INTERNATIONAL STANDARD

ISO 6508-1

Fourth edition
2016-08-15

Metallic materials — Rockwell hardness test —

Part 1:
Test method

Matériaux métalliques — Essai de dureté Rockwell —

Partie 1: Méthode d'essai

Reference number
ISO 6508-1:2016(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html .

The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 3, *Hardness testing*.

This fourth edition cancels and replaces the third edition (ISO 6508-1:2015), of which it constitutes a minor revision in order to clarify the scope of this part of ISO 6508.

ISO 6508 consists of the following parts, under the general title *Metallic materials — Rockwell hardness test*:

— *Part 1: Test method*

— *Part 2: Verification and calibration of testing machines and indenters*

— *Part 3: Calibration of reference blocks*

Metallic materials — Rockwell hardness test —

Part 1:
Test method

1 Scope

This part of ISO 6508 specifies the method for Rockwell regular and Rockwell superficial hardness tests for scales A, B, C, D, E, F, G, H, K, 15N, 30N, 45N, 15T, 30T, and 45T for metallic materials and is applicable to stationary and portable hardness testing machines.

For specific materials and/or products, other specific International Standards apply (for instance, ISO 3738-1 and ISO 4498).

NOTE Attention is drawn to the fact that the use of tungsten carbide composite for ball indenters is considered to be the standard type of Rockwell indenter ball. Steel indenter balls are allowed to continue to be used only when complying with Annex A.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6508-2:2015, *Metallic materials — Rockwell hardness test — Part 2: Verification and calibration of testing machines and indenters*

ISO 6508-3:2015, *Metallic materials — Rockwell hardness test — Part 3: 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 hardness value is derived from the difference, h, in the final and initial indentation depths and the two constants N and S (see Figure 1, Table 1, and Table 2) as shown in Formula (1):

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

4 Symbols, abbreviated terms and designations

4.1 See Table 1, Table 2, Table 3, and Figure 1.

Table 1 — Rockwell Regular scales

Rockwell Regular hardness scale	Hardness symbol Unit	Type of indenter	Preliminary force F_0	Total force F	Scaling Constant S	Full Range Constant N	Applicable range of application (Rockwell Regular hardness scales)
A	HRA	Diamond cone	98,07 N	588,4 N	0,002 mm	100	20 HRA to 95 HRA
B	HRBW	Ball 1,587 5 mm	98,07 N	980,7 N	0,002 mm	130	10 HRBW to 100 HRBW
C	HRC	Diamond cone	98,07 N	1,471 kN	0,002 mm	100	20 HRC[a] to 70 HRC
D	HRD	Diamond cone	98,07 N	980,7 N	0,002 mm	100	40 HRD to 77 HRD
E	HREW	Ball 3,175 mm	98,07 N	980,7 N	0,002 mm	130	70 HREW to 100 HREW
F	HRFW	Ball 1,587 5 mm	98,07 N	588,4 N	0,002 mm	130	60 HRFW to 100 HRFW
G	HRGW	Ball 1,587 5 mm	98,07 N	1,471 kN	0,002 mm	130	30 HRGW to 94 HRGW
H	HRHW	Ball 3,175 mm	98,07 N	588,4 N	0,002 mm	130	80 HRHW to 100 HRHW
K	HRKW	Ball 3,175 mm	98,07 N	1,471 kN	0,002 mm	130	40 HRKW to 100 HRKW

[a] The applicable range of application can be extended to 10 HRC if the surfaces of the diamond cone and spherical tip are polished for a penetration depth of at least 0,4 mm.

Table 2 — Rockwell Superficial scales

Rockwell Superficial hardness scale	Hardness symbol Unit	Type of indenter	Preliminary force F_0	Total force F	Scaling Constant S	Full Range Constant N	Applicable range of application (Rockwell Superficial hardness scales)
15N	HR15N	Diamond cone	29,42 N	147,1 N	0,001 mm	100	70 HR15N to 94 HR15N
30N	HR30N	Diamond cone	29,42 N	294,2 N	0,001 mm	100	42 HR30N to 86 HR30N
45N	HR45N	Diamond cone	29,42 N	441,3 N	0,001 mm	100	20 HR45N to 77 HR45N
15T	HR15TW	Ball 1,587 5 mm	29,42 N	147,1 N	0,001 mm	100	67 HR15TW to 93 HR15TW
30T	HR30TW	Ball 1,587 5 mm	29,42 N	294,2 N	0,001 mm	100	29 HR30TW to 82 HR30TW
45T	HR45TW	Ball 1,587 5 mm	29,42 N	441,3 N	0,001 mm	100	10 HR45TW to 72 HR45TW

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.

