Rockwell Hardness test - Test method

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Introduction

This Standard has been prepared based on the third edition of **ISO 6508-1** published in 2015 with some modifications of the technical contents.

The portions given side-lines or dotted underlines are the matters in which the contents of the corresponding International Standard have been modified.

1 Scope

This Standard specifies the method for Rockwell regular and Rockwell superficial hardness tests for metallic materials and is applicable to stationary and portable hardness testing machines. The scales and applicable range of application are shown in Tables 1 and 2.

For specific materials and/or products like hard metals, other specific standards apply (for instance, **ISO 3738-1 and ISO 4498).**

NOTE 1 Attention is drawn to the fact that, in **ISO 6508-1,** the use of tungsten carbide composite for ball indenters (hereafter referred to as "hard metal ball") is considered to be the standard type of Rockwell and Rockwell superficial indenter balls. Steel indenter balls are allowed to continue to be used only when complying with Annex A. This Standard will adopt hard metal balls as the standard indenter at the time of next revision.

NOTE 2 Attention is drawn to the fact that the result obtained with hard metal balls may be significantly different from the result obtained with steel balls.

NOTE 3 (Editor's note: this note is unrelated to English translation therefore omitted.)

NOTE 4 The International Standard corresponding to this Standard and the symbol of degree of correspondence are as follows.

ISO 6508-1:2015 Metallic materials-Rockwell hardness test-Part 1: Test method (MOD)

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and **JIS** are IDT (identical), **MOD** (modified), and **NEQ** (not equivalent) according to **ISO/IEC Guide 21-1.**

WARNING Persons carrying out tests based on this Standard should be familiar with normal laboratory practice. This Standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this Standard to establish appropriate safety and health practices.

2 Normative references

The following standard contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS B 7726 Rockwell hardness test-Verification and calibration of testing machines

JIS B 7730 Rockwell hardness test-Calibration of reference blocks

3 Principle

An indenter of specified size, shape, and material is forced into the surface of a test specimen under two force levels using the specific conditions defined in clause 7. The specified preliminary force is applied and the initial indentation depth is measured, followed by the application and removal of a specified additional force, returning to the preliminary force. The final indentation depth is then measured and the Rockwell hard ness value is derived from the difference, h, in the final and initial indentation depths and the two constants N and S (see Figure 1, Tables 1, 2 and 3) as:

$$\text{Rockwell hardness} = N - \frac{h}{S} \qquad \text{.....................................(1)}$$

4 Symbols, abbreviated terms and designations

4.1 For symbols and abbreviated terms, see Tables 1, 2 and 3, and Figure 1**.**

Table 1 Rockwell Regular scales

Scale	Hardness symbol	Type of indenter	Preliminary Force F_0 (N)	Total Force F (N)	Scaling Constant S (mm)	Full Range Constant N	Applicable Range of Application
A.	HRA	Diamond cone	98.07	588.4	0.002	100	20 to 95 HRA
B.	HRB	Ball 1587 5 mm	98.07	980.7	0.002	130	10 to 100 HRB
C.	HRC	Diamond cone	98.07	1 471	0.002	100	20[a)] to 70 HRC
D.	HRD	Diamond cone	98.07	980.7	0.002	100	40 to 77 HRD
E.	HRE	Ball 3.175 mm	98.07	980.7	0.002	130	70 to 100 HRE
F.	HRF	Ball 1.587 5 mm	98.07	588.4	0.002	130	60 to 100 HRF
G.	HRG	Ball 1.587 5 mm	98.07	1 471	0.002	130	30 to 94 HRG
H.	HRH	Ball 3.17 5 mm	98.07	588.4	0.002	130	80 to 100 HRH
K.	HRK	Ball 3.17 5 mm	98.07	1 471	0.002	130	40 to 100 HRK

Note [a)] The applicable range of application may be extended to 10 HRC if the indenter is of the appropriate size.

Table 2 Rockwell Superficial scales

Scale	Hardness symbol	Type of indenter	Preliminary Force F_0 (N)	Total Force F (N)	Scaling Constant S (mm)	Full Range Constant N	Applicable Range of application
15N	HR15N	Diamond cone	29.42	147.1	0.001	100	70 to 94 HR15N
30N	HR30N	Diamond cone	29.42	294.2	0.001	100	42 to 86 HR30N
45N	HR45N	Diamond cone	29.42	441.3	0.001	100	20 to 77 HR45N
15T	HR15T	Ball 1.587 5 mm	29.42	147.1	0.001	100	67 to 93 HR15T
30T	HR30T	Ball 1.587 5 mm	29.42	294.2	0.001	100	29 to 82 HR30T
45T	HR45T	Ball 1.587 5 mm	29.42	441.3	0.001	100	10 to 72 HR45T

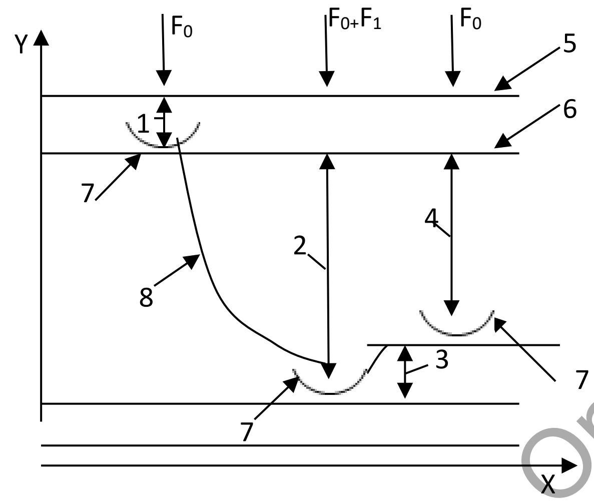
Scales using indenter balls with diameter 6.350 mm and 12.70 mm may also be used, if specified in the product specification or by special agreement. See ASTM E18 [11] for additional scales using these ball sizes.

NOTE 1 For certain materials, the applicable range of application might be narrower than those indicated.

NOTE 2 The numbers representing the test forces were originally based on units of kgf. For example, the total test force of 30 kgf has been converted to 294.2N.

Table 3 Symbols and abbreviated terms

Symbol	Content	Unit
F_0	Preliminary test force	N
F_1	Additional test force (total force minus preliminary force)	N
F	Total test force, $F = F_0 + F_1$	N
S	Scaling constant, corresponding to 1 HR, specific to the scale	mm
N	Full Range Constant, specific to the scale	
h	Permanent depth of indentation under preliminary test force after removal of additional test force	mm
HRA, HRC, HRD	Rockwell Regular hardness = $100 - \frac{h}{0.002}$	
HRB, HRE, HRF, HRG, HRH, HRK	Rockwell Regular hardness = $130 - \frac{h}{0.002}$	
HRN, HRT	Rockwell Superficial hardness = $100 - \frac{h}{0.001}$	



X	time	4.	permanent indentation depth, h
Y	indenter position	5.	surface of specimen
1	indentation depth by preliminary force, F_0	6.	reference plane for measurement
2	indentation depth by additional test force,F_1	7	position of indenter
3	elastic recovery just, after removal of additional Test force, F_1	8	indentation depth vs, time curve

Figure 1 Rockwell Principle diagram

4.2 The following is an example designation of Rockwell hardness.

Example: 70 HR 30T W

- W — Indication of type of ball used, S=steel ball, W= hardmetal ball
- 30T — Rockwell scale symbol (see Tables 1 or 2)
- HR — Rockwell hardness svmbol
- 70 — Rockwell hardness value

NOTE 1 ISO 6508-1 mentions only hard metal balls, W, as indenters.

NOTE 2 ISO 6508-1 permits using steel balls only for **HR30TSm** and **HR15TSm** scales defined in Annex A. A capital S and a lower-case m is used indicating the use of steel indenter balls and a diamond spot specimen holder, respectively.

5 Testing machine

5.1 Testing machine The testing machine shall be capable of applying the test forces for some or all of the Rockwell hardness scales as shown in Tables 1 and 2, performing the procedure defined in clause 7, and complying with all of the requirements defined in **JIS B 7726.**

5.2 Spheroconical diamond indenter Spheroconical diamond indenter (hereafter referred to as "diamond indenter") shall be in accordance with **JIS B 7726**, with an included angle of 120° and radius of curvature at the tip of 0.2 mm. Diamond indenters should be certified for use for either

- only the regular Rockwell diamond scales,
- only the superficial Rockwell diamond scales, or
- both the regular and the superficial Rockwell diamond scales.

5.3 Ball indenter, shall be hard metal intender ball and steel intender ball in accordance with **JIS B 7726**, with a diameter of 1.587 5 mm or 3.175 mm.

