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Metallic materials — Rockwell hardness test —

Part 1:
Test method (scales A, B, C, D, E, F, G, H, K, N, T)

Matériaux métalliques — Essai de dureté Rockwell —

Partie 1: Méthode d'essai (échelles A, B, C, D, E, F, G, H, K, N, T)

Reference number
ISO 6508-1:2005(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 6508-1 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 3, *Hardness testing*.

This second edition cancels and replaces the first edition (ISO 6508-1:1999), which has been technically revised.

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

— *Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)*

— *Part 2: Verification and calibration of testing machines (scales A, B, C, D, E, F, G, H, K, N, T)*

— *Part 3: Calibration of reference blocks (scales A, B, C, D, E, F, G, H, K, N, T)*

Introduction

The periodic checking of the testing machine described in informative Annex E is good metrological practice. It is intended to make the annex normative in the next revision of this part of ISO 6508.

Metallic materials — Rockwell hardness test —

Part 1:
Test method (scales A, B, C, D, E, F, G, H, K, N, T)

1 Scope

This part of ISO 6508 specifies the method for Rockwell and Rockwell superficial hardness tests (scales and field of application according to Table 1) for metallic materials.

Attention is drawn to the fact that, in this part of ISO 6508, the use of hardmetal for ball indenters is considered to be the standard type of Rockwell indenter ball. Steel indenter balls may be continued to be used if specified in a product specification, or by special agreement.

NOTE 1 Attention is drawn to the fact that results obtained with hardmetal balls can be significantly different than when using a steel ball. For specific materials and/or products, other specific International Standards apply (for instance ISO 3738-1 and ISO 4498-1).

NOTE 2 For certain materials, the fields of application may be narrower than those indicated.

2 Normative references

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

ISO 6508-2:2005, *Metallic materials — Rockwell hardness test — Part 2: Verification and calibration of testing machines (scales A, B, C, D, E, F, G, H, K, N, T)*

3 Principle

Forcing an indenter of specified size, shape and material into the surface of a test piece in two steps under specified conditions (see Clause 7). Measuring the permanent depth h of indentation under preliminary test force after removal of additional test force.

From the values of h and that of the two constants N and S (see Table 2), the Rockwell hardness is calculated according to the formula:

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

4 Symbols, abbreviated terms and designations

4.1 See Tables 1 and 2 and Figure 1.

Table 1 — Rockwell scales

Rockwell hardness scale	Hardness symbol	Type of indenter	Preliminary test force F_0	Additional test force F_1	Total test force F	Field of application (Rockwell hardness test)
A[a]	HRA	Diamond cone	98,07 N	490,3 N	588,4 N	20 HRA to 88 HRA
B[b]	HRB	Ball 1,587 5 mm	98,07 N	882,6 N	980,7 N	20 HRB to 100 HRB
C[c]	HRC	Diamond cone	98,07 N	1,373 kN	1,471 kN	20 HRC to 70 HRC
D	HRD	Diamond cone	98,07 N	882,6 N	980,7 N	40 HRD to 77 HRD
E	HRE	Ball 3,175 mm	98,07 N	882,6 N	980,7 N	70 HRE to 100 HRE
F	HRF	Ball 1,587 5 mm	98,07 N	490,3 N	588,4 N	60 HRF to 100 HRF
G	HRG	Ball 1,587 5 mm	98,07 N	1,373 kN	1,471 kN	30 HRG to 94 HRG
H	HRH	Ball 3,175 mm	98,07 N	490,3 N	588,4 N	80 HRH to 100 HRH
K	HRK	Ball 3,175 mm	98,07 N	1,373 kN	1,471 kN	40 HRK to 100 HRK
15N	HR15N	Diamond cone	29,42 N	117,7 N	147,1 N	70 HR15N to 94 HR15N
30N	HR30N	Diamond cone	29,42 N	264,8 N	294,2 N	42 HR30N to 86 HR30N
45N	HR45N	Diamond cone	29,42 N	411,9 N	441,3 N	20 HR45N to 77 HR45N
15T	HR15T	Ball 1,587 5 mm	29,42 N	117,7 N	147,1 N	67 HR15T to 93 HR15T
30T	HR30T	Ball 1,587 5 mm	29,42 N	264,8 N	294,2 N	29 HR30T to 82 HR30T
45T	HR45T	Ball 1,587 5 mm	29,42 N	411,9 N	441,3 N	10 HR45T to 72 HR45T

[a] The field of application can be extended to 94 HRA for testing carbides.