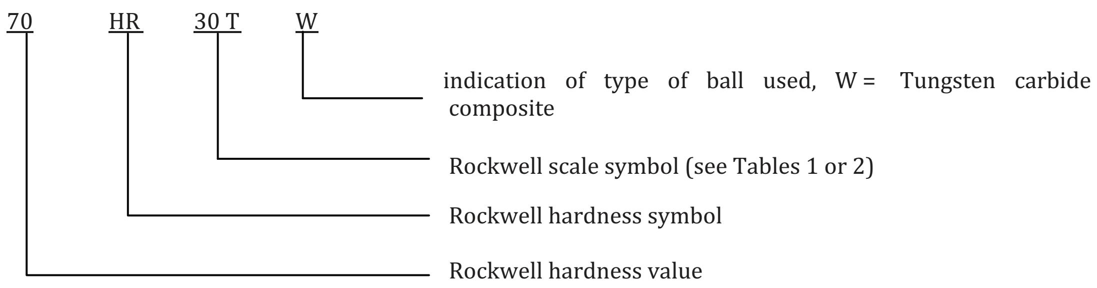
NOTE 2 The numbers representing the test forces were originally based on units of kgf. For example, the total test force of 30 kgf has been converted to 294,2 N.

Table 3 — Symbols and abbreviated terms

Symbol/ Abbreviated term	Definition	Unit
F_0	Preliminary test force	N
F_1	Additional test force (total force minus preliminary force)	N
F	Total test force	N
S	Scaling constant, 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 (permanent indentation depth)	mm
HRA HRC HRD	Rockwell Regular hardness $= 100 - \frac{h}{0,002}$	
HRBW HREW HRFW HRGW HRHW HRKW	Rockwell Regular hardness $= 130 - \frac{h}{0,002}$	
HRN HRTW	Rockwell Superficial hardness $= 100 - \frac{h}{0,001}$	

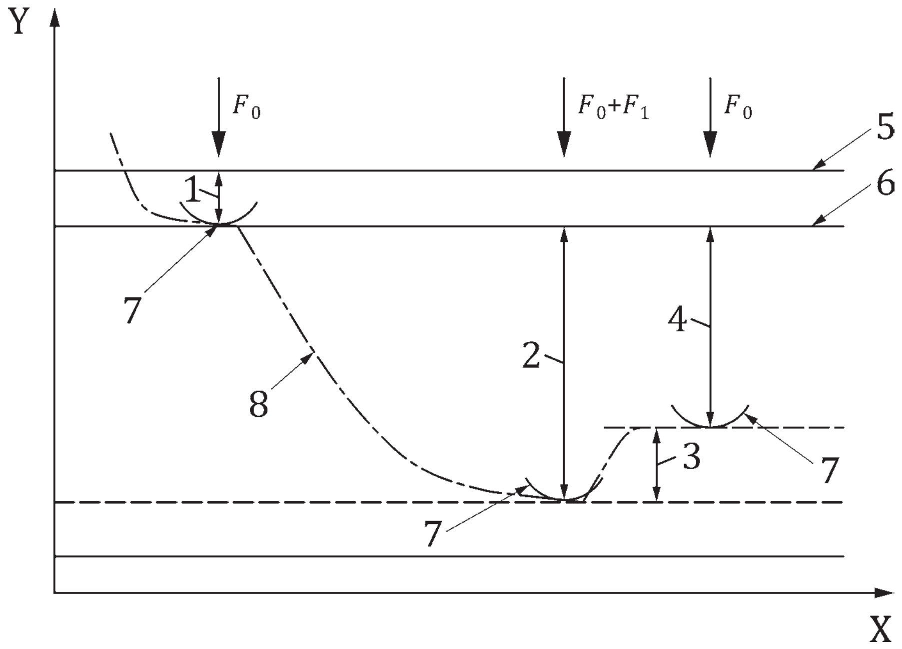
4.2 The following is an example of the designation of Rockwell hardness.

EXAMPLE



NOTE 1 Previous versions of this part of ISO 6508 allowed the use of steel indenter balls, which required the suffix S.

NOTE 2 For the 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.



Key

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

Figure 1 — Rockwell principle diagram

5 Testing machine

5.1 Testing machine, shall be capable of applying the test forces for some or all of the Rockwell hardness scales as shown in Table 1 and Table 2, performing the procedure defined in Clause 7, and complying with all of the requirements defined in ISO 6508-2.