NOTE 1 Ball indenters normally consist of a spherical ball and a separate appropriately designed holder. Single-piece spherically tipped indenters are allowed, provided that the surface of the indenter that makes contact with the test piece meets the size, shape, finish, and hardness requirements defined in **JIS B 7726, 5.3.2.**

NOTE 2 **Attention is drawn to the fact that, in ISO 6508-1**, the use of hardmetal indenter balls is the standard type of Rockwell indenter ball. Steel indenter balls can only be used when performing Rockwell HR30TSm andHR15TSm tests according to Annex A.

6 Test piece

6.1 The test shall be carried out on a surface which is smooth and even, free from oxide scale, foreign matter and, in particular, completely free from lubricants, unless specified otherwise in product or materials standards. An exception is made for reactive metals, such as titanium, which might adhere to the indenter. In such situations, a suitable lubricant such as kerosene may be used. The use of a lubricant shall be reported on the test report.

6.2 Preparation shall be carried out in such a way that any alteration of the surface hardness due to excessive heating or cold-working for example, is minimized. This shall be taken into account, particularly in the case of low-depth indentations.

6.3 The thickness of the test piece, or of the layer under test (see Annex B), shall be at least 10 times the permanent indentation depth, h, for diamond indenters and 15 times the permanent indentation depth, h, for ball indenters, unless it can be demonstrated that the use of a thinner test piece does not affect the measured hardness value.

NOTE 1 In general, no deformation should be visible on the back of the test piece after the test, although not all such marking is indicative of a bad test (see Annex A).

See Annex A for special requirements for testing very thin sheet metal using the ~~HR30Tm~~ and ~~HR15Tm~~ scales.

NOTE 2 **ISO 6508-1** permits application of only HR30TSm and HR15TSm scales (a combination of steel indenter balls and a diamond spot specimen holder) to the very thin sheet test pieces specified in Annex A.

6.4 For tests on convex cylindrical surfaces and spherical surfaces, see 7.11.

7 Procedure

7.1 This Standard has been developed with a laboratory temperature requirement of 10 °C to 35 °C. For environments outside the stated requirement, it is the responsibility of the testing laboratory to assess the impact on testing data produced with testing machines operated in such environments. When testing is performed outside the recommended temperature limits of 10 °C to 35 °C, the temperature shall be recorded and reported.

NOTE: If significant temperature gradients are present during testing and/or calibration, measurement uncertainty can increase and out of tolerance conditions can occur.

7.2 The daily verification defined in Annex E shall be performed before the first test of each day for each scale to be used. The condition of diamond indenters should be checked according to Annex F.

7.3 After each change, or removal and replacement, of the indenter, indenter ball, or test piece support, perform at least two tests and discard the results, then determine that the indenter and the test piece support are correctly mounted in the machine by performing the daily verification process defined in Annex E.

7.4 The diamond or ball indenter shall have been the indenter used during the last indirect verification. If the indenter was not used during the indirect verification and is being used for the first time, it shall be verified in accordance with the daily verification given in Annex E using at least two test blocks (one from the low and high ranges as defined in **JIS B 7726,** Table 4) for each Rockwell scale that is normally used. This does not apply to replacing a ball.

7.5 The test piece shall be placed on a rigid support and supported in such a manner that the surface to be indented is in a plane normal to the axis of the indenter and the line of the indenting force, as well as to avoid a displacement of the test piece.

Products of cylindrical shape shall be suitably supported, for example, on centering V-block or double cylinders made of material with a Rockwell hardness of at least 60 HRC. Special attention shall be given to the correct seating, bearing, and alignment of the indenters, the test piece, the centering V-blocks, and the specimen holder of the testing machine, since any perpendicular misalignment might result in incorrect results.

7.6 Bring the indenter into contact with the test surface and apply the preliminary test force, F_0, without shock, vibration, etc. The preliminary force application time should not exceed 2 s. The duration of the preliminary test force shall be $3 \pm^{1}_{2}$ s

NOTE: The requirements for the time durations are given with asymmetric limits.

$3 \pm^{1}_{2}$ indicates that 3 s is the ideal time duration, with an acceptable range of not less than 1s (3 s-2 s) to not more than 4 s (3 s+1 s).

7.7 Measure the initial indentation depth (indentation depth by the preliminary force, F). For many manual (dial-indicator) machines, this is done by setting the indicating dial to its set-point or zero position. For many automatic (digital) machines, the depth measurement is made automatically without the user's input and might not be dis played.

7.8 Apply the additional force F, without shock, vibration, oscillation, or overload to increase the force from F_0 to the total force, F. For the regular Rockwell scale tests, apply the additional test force, Fi, in not less than 1s and not more than 8 s. For all HRN and HRT Rockwell superficial test scales, apply the additional test force, Fi, in less than or equal to 4 s. It is recommended to perform the same test cycle used during indirect verification.

NOTE: There is evidence that some materials might be sensitive to the rate of straining which causes small changes in the value of the yield stress. The corresponding effect on the termination of the formation of an indentation can make an alteration in the hardness value.

7.9 The total test force, F, shall be maintained for a duration of $5\pm^{1}_{3}$ s. Remove the additional test force, F_1, and, while the preliminary test force, F_0, is maintained, after $4\pm^{1}_{3}$ s, the final reading shall be made.

As an exception for test materials exhibiting excessive plastic flow (indentation creep) during the application of the total test force, special considerations might be necessary since the indenter will continue to penetrate. When materials require the use of a total force duration that exceeds the 6 s allowed by the tolerances, the actual extended total force duration used shall be reported following the test results (for example, HRFW/ 10 s).

7.10 Measure the final indentation depth while the preliminary test force, F_0, is applied. The Rockwell hardness number is calculated from the permanent indentation depth, h, using the formula given in Formula (1) and the information given in Tables 1, 2, and 3. For most Rockwell hardness machines, the depth measurement is made in such a manner that the Rockwell hardness number is automatically calculated and displayed.

The derivation of the Rockwell hardness number described in 7.6 to 7.10 is illustrated in Figure 1.

7.11 For tests on convex cylindrical surfaces and spherical surfaces, the corrections given in Annex C (Table C.1, Table C.2, Table C.3 or Table C.4) or in Annex D (Table D.1) shall be applied.

In the absence of corrections for tests on concave surfaces, tests on such surfaces should be the subject of special agreement.

7.12 Throughout the test, the apparatus shall be protected from shock or vibration.

7.13 The distance between the centres of two adjacent indentations shall be at least three times the diameter of the indentation. The distance from the centre of any indentation to an edge of the test piece shall be at least two and a half times the diameter of the indentation.

8 Uncertainty of the results

A complete evaluation of the uncertainty should be done according to **ISO/IEC Guide 98-3 [3].** Independent of the type of sources, for hardness, there are two possibilities for the determination of the uncertainty.

- One possibility is based on the evaluation of all relevant sources appearing during a direct calibration. As a reference, an EURAMET Guide CG-16 [4] is available.
- The other possibility is based indirect calibration using a hardness reference block (abbreviated as CRM certified reference material) [2] [3] [4] [5]. A guideline for the determination is given in Annex G.

NOTE: Annex G states that it would be inappropriate to make any further allowance for this uncertainty in the test for assessing the properties specified in the standard specification.

9 Test report

The laboratory shall record at least the following information and that information shall be included in the test report, unless agreed by the parties concerned:

a) Reference to this Standard;

b) All details necessary for the complete identification of the test piece, including the curvature of the test surface and the correction;

c) The test temperature, if it is not within the limits of 10 °C to 35 °C;

d) The hardness result in the format defined in 4.2;

e) all operations not specified in this Standard, or regarded as optional;

f) Details of any occurrence which might have affected the result;

g) The actual extended total force duration time used, if greater than the 6s allowed by the tolerances;

h) The date the test was performed;

i) If conversion to another hardness scale is also performed, the basis and method of this conversion shall be specified (see ISO 18265, [12]).

10 Conversions to other hardness scales or tensile strength values

There is no general process for accurately converting Rockwell hardness into other scales, or hardness into tensile strength. Such conversions, therefore, should be avoided, unless a reliable basis for conversion can be obtained by comparison tests (see **also ISO 18265, [12]).**

Annex A (normative)

Special HR30Tm and HR15Tm test for thin products

A.1 General

This test is applicable to thin sheet metal products having a maximum thickness of 0.6 mm to the minimum thickness indicated in the product standards unless otherwise specified in the product specification or agreed by the parties concerned. It ensures the sufficient accuracy for products of a maximum hardness of 82 HR30Tm or 93 HR15Tm.

Here, m indicates the use of diamond spot specimen holder. The scale designation is TSm where steel indenter balls are used or TWm where hard-metal intender balls are used.

The product standard shall specify or the parties concerned shall agree when the Special HR80Tm or HR15Tm hardness test is to be applied.

This test is carried out under conditions similar to those in the HR30T or HR15T test.

NOTE 1 **ISO 6508-1** permits only a combination of steel ball indenter and diamond spot specimen holder (TSm).

NOTE 2 Prior to testing, hardness tests should be made on thin sheet samples of a known hardness to verify that the specimen holder (diamond spot specimen holder) surface does not affect the measurement results.