[b] The field of application can be extended to 10 HRBW if specified in the product specification or by special agreement.

[c] The field of application can be extended to 10 HRC if the indenter possesses the appropriate dimensions.

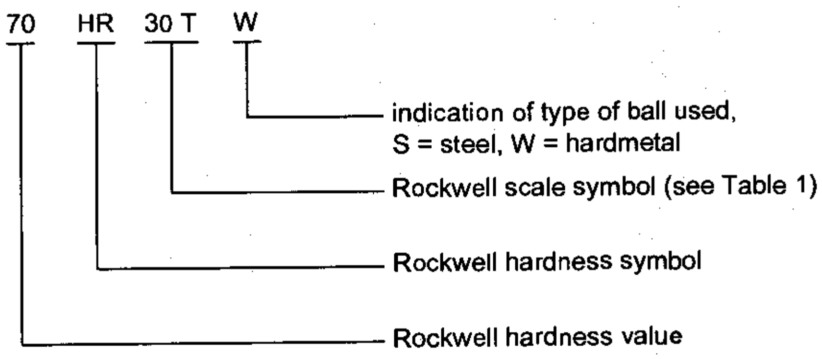
NOTE Indenter balls with diameter 6,350 mm and 12,70 mm may also be used, if specified in the product specification or by special agreement.

Table 2 — Symbols and abbreviated terms

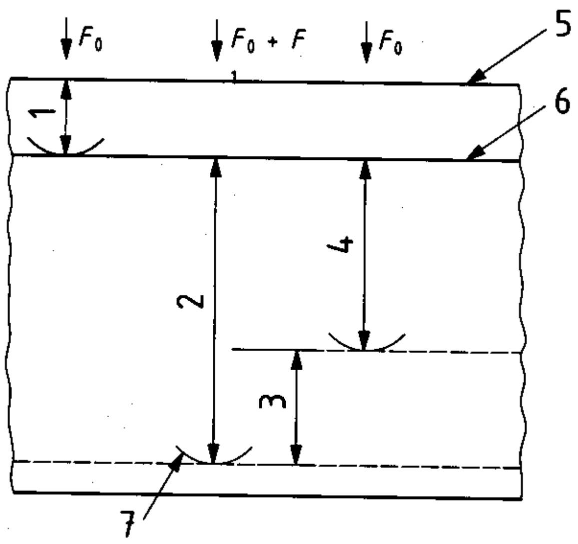
Symbol/ Abbreviated term	Designation	Unit
F_0	Preliminary test force	N
F_1	Additional test force	N
F	Total test force	N
S	Scale unit, specific to the scale	mm
N	Number, specific to the scale	
h	Permanent depth of indentation under preliminary test force after removal of additional test force (permanent indentation depth)	mm
HRA HRC HRD	Rockwell hardness $= 100 - \frac{h}{0{,}002}$	
HRB HRE HRF HRG HRH HRK	Rockwell hardness $= 130 - \frac{h}{0{,}002}$	
HRN HRT	Rockwell hardness $= 100 - \frac{h}{0{,}001}$	

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

EXAMPLE



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



Key

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

Figure 1 — Rockwell principle diagram

5 Testing machine

5.1 Testing machine, capable of applying predetermined forces as shown in Table 1 and in accordance with ISO 6508-2.

5.2 Conical diamond indenter, in accordance with ISO 6508-2, with an angle of 120° and radius of curvature at the tip of 0,2 mm.

5.3 Hardmetal ball indenter, in accordance with ISO 6508-2, with a diameter of 1,587 5 mm or 3,175 mm.

5.4 Measuring system, in accordance with ISO 6508-2.

NOTE A suggested procedure for periodic checks is given in Annex E. See also notes on diamond indenters in Annex F.

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 After the test, no deformation shall be visible on the surface of the test piece opposite the indentation, except for HR30Tm (in this case, the test shall be performed in accordance with Annex A).

The thickness of the test piece, or of the layer under test (minimum values given in Annex B), shall be at least ten times the permanent indentation depth for cone indenters and fifteen 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.

