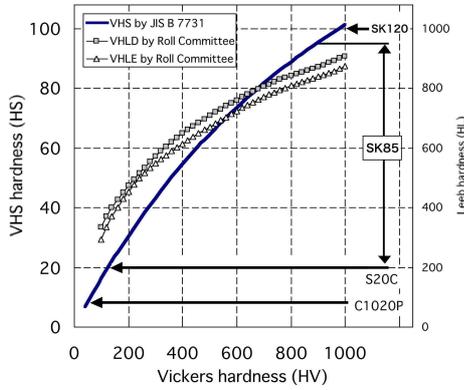


Fig.2 JIS B 7731 VHS Hardness Conversion for Shore Hardness Standard (HV to HS)

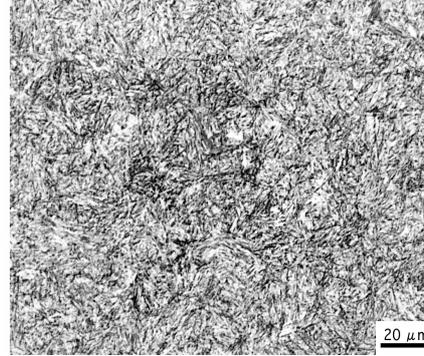


Fig.3 Micro Structure of Standard Block (Eutectoid steel SK85, Water quenched and tempered at 100°C)

Table 4 Uniformity of Hardness Standard Blocks

Block Hardness	Category	Test Points: n	Variation R Average			Estimated Value for $\sigma$ (=R bar/d2)			Coefficient of Variation (%)		
			R1	R2	R total	$\sigma_1$	$\sigma_2$	$\sigma_{total}$	CV1	CV2	CV total
60 HRC (700 HV)	HRC	5 x 2	0.068	0.12	0.143	0.029	0.052	0.046	0.049	0.086	0.077
	HV30	Same as above	2.69	2.83	3.92	1.16	1.22	1.27	0.165	0.174	0.182
	HV1	3 x 2	3.37	3.51	5.03	1.99	2.07	1.99	0.284	0.296	0.284
30 HRC (300 HV)	HRC	5 x 2	0.11	0.14	0.201	0.047	0.060	0.065	0.158	0.201	0.218
	HV10	Same as above	1.91	1.87	2.73	0.82	0.80	0.89	0.274	0.268	0.296
	HV1	3 x 2	2.57	2.58	3.88	1.52	1.52	1.53	0.506	0.508	0.510

Note 1: HRC: Average of 24 lots (480 pieces) HV: Results of investigation on the actual performance of 12 lots (240 pieces) (2004)

Note 2: R = HRC (or HV) max. – HRC (or HV) min. R1 and R2 represent measurements by different testers, and R total shows their average.

## 2.4 Determining Standard Values of Hardness Blocks Under Extensively Adopted Test Cycles

After being heat-treated and finished, hardness standard blocks are tested in one lot—20 pieces—according to reliable metrological standards to determine their standard values. Although it is not available as a primary hardness standard, the hardness value indicated on a hardness standard block must be representative of those obtained by hardness testing carried out at industrial sites. To achieve such a value, the test cycle for determining the value is important. Many proposals have been offered for test cycle factors, such as penetrating speed of indenter and loading time, as adopted extensively at industrial sites. A theoretical analysis of the results of experiments we performed with our high-accuracy standard blocks revealed that strain rate during hardness testing can be described by Equation (1), which supports the time-based definition of strain rate <sup>6)</sup>. The analysis strongly suggests that loading speed should be defined by time, irrespective of type of test and magnitude of test load, in other words, from nano-indentation through Brinell hardness. Accordingly, the corresponding ISO method of definition, which has become somewhat old, may need reconsideration. Let us also add that the test cycle when determining the standard value of a test block must represent those extensively adopted at industrial sites.

$$\dot{\epsilon}(t) = \frac{1}{2} \alpha \frac{n}{t} \quad (1)$$

## 2.5 Overall Accuracy of Hardness Testing Machines and Hardness Standard Blocks

Metrological verification of the overall accuracy of a hardness testing machine requires that relevant factors, such as test force, indenter measurement of indentation, and test cycle, be checked individually for industrial

acceptability primarily through the respective ISO specifications. Meanwhile, these factors can be examined in an integrated manner using a standard block—this is called indirect verification. As a matter of course, metrological accuracy should be complemented with material uncertainties. Hardness standard blocks made by YSTL embody its best efforts with respect of material, heat treatment, and finishing processes.