5.2 Spheroconical diamond indenter, shall be in accordance with ISO 6508-2, with an included angle of 120° and radius of curvature at the tip of 0,2 mm. Diamond indenters shall 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 tungsten carbide composite in accordance with ISO 6508-2, with a diameter of 1,587 5 mm or 3,175 mm (see NOTE 1 and NOTE 2).

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 ISO 6508-2:2015, 6.3.1, and meets the performance requirements of ISO 6508-2:2015, 6.3.2.

NOTE 2 Attention is drawn to the fact that the use of tungsten carbide composite for ball indenters is the standard type of Rockwell indenter ball. Steel indenter balls can only be used when performing Rockwell HR30TSm and HR15TSm 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 (minimum values are given in Annex B), shall be at least 10 times the permanent indentation depth for diamond indenters and 15 times the permanent indentation depth for ball indenters, unless it can be demonstrated that the use of a thinner test piece does not affect the measured hardness value.

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 for special requirements for testing very thin sheet metal using the HR30TSm and HR15TSm scales.

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

7 Procedure

7.1 This part of ISO 6508 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 ISO 6508-2:2015, Table 1) 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, oscillation, or overload.

The preliminary force application time should not exceed 2 s. The duration of the preliminary test force, F_0, shall be 3^{+1}_{-2} s.

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

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

7.7 Measure the initial indentation depth.

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 displayed.

7.8 Apply the additional force F_1 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, F_1, in not less than 1 s and not more than 8 s. For all HRN and HRTW Rockwell superficial test scales, apply the additional test force, F_1, 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^{+1}_{-3} s. Remove the additional test force, F_1, and, while the preliminary test force, F_0, is maintained, after 4^{+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, 65 HRF/10 s).

7.10 Measure the final indentation depth while the preliminary test force 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 Table 1, Table 2, and Table 3. For most Rockwell hardness machines, the depth measurement is made in a manner that automatically calculates and displays the Rockwell hardness number.

The derivation of the Rockwell hardness number 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) and in Annex D (Table D.1) shall be applied.

The correction values shall be reported on the test report.

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 on 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.

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) a reference to this part of ISO 6508, i.e. ISO 6508-1;

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

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 part of ISO 6508, 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 6 s 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 HR30TSm and HR15TSm 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, and of a maximum hardness of 82 HR30TSm or 93 HR15TSm. The product standard shall specify when the Special HR30TSm or HR15TSm hardness test is to be applied.

This test is carried out under conditions similar to those in the HR30TW or HR15TW test defined in this part of ISO 6508. The appearance of deformation on the bottom of the test pieces below the indent is permitted.

NOTE 1 The Sm in the scale designations indicates that a steel ball indenter and a diamond spot specimen holder are used for this testing.

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

The following requirements shall be met, in addition to those specified in this part of ISO 6508.

A.2 Ball indenter

A hardened steel ball indenter, that meets the requirements of ISO 6508-2, 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 approximately 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

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.