6.4 For tests on convex cylindrical surfaces and spherical surfaces, the corrections given in Annex C (Tables C.1, C.2, C.3 or C.4) and 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 a special agreement.

7 Procedure

7.1 The test is normally carried out at ambient temperature within the limits of 10 °C to 35 °C. However, because temperature variation may affect the results, users of the Rockwell test may choose to control the temperature within a tighter range.

NOTE The temperature of the test material and the temperature of the hardness testing machine may effect the test results; consequently users should ensure that the test temperature does not adversally affect the hardness measurement.

7.2 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. If a locking device is used, it should be used in accordance with Clause 3 of ISO 6508-2:2005.

Before beginning a series of tests or when more than 24 h have elapsed since the last test, and after each change, or removal and replacement, of the indenter or test piece support, it shall be ascertained that the indenter and the test piece support are correctly mounted in the machine. The first two readings after such a change has been made shall be disregarded.

Products of cylindrical shape shall be suitably supported, for example, on centering V-blocks of steel 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 may result in incorrect results.

7.3 Bring the indenter into contact with the test surface and apply the preliminary test force F_0 without shock, vibration or oscillation. The duration of the preliminary test force F_0 shall not exceed 3 s.

NOTE For testing machines with electronic control, the application time of the preliminary test force (T_a) and the duration time of the preliminary test force (T_{pm}) are combined by the following formula:

$$T_p = T_a/2 + T_{pm} \leqslant 3 \text{ s} \quad (2)$$

where

T_p is the total time of preliminary test force;

T_a is the application time of preliminary test force;

T_{pm} is the duration time of preliminary test force.

7.4 Set the measuring system to its datum position and, without shock, vibration or oscillation, increase the force from F_0 to F in not less than 1 s and not more than 8 s.

NOTE In normal practice, the duration from F_0 to F is between 2 s and 3 s on a test piece of about 60 HRC. For the Rockwell scales N and T, it is recommended that the duration is between 1 s and 1,5 s on a test piece of about 78 HR30N.

7.5 The total test force F shall be maintained for a duration of 4 s ± 2 s. Remove the additional test force F_1 and, while the preliminary test force F_0 is maintained, after a short time stabilisation, 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 may 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, this requirement should he specified in the product specification. In these cases, the actual extended total force duration used shall be reported following the test results (for example, 65 HRFW, 10 s).

7.6 The Rockwell hardness number is derived from the permanent indentation depth h using the formulas given in Table 2 and is usually read directly from the measuring system. The derivation of the Rockwell hardness number is illustrated in Figure 1.

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

7.8 The distance between the centres of two adjacent indentations shall be at least four times the diameter of the indentation (but not less than 2 mm).

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 (but not less than 1 mm).

8 Uncertainty of the results

A complete evaluation of the uncertainty should be done according to the *Guide to the expression of uncertainty in measurement* (GUM) [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 EA guideline [4] is available.

— The other possibility is based on indirect calibration using a hardness reference block [abbreviated as CRM (certified reference material)] (see [2–5] in the Bibliography). A guideline for the determination is given in Annex G.

It may not always be possible to quantify all the identified contributions to the uncertainty. In this case, an estimate of type A standard uncertainty may be obtained from the statistical analysis of repeated indentations into the test piece. Care should be taken, if standard uncertainties of type A and B are summarised, that the contributions are not counted twice (see Clause 4 of GUM:1993).

9 Test report

The test report shall include the following information:

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;

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

d) the result obtained (see the second-last paragraph of this clause);

e) all operations not specified in this part of ISO 6508, or regarded as optional;

f) details of any occurrence which may have affected the result (see Note);

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

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.

NOTE There is evidence that some materials may 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.

Annex A
(normative)

Conventional HR30Tm and HR15Tm test for thin products

A.1 General

This test is carried out under conditions similar to those in the HR30T or HR15T test defined in this part of ISO 6508 but, by agreement, the appearance of indentations on the back of the test pieces (not permitted in the HRT test) is allowed.

This test is applicable with adequate precision to products of thickness less than 0,6 mm up to the minimum thickness indicated in the product standards and of a maximum HR30T Rockwell hardness of 80 (respectively 90 HR15T). The product standard specifies when the conventional HR30Tm or HR15Tm hardness test shall be applied.