### 2.6 Useful Life

Irrespective of type, a hardness standard block is carefully heat-treated, and therefore its hardness does not change with time. However, the periphery of an indentation suffers work hardening due to the pressure being applied, which limits the useful life of a block. (The space between indentations is  $4d$ , where  $d$  is the diameter of an indentation.) For this reason, it is recommended to partition the working surface (See Fig. 4). Even if a space of  $4d$  is put between indentations for HRC blocks, however, it is unavoidable that hardness measurements on a block gradually shift with the number of indentations, as suggested in Fig. 5. Therefore, we recommend that about half of the limits shown in Table 5 be applied when an especially high accuracy is required. There is an initiative toward increasing the ISO-specified thickness of non-ferrous blocks, such as HRB, primarily for lengthening useful life, but this should be avoided in consideration of rolling rate and uniformity of re-crystallization, namely uniformity of hardness.

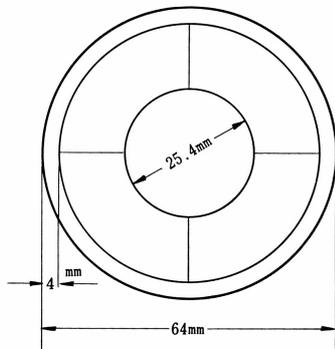


Fig.4 An Example of the Working Surface Divided into Five (n=5)

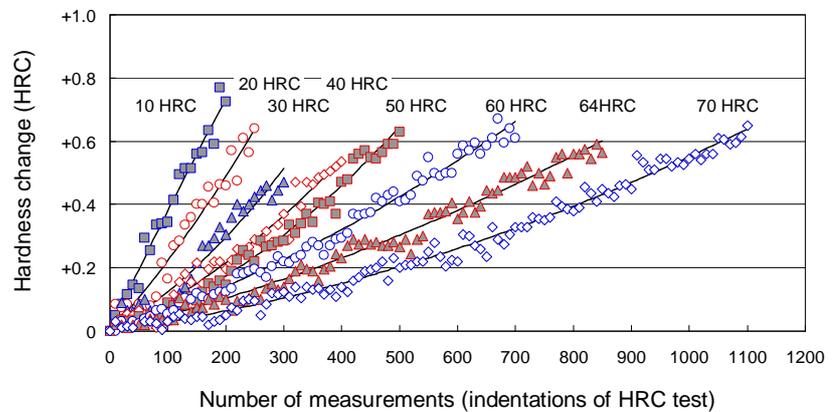


Fig.5 The number of indentations and hardness change

Table 5 The Result of Durability of Rockwell Standard Blocks

Hardness	60HRC	30HRC	90HRB	60HRB
Durable Limit (approx.)	500	260	250	200

(The 14th Japan Hardness Research Association)

### 2.7 Developing Ultra Microhardness and Nano-indentation Blocks

Reflecting increased use of electronics and downsizing of industries, there is growing demand for hardness standard blocks that can respond to smaller test loads. Currently, the standard values of Micro Vickers blocks are measured with a test force of 0.01kgf, in addition to 1kgf and 0.1kgf. The minimum test load of HVM 30 blocks made of pure 0.1 gold is as small as 0.001kgf, so they are available for ultra micro hardness testing. For the nano-indentation market, which has high growth potential, we developed and commercialized the UMV series of hardness blocks exclusively for hardness testing with loads not larger than 1gf. The series consists of UMV 900 and 700 for HV0.01, Fig.6 appearance of W single crystal HV 0.002 and 9.8mN nano-indentation testing, and Test Block for Nanoindentation (trial) UMV 500 and 200 for HV0.01, HV0.001 and 9.8 mN nano-indentation testing. We are now working on the trial production of metallic single crystal test blocks. <sup>7), 8), 9)</sup>



Fig.6 Appearance of W single crystal Nano-indentation Blocks

### 3. Conclusion

Hardness tests and standard blocks for hardness have continued to change with the times. Meantime, the accuracy of standard blocks has been significantly improved due to consistent efforts to meet user needs. It is no exaggeration to state that the history of studies on hardness in Japan represents the history of seeking greater accuracy from hardness standard blocks <sup>10), 11)</sup>. A standard block for hardness provides a temporary hardness standard based on the metrological standards of force and length. As such, we will continue to seek zero hardness dispersion in standard blocks, and would like to ask for the continued support and encouragement of block users.

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