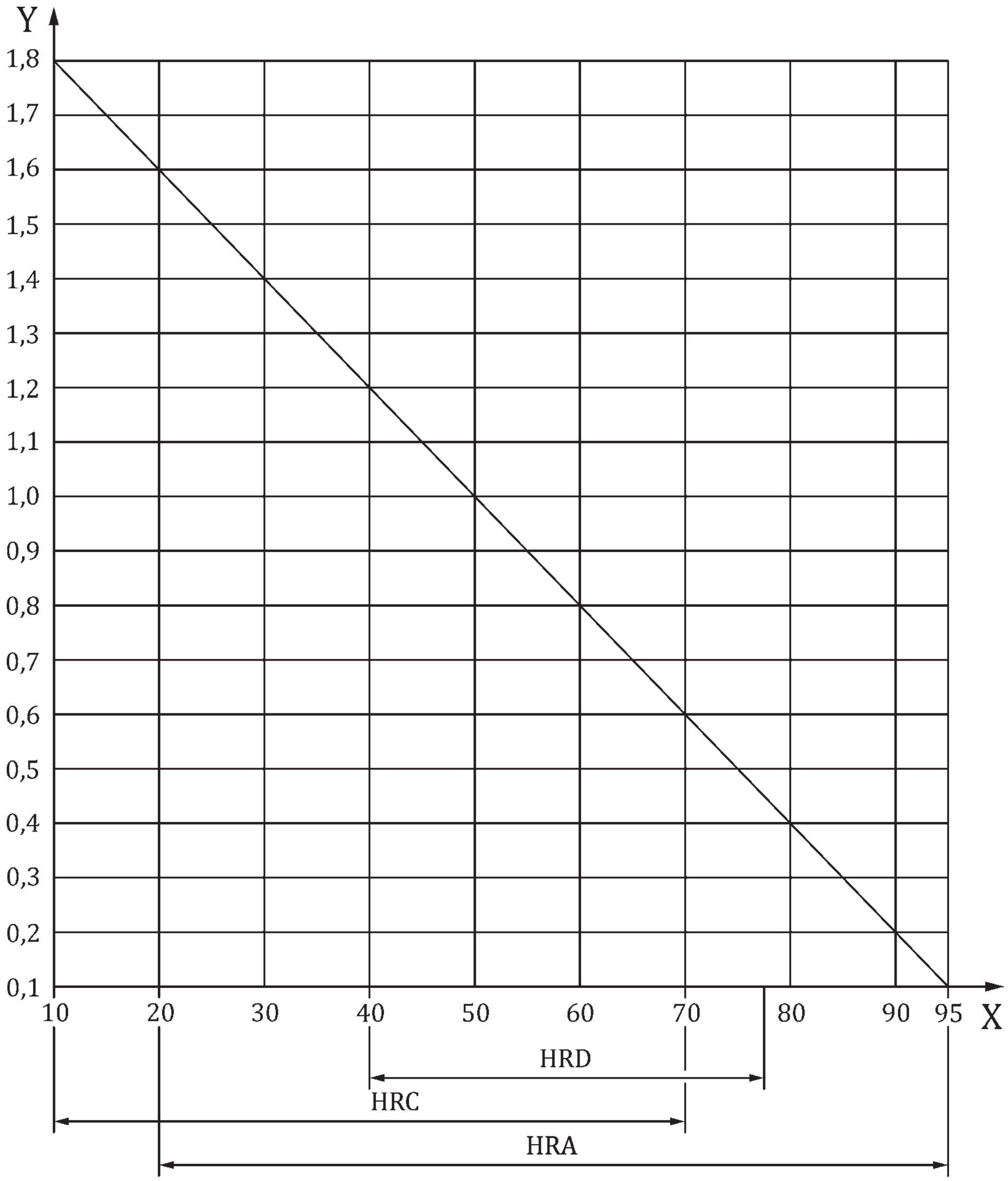
A.5 Position of the test piece

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 Figure B.1, Figure B.2, and Figure B.3.