The following requirements shall be met, in addition to those specified in this Standard.

A.2 Ball indenter

A hardened steel ball indenter or hard-metal ball indenter, that meets the requirements of **JIS B 7726,** with a diameter of 1.587 5 mm shall be used for this testing.

A.3 Test piece support

The test piece support shall comprise a polished and smooth flat diamond surface ap proximately 4.5 mm in diameter. This support surface shall be approximately centred on the axis of the indenter and shall be perpendicular to it. Care shall be taken to ensure that it is seated correctly on the machine table.

A.4 Test piece preparation

Normally the test piece preparation shall not be carried out. If it is necessary to remove material from the test piece, this should be done on both sides of the test piece. Care shall be taken to ensure that this process does not change the condition of the base metal, for example, by heating or work hardening. The base metal shall not be made thinner than the minimum allowable thickness.

A.5 Position of the test piece

The distance between the centres of two adjacent indentations or between the centre of one of the indentations and the edge of the test piece shall be at least 5 mm, unless otherwise specified.

Annex B (normative)

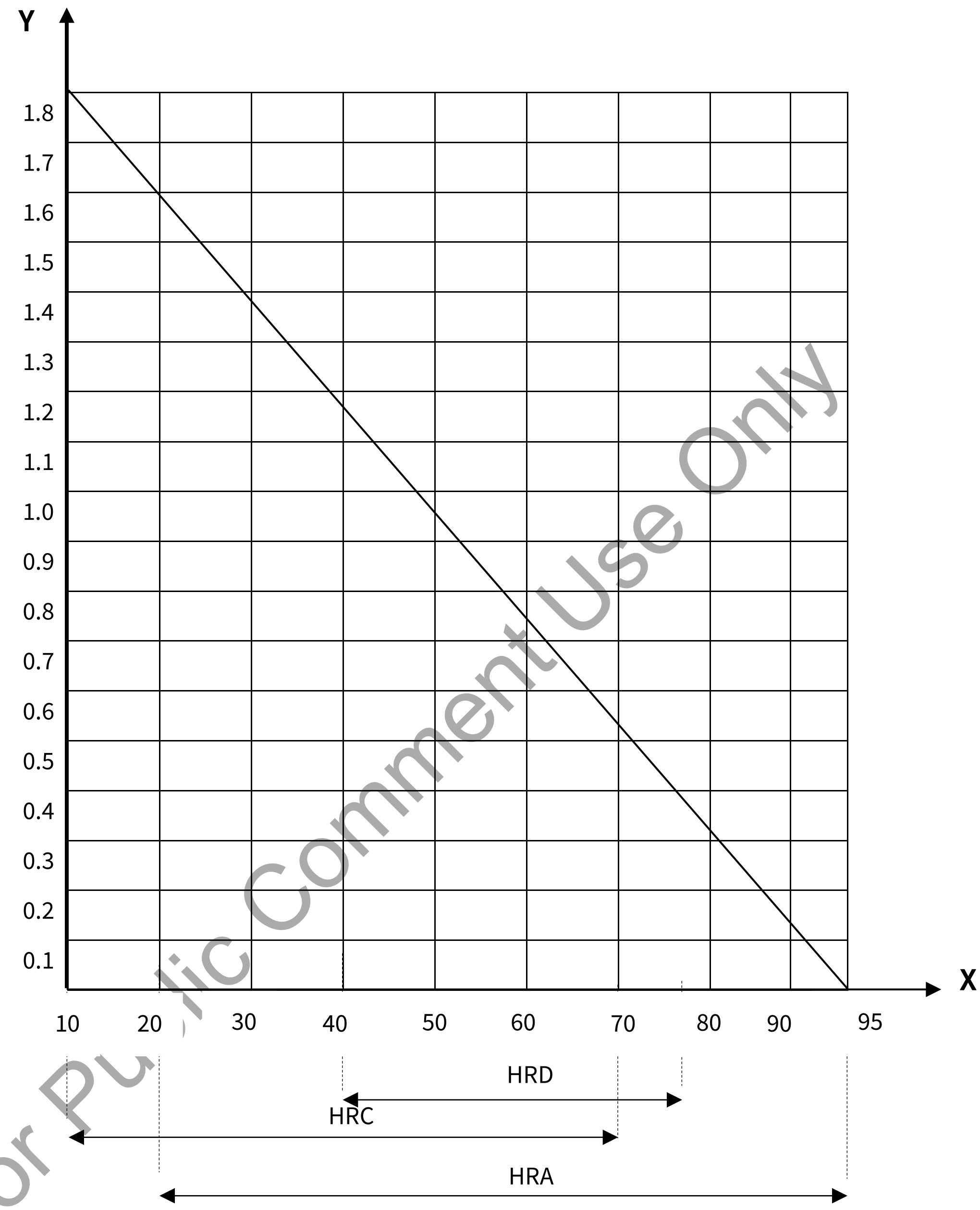
Minimum thickness of the test piece in relation to the Rockwell hardness

The minimum thickness of the test piece, or of the layer under test, is given in Figures B.1 to B.3.

NOTE: Table B.1 shows the formulae for calculating the minimum thickness (mm) of the test piece.

Table B.1 Formulae for calculating the minimum thickness of test piece from indenter and hardness

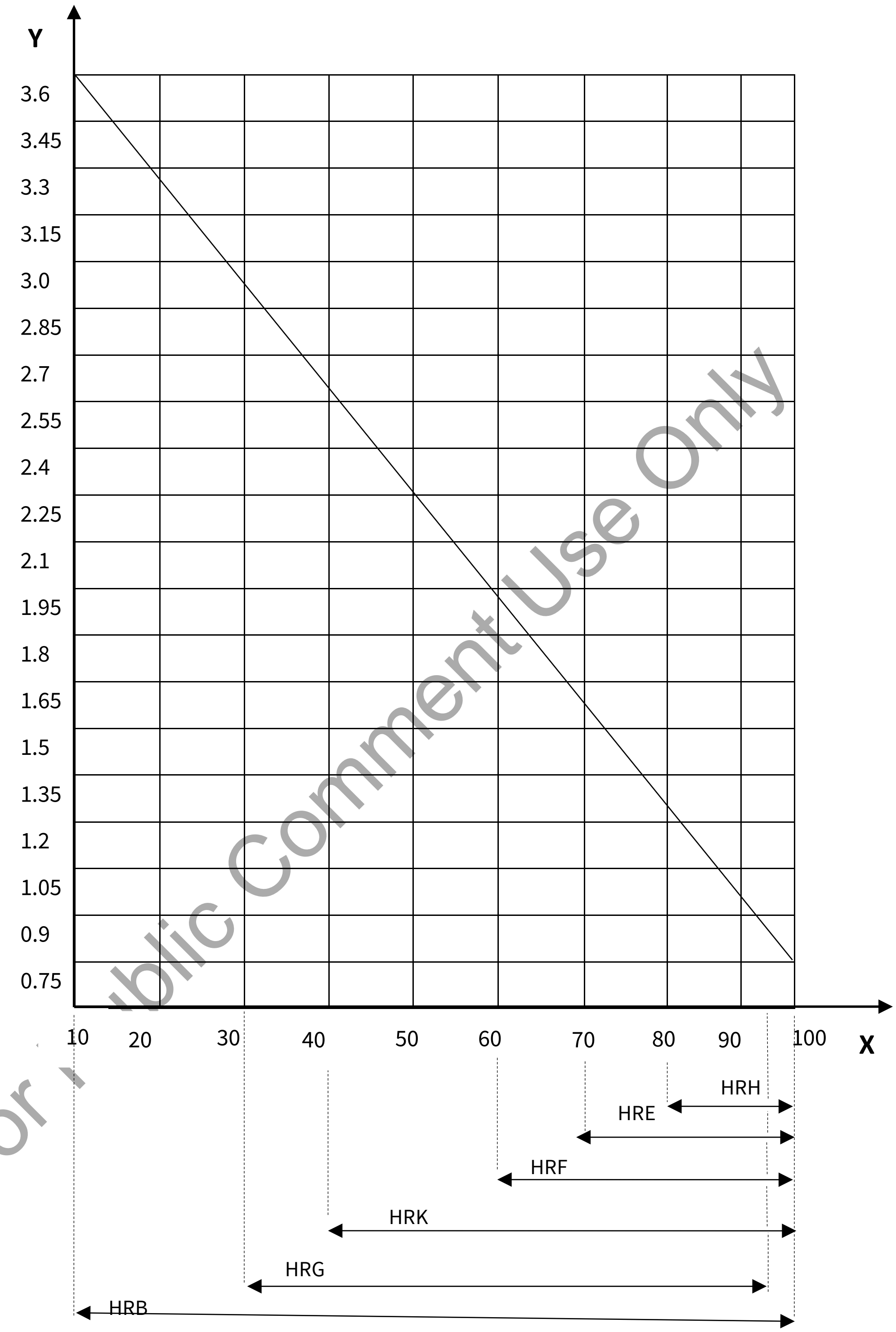
Type of indenter	Minimum thickness of test piece *t* (mm)	
	Rockwell regular hardness	Rockwell superficial hardness
Diamond indenter	10 *h* or 0.02 (100-H)	10 *h* or 0.01 (100-H)
Ball indenter	15 *h* or 0.03 (130-H)	15*h* or 0.015 (100-H)
Where, h: permanent indentation depth (mm) , H : hardness value		