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

A.2 Test piece support

The test piece support shall comprise a polished and smooth diamond plate approximately 4,5 mm in diameter. This support surface shall be 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.3 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.

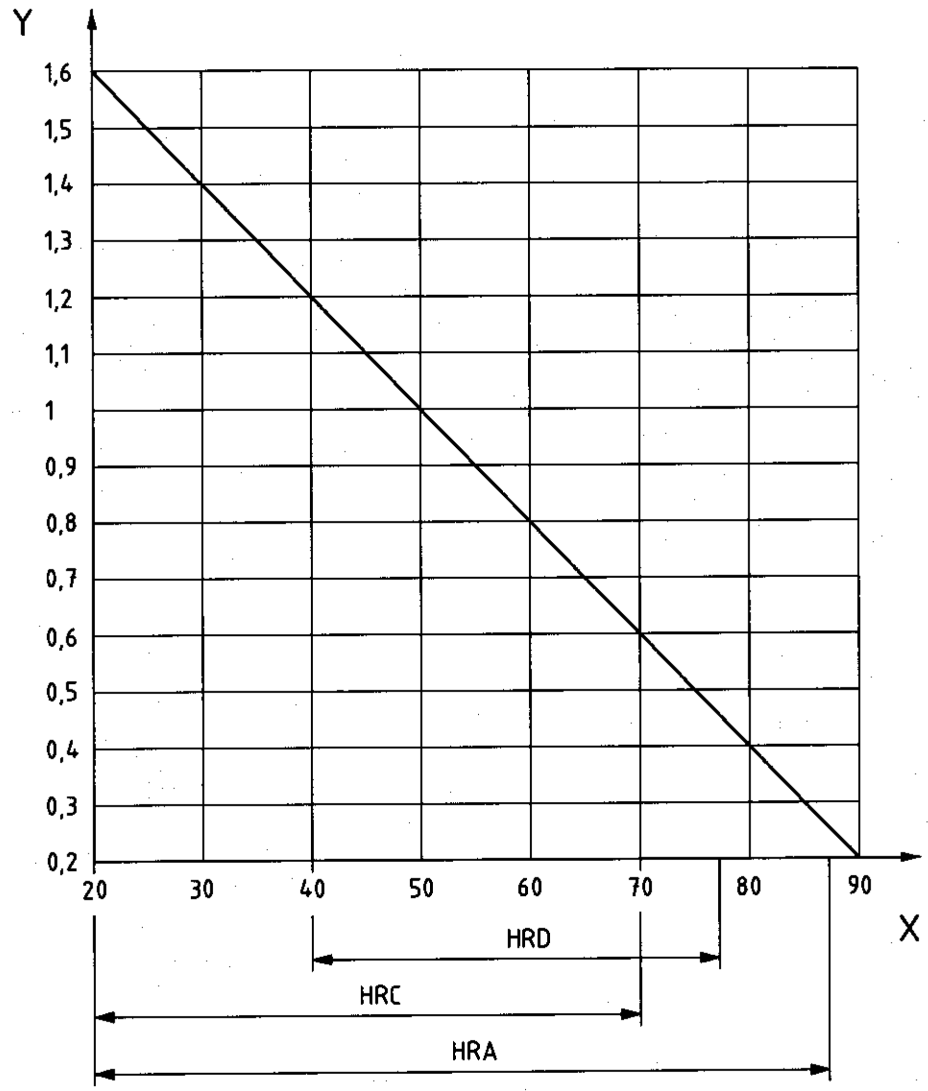
A.4 Position of the test piece

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, B.2 and B.3.