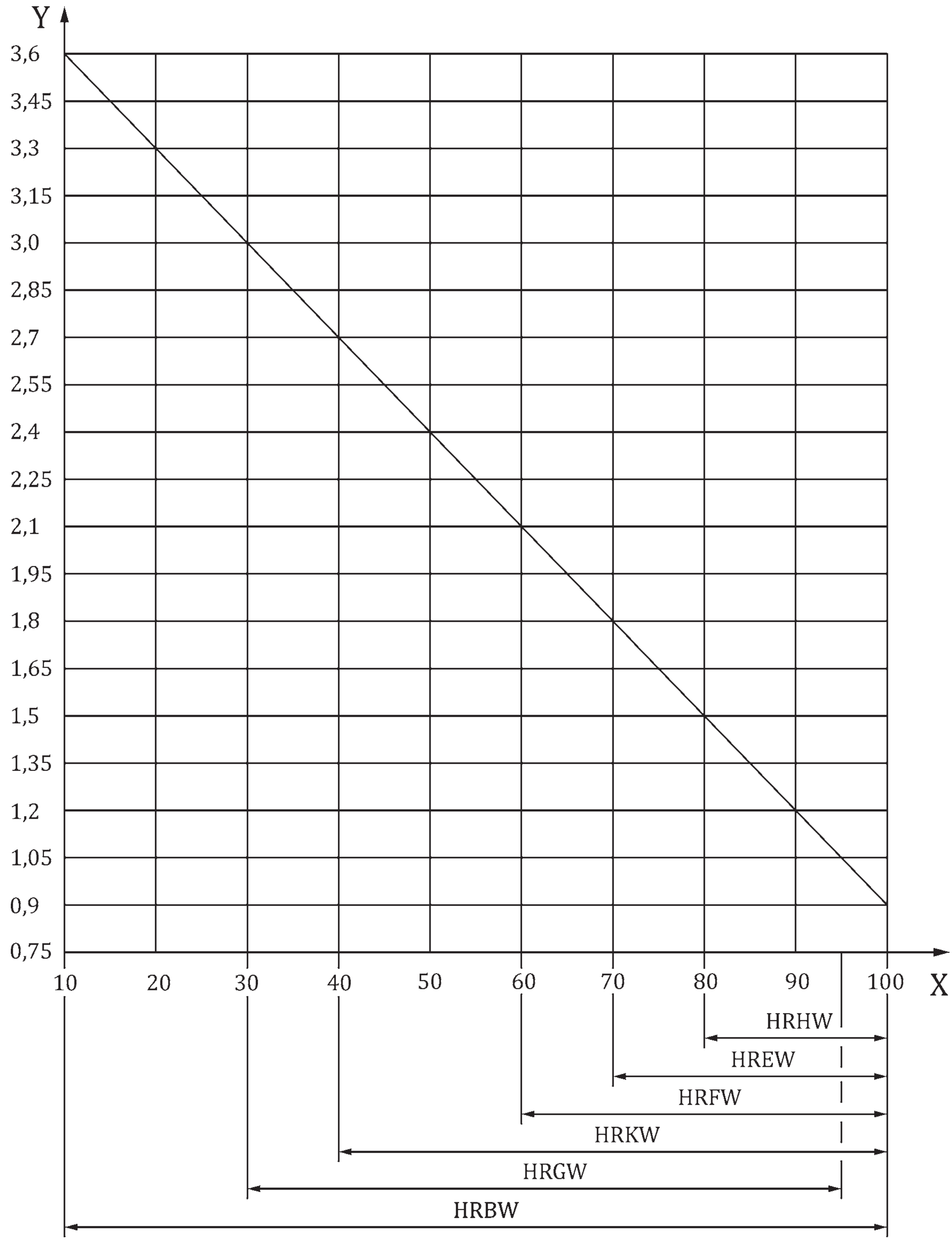


Key

X Rockwell hardness

Y minimum thickness of the test piece, mm

Figure B.1 — Test with diamond cone indenter (scales A, C, and D)