X Rockwell hardness

Y Minimum thickness of the test piece or of the layer under test (mm)

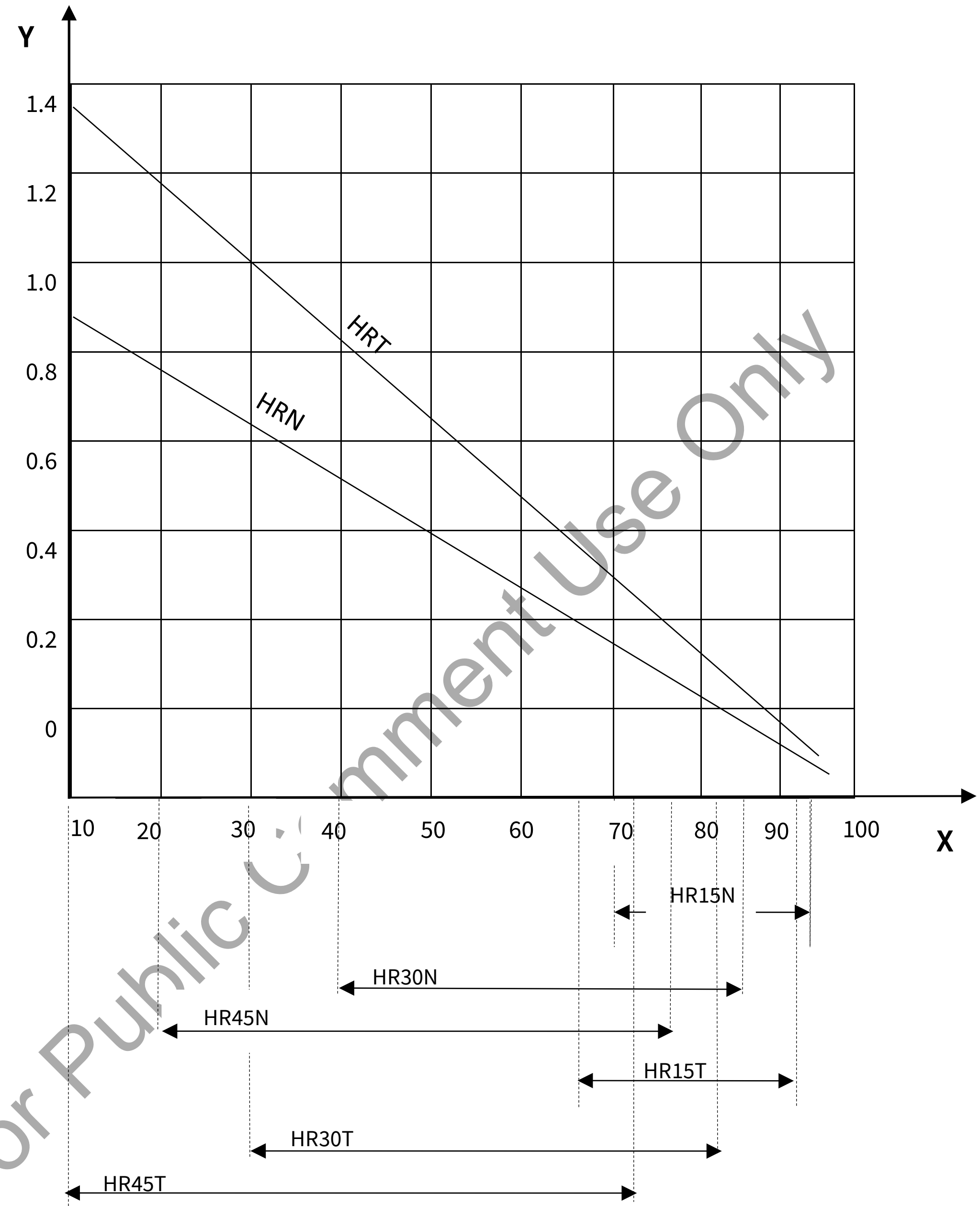
Figure B.1 Minimum thickness of test specimen for test with diamond cone indenter (scales A, C, and D)



X Rockwell hardness

Y Minimum thickness of the test piece or of the layer under test (mm)

Figure B.2 Minimum thickness of test specimen for test with ball indenter (scales B, E, F, G, H, and K)



X Rockwell hardness

Y Minimum thickness of the test piece or of the layer under test (mm)

Figure B.3 Minimum thickness of test specimen for Rockwell superficial test (scales N and T)

Annex C (normative)
Corrections to be added to Rockwell hardness values obtained on convex cylindrical surfaces

For tests on convex cylindrical surfaces, the corrections given in Tables C.1 to C.4 shall be applied. For radii other than those given in these tables, corrections may be derived by linear interpolation.

Table C.1 Test with diamond cone indenter (scales A, C, and D)

Rockwell Hardness reading	Radius of curvature (mm)								
	3	5	6.5	8	9.5	11	12.5	16	19
20				2.5	2.0	1.5	1.5	1.0	1.0
25			3.0	2.5	2.0	1.5	1.0	1.0	1.0
30			2.5	2.0	1.5	1.5	1.0	1.0	0.5
35		3.0	2.0	1.5	1.5	1.0	1.0	0.5	0.5
40		2.5	2.0	1.5	1.0	1.0	1.0	0.5	0.5
45	3.0	2.0	1.5	1.0	1.0	1.0	0.5	0.5	0.5
50	2.5	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5
55	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0
60	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
65	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
70	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0	0
75	1.0	0.5	0.5	0.5	0.5	0.5	0	0	0
80	0.5	0.5	0.5	0.5	0.5	0	0	0	0
85	0.5	0.5	0.5	0	0	0	0	0	0
90	0.5	0	0	0	0	0	0	0	0
NOTE: Corrections greater than 3 HRA, 3 HRC, and 3 HRD are not considered acceptable and are therefore not included in this table									

Table C.2 Tests with 1.587 5 mm ball indenter (scales B, F, and G)

Rockwell Hardness reading	Radius of curvature (mm)						
	3	5	6.5	8	9.5	11	12.5
20				4.5	4.0	3.5	3.0
30			5.0	4.5	3.5	3.0	2.5
40			4.5	4.0	3.0	2.5	2.5
50			4.0	3.5	3.0	2.5	2.0
60		5.0	3.5	3.0	2.5	2.0	2.0
70		4.0	3.0	2.5	2.0	2.0	1.5
80	5.0	3.5	2.5	2.0	1.5	1.5	1.5
90	4.0	3.0	2.0	1.5	1.5	1.5	1.0
100	3.5	2.5	1.5	1.5	1	1	0.5
NOTE: Corrections greater than 5 HRB, 5 HRF, and 5 HRG are not considered acceptable and are therefore not included in this table							

Table C.3 Rockwell superficial test (scales 15N, 30N, 45N) a) b)

Rockwell Hardness reading	Radius of curvature (mm)					
	1.6	3.2	5	6.5	9.5	12.5
20	(6.0)[c]	3.0	2.0	1.5	1.5	1.5
25	(5.5)[c]	3.0	2.0	1.5	1.5	1.0
30	(5.5)[c]	3.0	2.0	1.5	1.0	1.0
35	(5.0)[c]	2.5	2.0	1.5	1.0	1.0
40	(4.5)[c]	2.5	1.5	1.5	1.0	1.0
45	(4.0)[c]	2.0	1.5	1.0	1.0	1.0
50	(3.5)[c]	2.0	1.5	1.0	1.0	1.0
55	(3.5)[c]	2.0	1.5	1.0	0.5	0.5
60	3.0	1.5	1.0	1.0	0.5	0.5
65	2.5	1.5	1.0	0.5	0.5	0.5
70	2.0	1.0	1.0	0.5	0.5	0.5
75	1.5	1.0	0.5	0.5	0.5	0
80	1.0	0.5	0.5	0.5	0	0
85	0.5	0.5	0.5	0.5	0	0
90	0	0	0	0	0	0

Notes a) These corrections are approximate only and represent the averages, to the nearest 0.5 Rockwell superficial hardness units, of numerous actual observations of the test surfaces having the curvatures given in this table.

b) When testing convex cylindrical surfaces, the accuracy of the test will be seriously affected by misalignment of the elevating screw, V-specimen holder and indenter and by imperfections in the surface finish and straightness of the cylinder.

c) The corrections given in parentheses shall not be used, except by agreement.