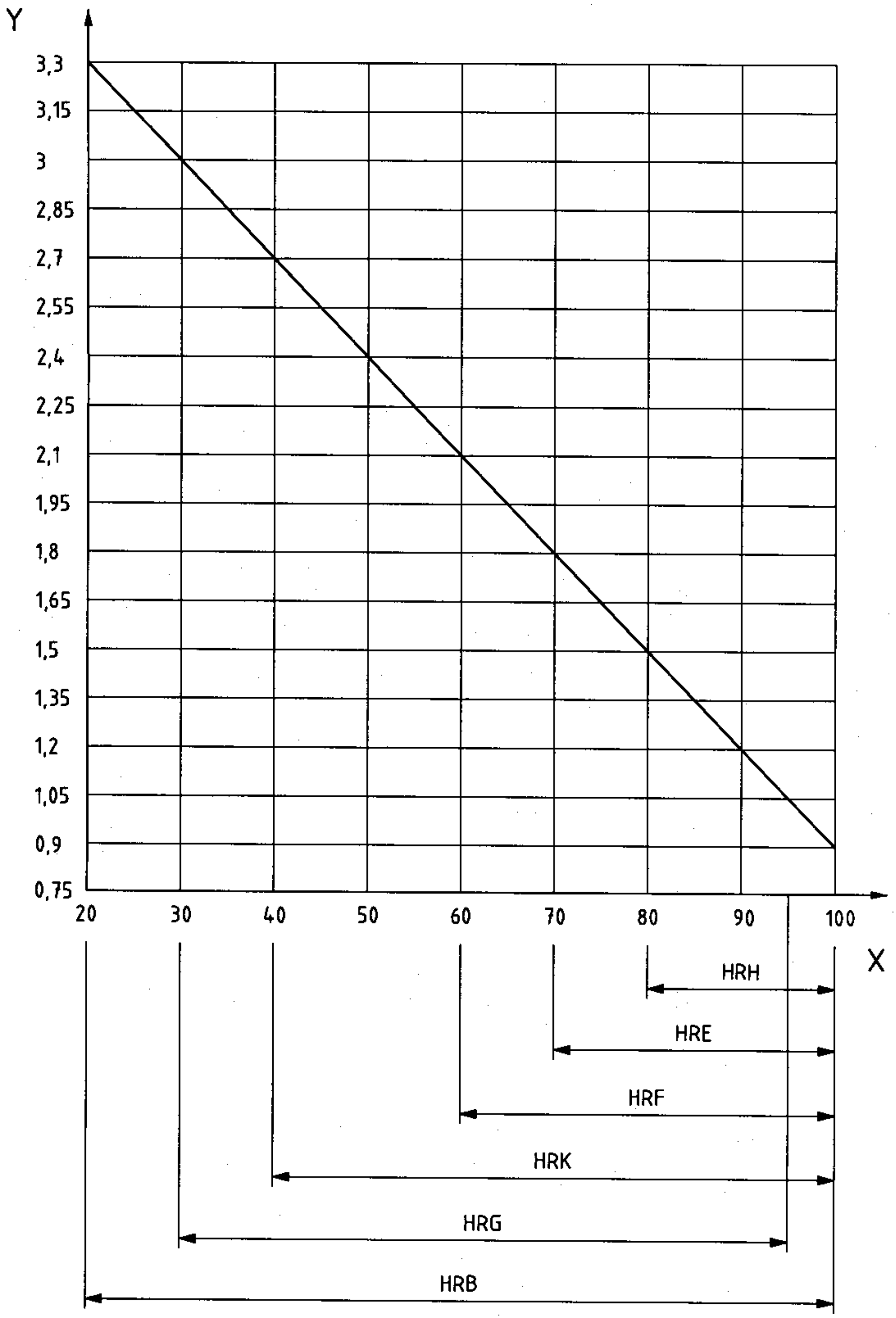


Key

X Rockwell hardness

Y minimum thickness of the test piece, mm

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

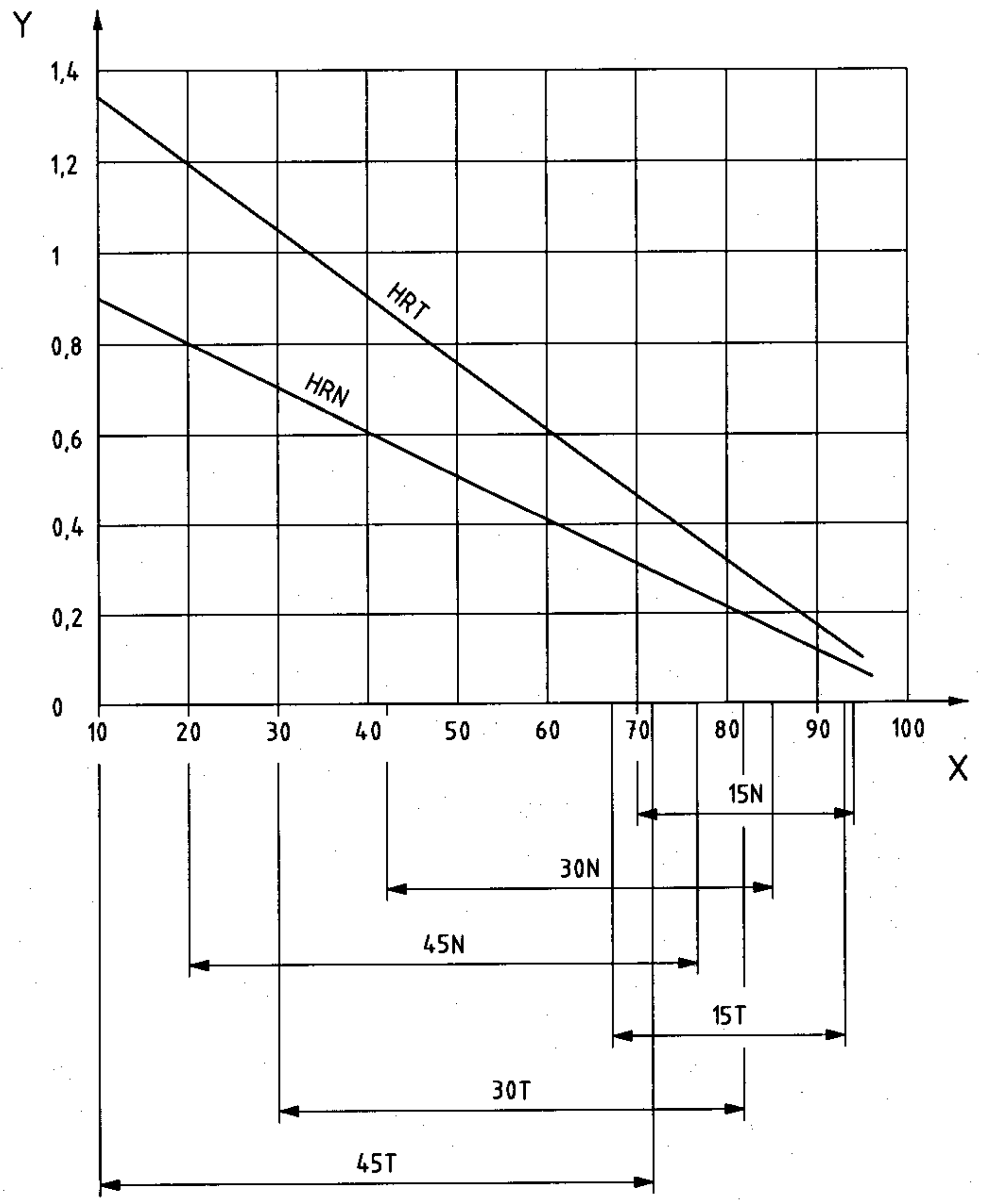


Key

X Rockwell hardness

Y minimum thickness of the test piece, mm

Figure B.2 — Test with ball indenters (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 Tables C.1, C.2, C.3 or C.4 shall be applied.

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, HRC and 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	1,0	1,0	0,5

NOTE Corrections greater than 5 HRB, HRF and HRG are not considered acceptable and are therefore not included in this table.

Table C.3 — Rockwell superficial test (scale N) [a, b]

Rockwell superficial hardness reading	Radius of curvature [c] mm					
	1,6	3,2	5	6,5	9,5	12,5
20	(6,0) [d]	3,0	2,0	1,5	1,5	1,5
25	(5,5) [d]	3,0	2,0	1,5	1,5	1,0
30	(5,5) [d]	3,0	2,0	1,5	1,0	1,0
35	(5,0) [d]	2,5	2,0	1,5	1,0	1,0
40	(4,5) [d]	2,5	1,5	1,5	1,0	1,0
45	(4,0) [d]	2,0	1,5	1,0	1,0	1,0
50	(3,5) [d]	2,0	1,5	1,0	1,0	1,0
55	(3,5) [d]	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 misalignement of the elevating screw, V-anvil and indenter and by imperfections in the surface finish and straightness of the cylinder.

[c] For radii other than those given in this table, corrections may be derived by linear interpolation.