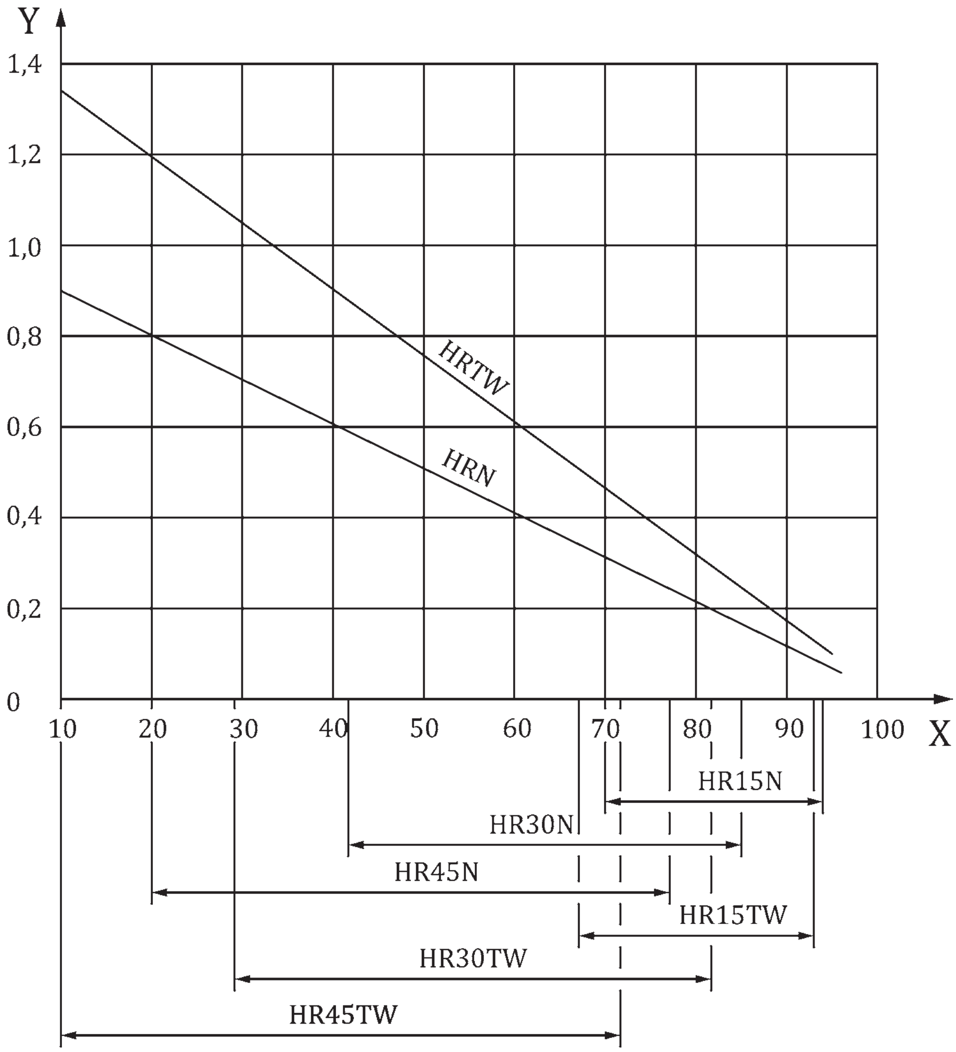


Key

X Rockwell hardness

Y minimum thickness of the test piece, mm

Figure B.2 — Test with ball indenter (scales B, E, F, G, H, and K)



Key

X Rockwell hardness

Y minimum thickness of the test piece, mm

Figure B.3 — 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 Table C.1, Table C.2, Table C.3, or Table 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
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.2 *(continued)*

Rockwell hardness reading	Radius of curvature mm						
	3	5	6,5	8	9,5	11	12,5
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	1,0	1,0	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 superficial 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

[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 superficial hardness reading	Radius of curvature mm						
	1,6	3,2	5	6,5	8	9,5	12,5
20	(13)[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

[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 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 ΔH, given in Table D.1, are calculated using Formula (D.1):

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

where

H is the Rockwell hardness reading;

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 ISO 6508-3 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 range of the results using the formulae defined below. If the bias and repeatability range 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 ISO 6508-2:2015, Clause 5, 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):

$$b = \overline{H} - H_{CRM} \tag{E.1}$$

where

$\overline{H}$ 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 $\overline{H}$ is defined according to Formula (E.2):

$$\overline{H} = \frac{H_1 + ... + H_n}{n} \tag{E.2}$$

where

$H_1, H_2, H_3, H_4, ..., H_n$ are the hardness values corresponding to all the indentations arranged in increasing order of magnitude;

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

$$r = H_n - H_1 \tag{E.3}$$

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

Rockwell hardness scale	Hardness range of the reference block	Permissible bias, *b*	Maximum permissible repeatability range, *r*, of the testing machine[a]
A	20 to ≤75 HRA >75 to ≤95 HRA	±2 HRA ±1,5 HRA	0,02 (100 - $\overline{H}$) or 0,8 HRA[b]
B	10 to ≤45 HRBW >45 to ≤80 HRBW >80 to ≤100 HRBW	±4 HRBW ±3 HRBW ±2 HRBW	0,04 (130 - $\overline{H}$) or 1,2 HRBW[b]
C	10 to ≤70 HRC	±1,5 HRC	0,02 (100 - $\overline{H}$) or 0,8 HRC[b]
D	40 to ≤70 HRD >70 to ≤77 HRD	±2 HRD ±1,5 HRD	0,02 (100 - $\overline{H}$) or 0,8 HRD[b]
E	70 to ≤90 HREW >90 to ≤100 HREW	±2,5 HREW ±2 HREW	0,04 (130 - $\overline{H}$) or 1,2 HREW[b]
F	60 to ≤90 HRFW >90 to ≤100 HRFW	±3 HRFW ±2 HRFW	0,04 (130 - $\overline{H}$) or 1,2 HRFW[b]
G	30 to ≤50 HRGW >50 to ≤75 HRGW >75 to ≤94 HRGW	±6 HRGW ±4,5 HRGW ±3 HRGW	0,04 (130 - $\overline{H}$) or 1,2 HRGW[b]
H	80 to ≤100 HRHW	±2 HRHW	0,04 (130 - $\overline{H}$) or 1,2 HRHW[b]
K	40 to ≤60 HRKW >60 to ≤80 HRKW >80 to ≤100 HRKW	±4 HRKW ±3 HRKW ±2 HRKW	0,04 (130 - $\overline{H}$) or 1,2 HRKW[b]
15N, 30N, 45N	All ranges	±2 HRN	0,04 (100 - $\overline{H}$) or 1,2 HRN[b]
15T, 30T, 45T	All ranges	±3 HRTW	0,06 (100 - $\overline{H}$) or 2,4 HRTW[b]

[a] $\overline{H}$ 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.

From Table E.1, for the HRC scale, the maximum permissible repeatability range at 24,6 HRC is calculated 0,02 (100 − 24,6) = 1,51 HRC. This is greater than 0,8 HRC; therefore, the maximum permissible repeatability range of the testing machine for this reference block is 1,51 HRC.

Since r = 1,2 HRC, the repeatability range of the testing machine 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.