Table C.4 Rockwell superficial test (scales 15T, 30T, 45T) a) b)

Rockwell Hardness reading	Radius of curvature (mm)						
	1.6	3.2	5	6.5	8	9.5	12.5
20	(13.0)c)	(9.0)c)	(6.0)c)	(4.5)c)	(3.5)c)	3.0	2.0
30	(11.5)c)	(7.5)c)	(5.0)c)	(4.0)c)	(3.5)c)	2.5	2.0
40	(10.0)c)	(6.5)c)	(4.5)c)	(3.5)c)	3.0	2.5	2.0
50	(8.5)c)	(5.5) c)	(4.0)c)	3.0	2.5	2.0	1.5
60	(6.5)c)	(4.5)c)	3.0	2.5	2.0	1.5	1.5
70	(5.0)c)	(3.5)c)	2.5	2.0	1.5	1.0	1.0
80	3.0	2.0	1.5	1.5	1.0	1.0	0.5
90	1.5	1.0	1.0	0.5	0.5	0.5	0.5

Notes a) These corrections are approximate only and represent the averages, to the nearest 0.5 Rockwell superficial hardness units, of numerous actual observations of the test surfaces having the curvatures given in this table.

b) When testing convex cylindrical surfaces, the accuracy of the test will be seriously affected by misalignment of the elevating screw, V-specimen holder and indenter and by imperfections in the surface finish and straightness of the cylinder.

c) The corrections given in parentheses shall not be used, except by agreement.

Annex D (normative)

Corrections to be added to Rockwell hardness C scale values obtained on spherical test surfaces of various diameters

For tests on convex spherical surfaces, the corrections given in Table D.1 shall be applied.

Table D.1 Correction values AH to be added to Rockwell hardness C scale values

Rockwell Hardness reading	Diameter of sphere *d* (mm)								
	4	6.5	8	9.5	11	12.5	15	20	25
55 HRC	6.4	3.9	3.2	2.7	2.3	2.0	1.7	1.3	1.0
60 HRC	5.8	3.6	2.9	2.4	2.1	1.8	1.5	1.2	0.9
65 HRC	5.2	3.2	2.6	2.2	1.9	1.7	1.4	1.0	0.8

The values of the correction to be added to Rockwell hardness C scale AH, given in Table D.1, are calculated using the following formula:

$$\Delta H = 59 \times \frac{\left(1 - \frac{H}{160}\right)^2}{d} \quad \text{(D.1)}$$

Where, *H* is the Rockwell hardness C scale reading (before correction);
d is the diameter of the sphere, expressed in millimetres.

Annex E (normative)

Daily verification procedure

E.1 General

A daily verification of the machine shall be carried out on each day that the machine is used by performing tests in each hardness scale that is to be used that day. Select at least one hardness reference block that meets the requirements of JIS B 7730 from the ranges defined in Table E.1. It is recommended that the hardness level selected be close to the levels to be tested. Only the calibrated surface of the test blocks are to be used for testing. Perform at least two indentations on each block and calculate the bias and repeatability of the results using the formulas defined below. If the bias and repeat ability are within the permissible limits given in Table E.1, the machine may be regarded as satisfactory. If not, verify that the indenter, specimen holder, and tester are in good condition and repeat the test. If the machine continues to fail the daily test, an indirect verification, according to JIS B 7726, clause 6, shall be performed.

A record of the daily verification results should be maintained over a period of time, and used to measure reproducibility and monitor drift of the machine.

E.2 Bias

The bias, b, of the testing machine in Rockwell units, under the particular verification conditions, is expressed by Formula (E.1):

$$b = H - H_{CRM} \quad \text{(E .1)}$$

Where, H is the mean hardness value from Formula (E.2);
H_{CRM} is the certified hardness of the reference block used.

The mean hardness value of the indentations H is defined according to Formula (E.2);

$$\overline{H} = \frac{H_1 + \ldots\ldots + H_n}{n} \quad \textbf{(E.2)}$$

Where, $H_1, H_2, H_3, H_4, \ldots H_n$ are the hardness values corresponding to all the indentations;
n is the total number of indentations.

E.3 Repeatability range

To determine the repeatability range for each reference block, let H_1, ..., H_n be the values of the measured hardness arranged in increasing order of magnitude.

The repeatability of the testing machine in Rockwell units, under the particular verification conditions, is determined by Formula (E.3):

$$r = H_n - H_1 \quad \text{(E.3)}$$

Table E.1 Permissible repeatability range and error of the testing machine

Rockwell hardness Scale	Hardness range of the reference block	Permissible bias b Rockwell units	Permissible repeatability range of the testing machine[a)]
A	20 to ≤ 75 HRA >75 to ≤ 95 HRA	± 2 HRA ± 1.5HRA	≤ 0.02(100- $\overline{H}$) or 0.8 Rockwell units [b)]
B	10 to ≤ 45 HRB >45 to ≤ 80 HRB >80 to ≤ 100 HRB	± 4 HRB ± 3 HRB ± 2 HRB	≤ 0.04(130- $\overline{H}$) or 1.2 Rockwell units [b)]
C	10 to ≤ 70 HRC	± 1.5HRC	≤ 0.02(100- $\overline{H}$) or 0.8 Rockwell units [b)]
D	40 to ≤ 70 HRD >70 to ≤ 77 HRD	± 2 HRD ± 1.5HRD	≤ 0.02(100- $\overline{H}$) or 0.8 Rockwell units [b)]
E	70 to ≤ 90 HRE >90 to ≤ 100 HRE	± 2.5H¯RE ± 2 HRE	≤ 0.04(130- $\overline{H}$) or 1.2 Rockwell units [b)]
F	60 to ≤ 90 HRF >90 to ≤ 100 HRF	± 3 HRF ± 2 HRF	≤ 0.04(130- $\overline{H}$) or 1.2 Rockwell units [b)]
G	30 to ≤ 50 HRG >50 to ≤ 75 HRG >75 to ≤ 94 HRG	± 6 HRG ± 4.5HRG ± 3 HRG	≤ 0.04(130- $\overline{H}$) or 1.2 Rockwell units [b)]
H	80 to ≤ 100 HRC	± 2 HRH	≤ 0.04(130- $\overline{H}$) or 1.2 Rockwell units [b)]
K	40 to ≤ 60 HRK >60 to ≤ 80 HRK >80 to ≤ 100 HRK	± 4 HRK ± 3 HRK ± 2 HRK	≤ 0.04(130- $\overline{H}$) or 1.2 Rockwell units [b)]
15N, 80N, 45N	All ranges	± 2 HRN	≤ 0.04(100- $\overline{H}$) or 1.2 Rockwell units [b)]
15T, 30T, 45T	All ranges	± 3 HRT	≤ 0.06(100- $\overline{H}$) or 2.4 Rockwell units [b)]

Notes a) H is the mean hardness value.

b) Whichever is greater.

Example 1 A low-hardness HRC block gave the following daily verification results:

24.0 HRC and 25.2 HRC

From Formula (E.2), it follows $\overline{H}$ =24.6 HRC and from Formula (E.3), it follows r =1.2 HRC Rockwell units.

From Table E.1, for the HRC scale, the permissible repeatability range at HRC 24.6 = 0.02 (100-24.6) = 1.51 HRC Rockwell units. This is greater than 0.8 HRC Rockwell units, therefore, the permissible repeatability range of the testing machine for this reference block is 1.51 HRC Rockwell units.

Since r =1.2 HRC Rockwell units, the repeatability of the testing ma chine is acceptable.

Example 2 A high-hardness HRC block gave the following daily verification results:

63.1 HRC and 63.9 HRC

From Formula (E.2), it follows $\overline{H}$ = 63.5 HRC and from Formula (E.3), it follows r = 0.8 HRC Rockwell units

From Table E.1, for the HRC scale, the permissible repeatability range at HRC 63.5 = 0.02 (100-63.5) = 0.73 HRC Rockwell units. This is less than 0.8 HRC Rockwell units, therefore, the permissible repeatability range of the testing machine for this reference block is 0.8 HRC Rockwell units.

Since r = 0.8 HRC Rockwell units, the repeatability of the testing ma chine is acceptable.

Annex F (normative)

Inspection of diamond indenters

Experience has shown that a number of initially satisfactory indenters can become defective after use for a comparatively short time. This is due to small cracks, pits, or other flaws in the surface. If such faults are detected in time, many indenters can be reclaimed by regrinding. If not, any small defects on the surface rapidly worsen and make the indenter useless. Therefore, the condition of indenters should be checked initially and at frequent intervals using appropriate optical devices (microscope, magnifying glass, etc.)