[d] The corrections given in parentheses shall not be used, except by agreement.

Table C.4 — Rockwell superficial test (scale T) [a, b]

Rockwell superficial hardness reading	Radius of curvature [c] mm						
	1,6	3,2	5	6,5	8	9,5	12,5
20	(13) [d]	(9,0) [d]	(6,0) [d]	(4,5) [d]	(3,5) [d]	3,0	2,0
30	(11,5) [d]	(7,5) [d]	(5,0) [d]	(4,0) [d]	(3,5) [d]	2,5	2,0
40	(10,0) [d]	(6,5) [d]	(4,5) [d]	(3,5) [d]	3,0	2,5	2,0
50	(8,5) [d]	(5,5) [d]	(4,0) [d]	3,0	2,5	2,0	2,0
60	(6,5) [d]	(4,5) [d]	3,0	2,5	2,0	1,5	1,5
70	(5,0) [d]	(3,5) [d]	2,5	2,0	1,5	1,0	1,5
80	3,0	2,0	1,5	1,5	1,0	1,0	1,0
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 misalignement of the elevating screw, V-anvil and indenter and by imperfections in the surface finish and straightness of the cylinder.

[c] For radii other than those given in this table, corrections may be derived by linear interpolation.

[d] 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

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 the following formula:

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

where

H is the Rockwell hardness reading;

d is the diameter of the sphere, expressed in millimetres.

Annex E
(informative)

Procedure for periodic checking of the testing machine by the user

A check of the machine should be carried out on each day that the machine is used, at approximately each hardness level and for each range or scale that is to be used.

Prior to making the check, the measuring system should be indirectly verified (for each range/scale and hardness level) using a reference indentation on a hardness reference block, calibrated in accordance with ISO 6508-3. The measured dimension should agree with the certified value to within the maximum permissible error given in Table 5 of ISO 6508-2:2005. If the measuring system fails this test, appropriate action should be taken.

The check involves at least one indentation being made on a hardness reference block, calibrated in accordance with ISO 6508-3. If the difference between the mean measured hardness and the block's certified value is within the permissible error limits given in Table 5 of ISO 6508-2:2005, the machine may be regarded as satisfactory. If not, an indirect verification should be performed.

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

Annex F
(informative)

Notes on 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 may 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 should be reverified in accordance with 4.3.1 of ISO 6508-2:2005.

Annex G
(informative)

Uncertainty of the measured hardness values

G.1 General requirements

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 (indirect verification). 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 direct verification.

Figure G.1 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.