From Table E.1, for the HRC scale, the maximum permissible repeatability range at 63,5 HRC is calculated 0,02 (100 – 63,5) = 0,73 HRC. This is less than 0,8 HRC; therefore, the permissible repeatability range of the testing machine for this reference block is 0,8 HRC.

Since r = 0,8 HRC, the repeatability range of the testing machine 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 ISO 6508-2.

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** “produce” *primary hardness reference blocks* for the calibration laboratory level. 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 with the measured hardness value. Two different approaches to this calculation are given in Table G.1 and Table 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 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,

and can be implemented in different ways into the determination of uncertainty.

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 have to be reduced by b or the uncertainty U_{corr} has to be increased by b. The procedure for the determination of U_{corr} is explained in Table G.1.[6][7]

The combined expanded measurement uncertainty for a single hardness measurement is calculated as shown in Formula (G.1):

$$U = k \times \sqrt{u_H^2 + u_{ms}^2 + u_{HTM}^2} \quad \text{(G.1)}$$

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 ISO 6508-2 and is defined according to Formula (G.2):

$$u_{\mathrm{HTM}} = \sqrt{u_{\mathrm{CRM}}^2 + u_{\mathrm{HCRM}}^2 + u_{\mathrm{ms}}^2} \tag{G.2}$$

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, calculated as the standard deviation of the mean of the hardness measurements when measuring 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:

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

or by

$$X_{\mathrm{ucorr}} = x \pm \left(U_{\mathrm{corr}} + |b|\right) \tag{G.4}$$

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 ISO 6508-2 using the value $\Delta H_{\mathrm{HTMmax}} = |b| + U_{\mathrm{HTM}}$, rather than only the bias value, *b*, when determining compliance with the maximum permissible deviation of the bias (see ISO 6508-2).

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 ISO 6508-2 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 for a single future hardness measurement is calculated as shown in Formula (G.5):

$$U = k \times \sqrt{u_{\mathrm{H}}^2 + u_{\mathrm{ms}}^2} + b_{\mathrm{E}} \tag{G.5}$$

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 ISO 6508-2, and the result of the measurement is given by

$$X = x \pm U \tag{G.6}$$

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 = 60,5 HRC

Resolution of the hardness testing machine, δ_{ms}: δ_{ms} = 0,1 HRC

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 $\overline{x}_{\mathrm{CRM}} = 62{,}82$ HRC . 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 = −0,72 HRC

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_{i} 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}: 61,7 HRC; 61,9 HRC; 62,0 HRC; 62,1 HRC; 62,1 HRC

Mean measurement value, $\overline{H}$: $\overline{H} = 61{,}69$ HRC

Standard deviation of the measurement values, s_{H} : $s_{\mathrm{H}} = 0{,}17$ HRC where

$$\overline{H} = \frac{\sum_{i=1}^{n} H_i}{n} \tag{G.7}$$

and

$$s_{\mathrm{H}} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(H_i - \overline{H}\right)^2} \tag{G.8}$$

where $n = 5$.

The value of s_{H} based on measurements from the last indirect verification according to ISO 6508-2 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 M1

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 $\bar{x}_{CRM} = 62{,}82$ HRC (see NOTE 1)	$b = -0{,}72$ HRC $U_{HTM} = 0{,}66$ HRC $u_{HTM} = \frac{0{,}66}{2}$ HRC $= 0{,}33$ HRC
2	The standard deviation of repeatability measurements	s_H	$s_H = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(H_i - \bar{H}\right)^2}$	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	$u_H = t \times s_H$, see NOTE 3	$t = 1{,}14$ for $n = 5$ (see ISO/IEC Guide 98-3:2008, G.3 and Table G.2)	$u_H = (1{,}14 \times 0{,}17)$ HRC $= 0{,}19$ HRC
4	Standard uncertainty due to resolution of the hardness value indicating display	u_{ms}	$u_{ms} = \frac{\delta_{ms}}{2\sqrt{3}}$	$\delta_{ms} = 0{,}1$ HRC	$u_{ms} = \frac{0{,}1}{2\sqrt{3}} = 0{,}03$
5	Determination of the corrected expanded uncertainty	U_{corr}	$U_{corr} = k \times \sqrt{u_H^2 + u_{ms}^2 + u_{HTM}^2}$	Steps 1, 3, and 4 $k = 2$	$U_{corr} = 2 \times \sqrt{0{,}19^2 + 0{,}03^2 + 0{,}33^2}$ $U_{corr} = 0{,}76$ HRC
6	Measurement result with modified hardness	X_{corr}	$X_{corr} = (x - b) \pm U_{corr}$	Steps 1 and 5	$x = 60{,}5$ HRC $X_{corr} = (61{,}2 \pm 0{,}8)$HRC
7	Measurement result with modified uncertainty	X_{ucorr}	$X_{ucorr} = x \pm \left(U_{corr} + \lvert b \rvert\right)$	Steps 1 and 5	$x = 60{,}5$ HRC $X_{ucorr} = (60{,}5 \pm 1{,}5)$ HRC

NOTE 1 If $0{,}8\ b_E < b < 1{,}0\ b_E$, 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 ISO 6508-2 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_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.