- the verification of the indenter is no longer valid when the indenter shows defects;
- Reground or otherwise repaired indenters shall be verified in accordance with the requirements of **JIS B 7726.**

Annex G (informative)

Uncertainty of the measured hardness values

G.1 General requirements

Measurement uncertainty analysis is a useful tool to help determine sources of error and to understand differences in test results. This Annex gives guidance on uncertainty estimation but the methods contained are for information only, unless specifically instructed otherwise by the customer. Most product specifications have tolerances that have been developed over the past years based mainly on the requirements of the product but also, in part, on the performance of the machine used to make the hardness measurement. These tolerances therefore incorporate a contribution due to the uncertainty of the hardness measurement and it would be inappropriate to make any further allowance for this uncertainty by, for example, reducing the specified tolerance by the estimated uncertainty of the hardness measurement. In other words, where a product specification states that the hardness of an item shall be higher or lower than a certain value, this should be interpreted as simply specifying that the calculated hardness value(s) shall meet this requirement, unless specifically stated otherwise in the product standard. However, there might be special circumstances where reducing the tolerance by the measurement uncertainty is appropriate. This should only be done by agreement of the parties involved.

The approach for determining uncertainty presented in this Annex considers only those uncertainties associated with the overall measurement performance of the hardness testing machine with respect to the hardness reference blocks (abbreviated as CRM below). These performance uncertainties reflect the combined effect to all the separate uncertainties. Because of this approach, it is important that the individual machine components are operating within the tolerances. It is strongly recommended that this procedure should be applied for a maximum of one year after the successful passing of a verification and calibration.

Annex I shows the four-level structure of the metrological chain necessary to define and disseminate hardness scales. The chain starts at the international level using international definitions of the various hardness scales to carry out international intercomparisons. A number of primary hardness standard machines at the national level (the second level) "produce" primary hardness reference blocks for the calibration laboratory level. These blocks will help define the hardness calibration machine (third level). Finally, the calibration machine enables hardness reference blocks at User level (fourth level) to be obtained. Naturally, direct calibration and the verification of these machines should be at the highest possible accuracy.

G.2 General procedure

This procedure calculates an expanded uncertainty, U, associated the measured hardness value. Two different approaches to this calculation are given in Tables G.1 and G.2, together with details of the symbols used. In both cases, a number of uncorrelated standard uncertainty sources are combined by the Root-Sum-Square (RSS) method and then multiplied by the coverage factor k = 2. In one approach, the uncertainty contribution from a systematic source is then added arithmetically to this value. In the other approach, a correction is made to the measurement resulting to compensating for this systematic component.

NOTE: This uncertainty approach makes no allowance for any possible drift in the machine performance subsequent to its last calibration, as it assumes that any such changes will be insignificant in magnitude. As such, most of this analysis could be performed immediately after the machine's calibration and the results included in the machine's calibration certificate.

G.3 Bias of the machine

The bias, b, of a hardness testing machine (also termed 'error') is derived from the difference between the following values, and can be implemented in different ways into the determination of uncertainty (G.4.2 and G.4.3) [see Formula (E.1)]:

- the certified calibration value of the hardness reference block, and
- the mean hardness value of the five indentations made in the hardness reference block during calibration of the hardness testing machine.

G.4 Procedures for calculating uncertainty: Hardness measurement values

G.4.1 General

Two methods are given for determining the uncertainty of hardness measurements:

-Method M1: accounts for the systematic bias of the hardness machine in two different ways;

-Method M2: allows the determination of uncertainty without having to consider the magnitude of the systematic bias.

Additional information on calculating hardness uncertainties can be found in the literature. [3] [4]

NOTE: In this Annex, the abbreviation "CRM" stands for "Certified Reference Material". In hardness testing standards, certified reference material is equivalent to the hardness reference block, i.e., a piece of material with a certified value and associated uncertainty.

G.4.2 Procedure with bias (method M1)

The method M1 procedure for the determination of measurement uncertainty is explained in Table G.1.

The measurement bias, b, of the hardness testing machine can be expected to be a systematic effect. In **ISO/IEC Guide 98-3**, [3] it is recommended that a correction be used to compensate for systematic effects, and this is the basis of M1. The result of using this method is either all determined hardness values x have to be reduced by b [see Formula (G.3)] or the uncertainty U_{corr} has to be increased by *b* [see Formula (G.4)]. The procedure for the determination of U_{corr} is explained in Table G.1. [6] [7]

The combined expanded measurement uncertainty U_{corr} for a single hardness measurement is calculated as:

$$U_{corr} = k \times \sqrt{u^2_H + u^2_{ms} + u^2_{HTM}} \quad \text{..........} \quad (G.1)$$

where, u_H is a contribution to the measurement uncertainty due to the lack of measurement repeatability of the hardness testing machine;

u_{ms} is a contribution to the measurement uncertainty due to the resolution of the hardness testing machine;

u_{HTM} is a contribution to the measurement uncertainty due to the standard uncertainty of the bias, *b*, measurement generated by the hardness testing machine [this value is reported as a result of the indirect verification defined in **JIS B 7726** and is defined according to Formula (G.2)]:

$$U_{HTM} = \sqrt{u^2_{CRM} + u^2_{HCRM} + u^2_{ms}} \quad \text{....... (G.3)}$$

where, u_{CRM} is the contribution to the measurement uncertainty due to the calibration uncertainty of the certified value of the CRM according to the calibration certificate for k=1;

u_{HCRM} is the contribution to the measurement uncertainty due to the combination of the lack of measurement repeatability of the hardness testing machine and the hardness non-uniformity of the CRM;

u_{ms} is the contribution to the measurement uncertainty due to the resolution of the hardness testing machine when measuring the CRM.

The result of the measurement is given by Formula (G.3) and Formula (G.4), respectively:

$$X_{corr} = (x - b) \pm U_{corr} \quad \text{....... (G.3)}$$

where, X_{corr} hardness measurement value corrected with the bias, *b*

or by

$$X_{ucorr} = {}_x \pm (U_{corr} \pm |b|) \quad \text{....... (G.4)}$$

Where, X_{ucorr} hardness measurement value obtained by adding the bias, *b*, to the uncertainty

depending on whether the bias (error), *b*, is considered to be part of the mean value or of the uncertainty.

When method M1 is used, it can also be appropriate to include additional uncertainty contributions within the RSS term relating to the value of b employed. This will particularly be the case when

_ the measured hardness is significantly different from the hardness levels of the blocks used during the machine's calibration,

_ the machine's bias value varies significantly throughout its calibrated range,

_ the material being measured is different from the material of the hardness reference blocks used during the machine's calibration, or

_ the day-to-day performance (reproducibility) of the hardness testing machine varies significantly.

The calculations of these additional contributions to the measurement uncertainty are not discussed here. In all circumstances, a robust method for estimating the uncertainty associated with *b* is required.

G.4.3 Procedure without bias (method M2)

As an alternative to method M1, method M2 can be used in some circumstances. Method M2 is a simplified method which can be used without needing to consider the magnitude of any systematic error of the hardness testing machine; however, Method M2 usually over-estimates the real measurement uncertainty.

The procedure for the determination of U is explained in Table G.2.

Method M2 is only valid for hardness testing machines that have passed an indirect verification in accordance with JIS B 7726 using the maximum deviation including the expanded uncertainty of the testing machine, $\Delta H_{HTMmax} = |b| + U_{HTM}$, rather than only the bias value, b, when determining compliance with the maximum permissible deviation of the bias.

In method M2, the bias (error) limit (the positive amount by which the machine's reading is allowed to differ from the reference block's value, as specified in **JIS B 7726)** is used to define one component b_E of the uncertainty. There is no correction of the hardness values with respect to the bias limit.

The combined expanded measurement uncertainty U for a single future hardness measurement is calculated as:

$$U = k \times \sqrt{u^2_H + u^2_{ms}} + b_E \quad \text{(G.5)}$$

where, u_H is a contribution to the measurement uncertainty due to the lack of measurement repeatability of the hardness testing machine;

U_{ms} is a contribution to the measurement uncertainty due to the resolution of the hardness testing machine;

B_E is the maximum permissible deviation of the bias as specified in **JIS B 7726,**

and the result of the measurement, X, is given by

$$X = x \pm U \quad \text{(G.6)}$$

G.5 Expression of the result of measurement

When reporting the measurement result, the method (M1 or M2) used to estimate the uncertainty should also be specified.

Example: A hardness testing machine makes a single Rockwell C hardness measurement, x, on a test sample.

Single hardness measurement value, x: x = 60.5HRC

Resolution of the hardness testing machine, δ_{ms} : δ_{ms} = 0.1HRC

The last indirect verification of the testing machine determined a measurement bias, b, with an uncertainty of the bias U_{HTM} using a CRM of $\overline{x}_{CRM}$ = 62.82HRC. The hardness of this CRM was the closest to the test sample hardness of those CRMs used for the indirect verification.

Testing machine measurement bias, b : b = -0.72HRC

Uncertainty of the testing machine measurement bias, U_{HTM} : U_{HTM} = 0.66 HRC

To determine the lack of repeatability of the testing machine, the laboratory made five HRC measurements H on a CRM having a similar hardness to the test sample. The five measurements were made adjacent to each other adhering to spacing requirements in order to reduce the influence of block non-uniformity.

Five measurement values, H_i : 61.7HRC; 61.9HRC; 62.0HRC; 62.1HRC; 62.1HRC

Mean measurement value, $\overline{H}$ $\overline{H}$ = 61.96HRC

Standard deviation of the measurement values, s_H: s_H = 0.17HRC

where,

$$\overline{H} = \frac{\sum_{i-1}^{n} H_1}{n} \quad \text{……… (G.7)}$$

and

$$S_H = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (H_i - \overline{H})^2} \quad \text{……… (G.8)}$$

where, n = 5

The value of s_H based on measurements from the last indirect verification according to **JIS B 7726** may be used instead of conducting the above repeatability tests; however, this standard deviation value will usually overestimate the lack of repeatability uncertainty component since it also includes the CRM non-uniformity.

Table G.1 Determination of the measurement result according to method MI

Step	Sources of uncertainty	Symbols	Formula	Literature/Certificate	Example [..] = HRC
1	Bias value *b* and uncertainty U_{HTM} of the bias of the hardness testing machine from the indirect verification	B U_{HTM} u_{HTM}	$U_{HTM} = \frac{U_{HTM}}{2}$	*b* and U_{HTM} according to indirect verification report using a CRM of $\overline{X}_{CRM}$ =62.82HRC (see NOTE 1)	b= 0.72HRC U_{HTM} =0.66 HRC $U_{HTM} = \frac{0.66}{2}$ HRC =0.33 HRC
2	The standard deviation of repeatability measurements	s_H	$S_H = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(H1 - H)^2}$	Five measurements are made by the laboratory on a CRM having a hardness similar to the test sample (see NOTE 2)	S_H = 0.17 HRC
3	Standard uncertainty due to lack of repeatability	U_H	U_H = 1 X S_H (see NOTE 3)	t=1.14 for n=5 (See ISO/IEC Guide 98.3, G=3 and Table G-2)	U_H = (1.14×0.17) HRC =0.19 HRC
4	Standard uncertainty due to resolution of the hardness value indicating display	U_{ms}	$U_{ms} = \frac{d_{ms}}{2\sqrt{3}}$	d_{ms} = 0.1HRC	$U_{ms} = \frac{0.1}{2\sqrt{3}}$ = 0.03
5	Determination of the corrected expanded uncertainty	U_{corr}	$U_{corr} = k \times \sqrt{U^2_H + U^2_{ms} + U^2_{HTM}}$	Steps 1,3, and 4 K=2	$U_{corr} = 2 \times \sqrt{0.192 + 0.03^2 + 0.33^2}$ U_{corr} = 0.76 HRC
6	Measurement result with modified hardness	X_{corr}	X_{corr} = (x –b) ±U_{corr}	Steps 1 and 5	X = 60.5 HRC X_{corr} = (61.2 ±0.8) HRC
7	Measurement result with modified uncertainty	X_{ucorr}	X_{uacorr} = x ±(U_{corr} + |b|)	Steps 1 and 5	X = 60.5 HRC X_{ucorr} = (60.5 ±1.5) HRC

NOTE 1 If $0.8b_E<b<1.0b_E$, the relationship of hardness values between CRM and sample should be considered.

NOTE 2 To reduce the influence of block non-uniformity, the measurements should be made close to each other, adhering to spacing requirements. The value of s_H , based on measurements from the last indirect verification according to **JIS B 7726** can be used, but will usually overestimate the lack of repeatability uncertainty component since it includes the **CRM** non-uniformity.

NOTE 3 In circumstances where the average of multiple hardness measurements on a test sample is to be reported, rather than a single hardness measurement, the value of s, in Step 3 should be replaced with the standard deviation of the multiple hardness measurements of the sample under test divided by the square-root of the number of hardness measurements n, and the value of t should be appropriate for the measurements (u_H=1x $S_H/\sqrt{n}$). The calculated uncertainty contribution, u_H. will then also account for the non-uniformity of the test sample.

Table G.2 Determination of the measurement result according to method M2

Step	Description	Symbols	Formula	Literature/Certificate	Example [..] = HRC
1	Expanded uncertainty derived from maximum permissible error (permissible deviation of the bias of the testing machine)	b_E	b_E = Maximum positive value of permissible bias	Permissible bias b according to JIS B 7726, Table 5	b-1.50
2	The standard deviation of repeatability measurements	S_H	$S_H = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(H_i - \bar{H}\ )^2}$	Five measurements are made by the laboratory on a CRM having a hardness similar to the test	S_H= 0.17 HRC
3	Standard uncertainty due to lack of repeatability	U_H	$U_H = t \times S_H$	t=1.14 n=5 (See ISO/IEC Guide 98-3, G.3 and Table G.2)	U_H=1.14 × 0.17=0.19
4	Standard uncertainty due to resolution of the hardness value indicating display	U_{ms}	$U_{ms} = \frac{d_{ms}}{2\sqrt{3}}$	d_{ms} = 0.1 HRC	$U_{ms} = \frac{0.1}{2\sqrt{3}} = 0.03$
5	Determination of the expanded uncertainty	U	$U = k \times \sqrt{u_H^2 + u_{ms}^2} + b_E$	Steps 1, 3, and 4 k = 2	$U = 2 \times \sqrt{0.19^2 + 0.03^2} + 1.50$ U = 1.88 HRC
6	Result of the measurement	X	$X = x \pm U$		x=60.5 HRC X = (60.5±1.9) HRC

NOTE: The value of s_H, based on measurements from the last indirect verification according to JIS B 7726 can be used, but will usually overestimate the lack of repeatability uncertainty component since it includes the CRM non-uniformity. In circumstances where the average of multiple hardness measurements on a test sample is to be reported, rather than a single hardness measurement, the value of s_H in Step 3 should be replaced with the standard deviation of the multiple hardness measurements of the sample under test divided by the square-root of the number of hardness measurements n and the value of t should be appropriate for the n measurements ($u_H = t \times s_H / \sqrt{n}$. The calculated uncertainty contribution, u_H, will then also account for the non-uniformity of the test sample.

Annex H (informative)

CCM-Working Group on Hardness

In 1999, at the 88th Session of the International Committee of Weights and Measures. (CIPM), Dr. Kozo lizuka, President of the Consultative Committee for Mass and Related Quantities (CCM), stated "Although the definition of hardness scales is certainly conventional in the sense of the use of arbitrarily chosen formula, the testing method is defined by a combination of physical quantities expressed by SI units; the standard of hardness is established and maintained in most of NMIS and the traceability to the standard of NMIs is demanded in industry and elsewhere." The subsequent discussions led to the realization that hardness standards should be included in the key comparison database (KCDB) for the Mutual Recognition Arrangement (MRA), and thus, a full Working Group on Hardness (CCM-WGH) was established in the framework of the CCM. [8]

The establishment of the CCM-WGH provided a technical-diplomatic framework in which hardness influenced parameters can be examined, and improved international definitions of the hardness tests can be proposed and approved for NMI use to reduce the measurement differences at the highest national level. Due to the necessity of international agreement, the CCM-WGH has a close liaison with ISO/TC 164/SC 3 in order to ensure proper dissemination of the hardness scales. The most significant improvement of the CCM-WGH definitions is that the parameters of the hardness test are defined with specific values, rather than ranges of acceptable limits as specified by this test method. As applicable, this test method has adopted the defined values of the CCM-WGH definitions as the values to use.

The CCM-WGH definitions are published at http://www.bipm.org/

Annex I (informative)

Rockwell hardness measurement traceability

I.1 Traceability definition

The path to traceability for a Rockwell hardness measurement is different compared to many other measurement quantities, such as length or temperature. This is primarily because hardness measurement, including Rockwell, is made following a defined test procedure using a testing machine that makes multiple measurements of different parameters (e.g., force, depth, time) during the test. Each of these measurements, as well as other test parameters, influences the hardness result.

The International Vocabulary of Metrology (VIM3) [10] defines metrological traceability as the property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

From this definition, two things are necessary for a measurement result to have traceability:

a) an unbroken chain of calibrations, each contributing to the measurement uncertainty;

b) a reference to which traceability is claimed.

These will define the metrological traceability chain.