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	b_E	b_E = Maximum positive value of permissible bias	Permissible bias, *b*, according to ISO 6508-2:2015, Table 2	$b_E = 1{,}50$
2	The standard deviation of repeatability measurements.	s_H	$s_H = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(H_i - \overline{H}\right)^2}$	Five measurements are made by the laboratory on a CRM having a hardness similar to the test sample (see NOTE)	$s_H = 0{,}17$ 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 98-3:2008, G.3 and Table G.2)	$u_H = 1{,}14 \times 0{,}17 = 0{,}19$
4	Standard uncertainty due to resolution of the hardness value indicating display	u_{ms}	$u_{ms} = \frac{\delta_{ms}}{2\sqrt{3}}$	$\delta_{ms} = 0{,}1$ 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 $X = \left(60{,}5 \pm 1{,}9\right)$ HRC

NOTE The value of s_H based on measurements from the last indirect verification according to ISO 6508-2 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 nonuniformity 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 Iizuka, 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.

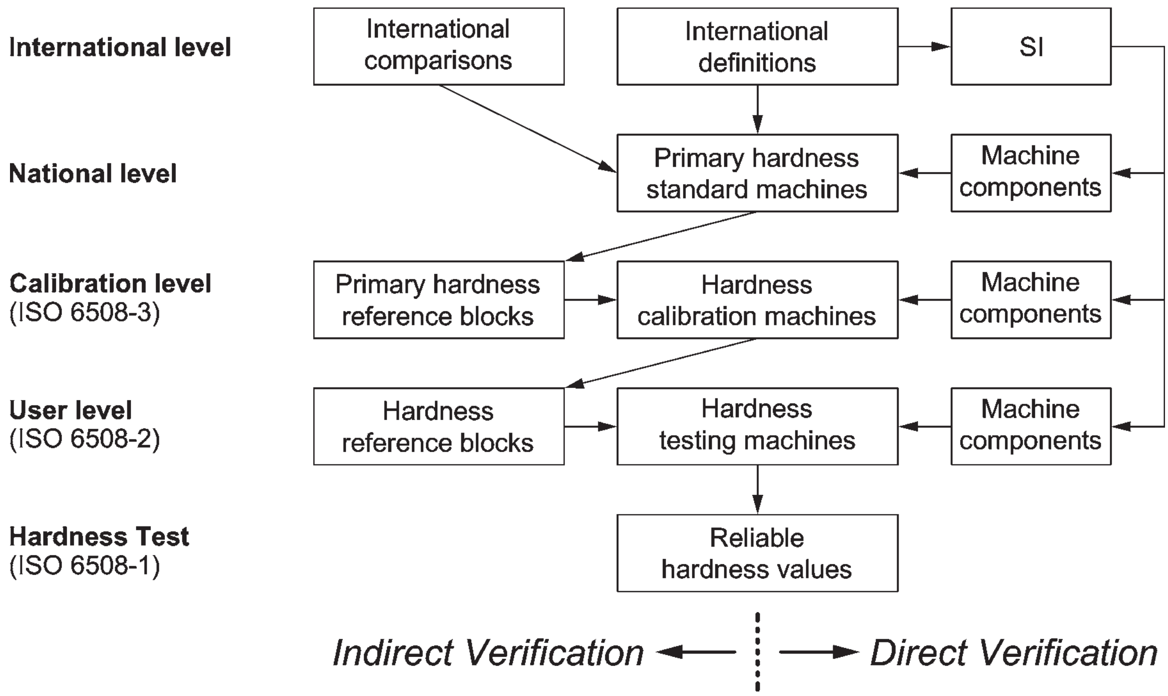
I.2 Chains of calibrations

ISO 6508-2 specifies a set of calibration and verification procedures required to demonstrate that the testing machine is suitable for use in accordance with this part of ISO 6508. 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*.

ISO 6508-3 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 traceability 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 I.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 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 fulfilment 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 I.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 NMI'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 the ISO 6508 (all parts). 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 the ISO 6508 (all parts).

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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