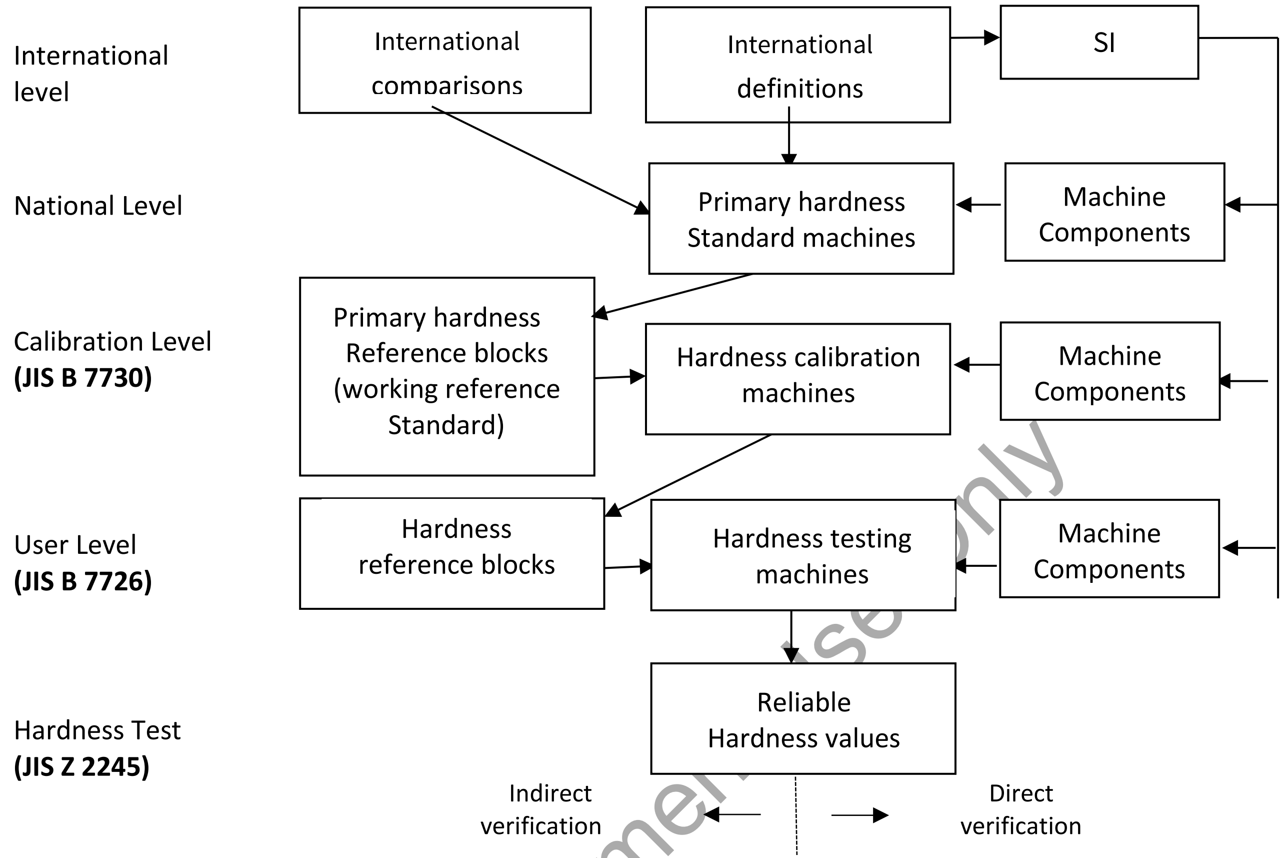
I.2 Chains of calibrations

JIS B 7726 specifies a set of calibration and verification procedures required to demonstrate that the testing machine is suitable for use in accordance with this Standard. The calibration procedures include direct measurements of various components affecting the machine's performance, such as the test forces, indenter shape, and depth measuring equipment, as well as hardness measurements of a range of reference blocks. Each of these calibration measurements has specified limits within which the result should lie in order for the machine to pass its verification. Historically, the calibration and verification of the machine components has been termed the machine's Direct Verification and the calibration and verification of the testing machine by reference block measurements is Indirect Verification.

JIS B 7730 specifies both the procedure required to calibrate the reference blocks used in the Indirect Verification of the testing machine and also the required calibration and verification procedures of the machine used to calibrate these blocks.

When considering an "unbroken chain of calibrations" to provide measurement trace ability to the testing machine, it is apparent that this could come via either the Direct Verification or Indirect Verification path.

Direct Verification requirements specify measurements of individual components of the testing machine, with traceability of each of these measurements being achieved through calibration chains to the International System of units (SI), usually as realized by a National Metrology Institute (NMI). These calibration chains are illustrated on the right-hand side of Figure I.1. Together, these calibration chains form a traceability path for a testing machine.



NOTE: The left-hand side of Figure 1.1 illustrates a traceability path made through a single calibration chain for each level in the calibration hierarchy (i.e. National, Calibration and User) that includes the calibration of reference blocks and the subsequent Indirect Verification of Rockwell hardness machines. A (National level) primary standard machine calibrates primary reference blocks [working reference standard (test sample)] that are then used to calibrate a (Calibration level) calibration machine. This machine calibrates reference blocks that are finally used to calibrate a (User level) testing machine.

Figure I.1 Chains of Calibration

I.3 Rockwell hardness reference

The other requirement for achieving traceability is a reference to which traceability is claimed. Rockwell hardness is not a fundamental property of a material, but rather an ordinal quantity dependent on a defined test method. Ideally, the ultimate reference for a Rockwell hardness measurement should be an internationally agreed definition of this method, including values of all test parameters. Hardness traceability would then be, to this definition through a laboratory's realization or fulfillment of the definition, the accuracy of this realization being reflected in the laboratory's measurement uncertainty and confirmed by international comparisons. The internationally agreed definition would be developed by the CCM Working Group on Hardness (CCM-WGH) (see Annex H) and realized by NMIs that standardize Rockwell hardness. At this time, the CCM-WGH has not developed definitions for all Rockwell hardness scales so, for the undefined scales, the highest reference is usually an NMI's realization of the Rockwell scale based on its own chosen definition of the test.

I.4 Practical issues

Either one of the two traceability paths of calibration chains illustrated in Figure I.1 (left-hand side and right-hand side) could theoretically provide traceability to an appropriate Rockwell hardness reference. However, there are practical issues with both that should be considered. For the Direct Verification path given on the right-hand side of Figure 1.1, it is extremely difficult to identify, measure, and, if necessary, correct for all parameters that might affect the measured hardness value. Even if the machine passes its Direct Verification, traceability will not be ensured if one or more uncontrolled or unidentified parameters have a significant effect. This is often the case and becomes more of an issue at lower levels in the calibration hierarchy.

The Indirect Verification calibration chain shown on the left-hand side of Figure I.1 also has practical issues to be considered. One consequence of using a testing machine having multiple components, each making measurements during the hardness test, is that an error in one component's measurement can be compensated or offset by an error in a different component's measurement. This can result in accurate hardness measurements for the specific hardness levels and block materials tested during the indirect verification; however, measurement error can increase when testing other hardness levels or materials. If the errors in the individual machine components are significant, then traceability may not be ensured again.

I.5 Rockwell hardness measurement traceability

I.5.1 General

The above issues indicate that both types of traceability path usually need to be in place for achieving Rockwell hardness measurement traceability. This does not mean that traceability cannot be achieved based on only one of the two paths, if careful examination and evaluation of the measurement process is made. For example, at the National Level, the traceability of an NMI's primary Rockwell hardness standard machine is achieved through a Direct Verification calibration chain since there is no recognized higher-level hardness reference artefact. Traceability through this path is possible since NMIs typically have the capability to thoroughly evaluate their measurement systems, and their uncertainty levels are confirmed through international comparisons with other NMIs. In contrast, decades of Rockwell hardness measurement experience has shown that, for the lower levels in the calibration hierarchy, it is most practical to obtain traceability and determine measurement uncertainty based primarily on the Indirect Verification calibration chain; however, proper traceability of the individual machine component quantity values is also important. This traceability scheme has proven to be suitable for industrial Rockwell hardness measurements.

I.5.2 Calibration level traceability

Measurement traceability is best obtained through the Indirect Verification calibration chain using primary reference blocks that have been calibrated at the National level (NMI). This is also the path that should be used for the determination of measurement uncertainty. At the same time, however, the specified components of the calibration machine should be calibrated on a frequent basis to ensure that offsetting errors are not significant. Hardness traceability should be to the NMT's realization of the CCM-WGH definition of the Rockwell scale or, when there is an absence of a CCM-WGH definition; traceability should be to the NMI's realization of its own chosen definition. If the NMI does not provide calibrated reference blocks or conduct comparison measurements with a Calibration laboratory and it is not practical to use reference blocks of another NMI, then the reference to which traceability is claimed might need to be to the Calibration laboratory's realization of the Rockwell scale definition based on an international test method, such as that defined by this Standard. In this case, the Calibration laboratory's measurement traceability can be achieved through the Indirect Verification path using consensus reference block standards, or through the Direct Verification path confirmed by intercomparisons.

I.5.3 User level traceability

Measurement traceability is best obtained through the Indirect Verification calibration chain using reference blocks that have been calibrated at the Calibration level or National level. As with Calibration level traceability, this is the most practical path and should also be used for the determination of measurement uncertainty. It is also desirable that the components of the hardness machine periodically undergo Direct Verification to ensure that offsetting errors are not significant. However, typical industrial practice is for these measurements to be made only when the hardness machine is manufactured or repaired, which is the minimum requirement of this Standard.

NOTE: The following terms used in this Annex are in accordance with the VIM3 [10]: calibration, calibration hierarchy, metrological traceability, metrological traceability chain, ordinal quantity and verification.

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