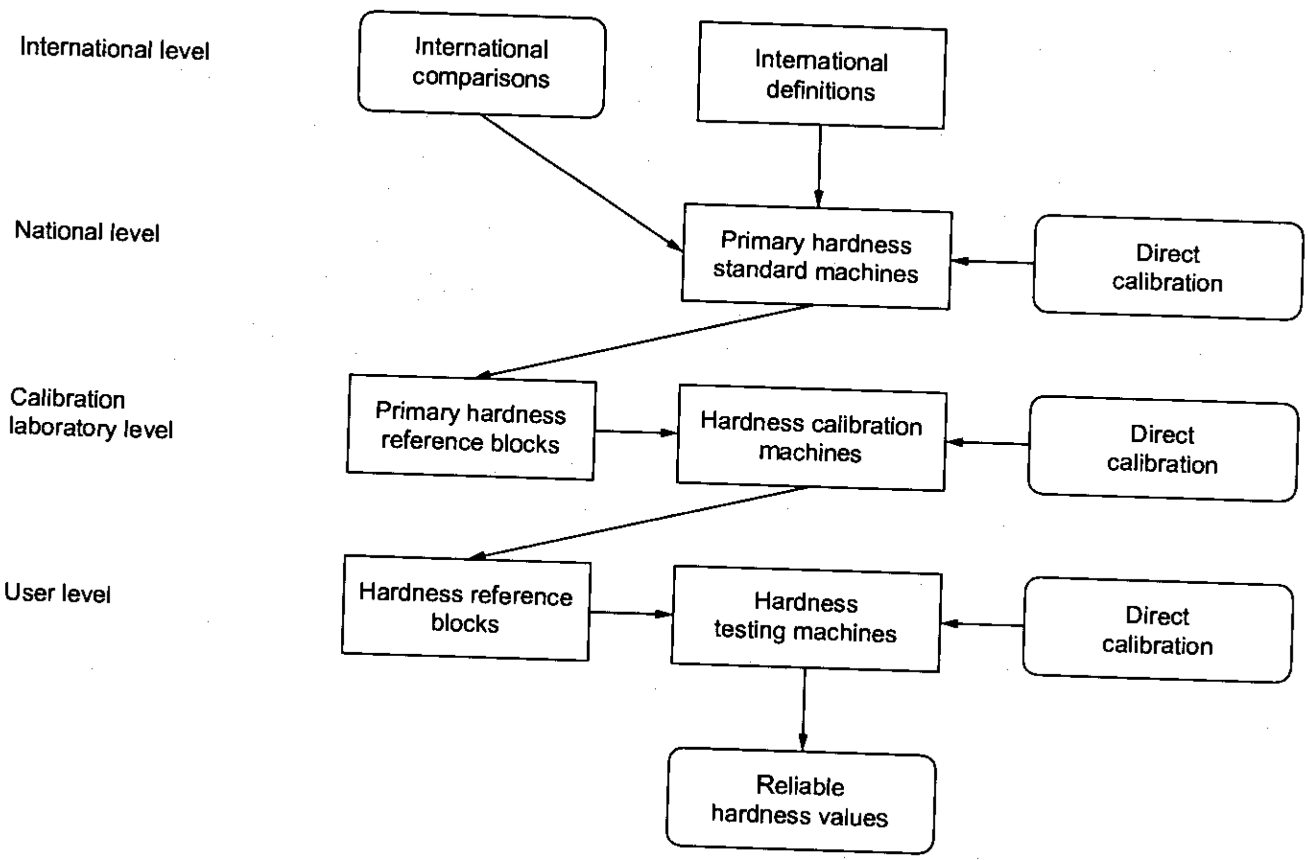


Figure G.1 — Structure of the metrological chain for the definition and dissemination of hardness scales

G.2 General procedure

The procedure calculates a combined uncertainty u_I by the Root-Squared-Sum-Method (RSS) out of the different sources given in Table G.1, containing all symbols used and their designation. The expanded uncertainty, U, is derived from u_I by multiplying with the coverage factor, $k = 2$.

G.3 Bias of the machine

The bias b of a hardness testing machine (also named error) which is derived from the difference between

— the mean value of the five indentations during calibration of the hardness testing machine, and

— the calibration value of the hardness reference block,

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

G.4 Procedures for calculating uncertainty: hardness measurement values

NOTE In this Annex, the index CRM "Certified Reference Material" means, according to the definitions of the hardness testing standards, "Hardness Reference Block".

G.4.1 Procedure without bias (method 1)

Method 1 (abbreviated as M1) is a simplified method, which can be used without considering the systematic error of the hardness testing machine.

In M1, the error limit, that means the range in which the machine is allowed to differ from the reference standard, is used to define the source u_E of the uncertainty. There is no correction of the hardness values with respect to the error.

The procedure for the determination of U is explained in Table G.1 (see [3, 4] in the Bibliography).

$$U = k \cdot \sqrt{u_E^2 + u_{CRM}^2 + u_H^2 + u_{\bar{x}}^2 + u_{ms}^2} \quad (G.1)$$

Where the result of the measurement is given by

$$\bar{X} = \bar{x} \pm U \quad (G.2)$$

G.4.2 Procedure with bias (method 2)

As an alternative to (M1), method 2 (abbreviated as M2) may be used, which is correlated with the conduct of a control chart. M2 may lead to smaller values of uncertainty.

The error b (step 10) can be expected to be a systematic effect. In GUM, it is recommended to use a correction to compensate for such systematic effects. This is the base of M2. The error limit u_E is no longer in the calculation of the uncertainty but all determined hardness values have to be corrected by b or U_{corr} has to be increased by b. The procedure for the determination of U_{corr} is explained in Table G.1, (see [6, 7] in the Bibliography).

$$U_{corr} = k \cdot \sqrt{u_{CRM}^2 + u_H^2 + u_{\bar{x}}^2 + u_{ms}^2 + u_b^2} \quad (G.3)$$

Where the result of the measurement is given by

$$\bar{X}_{corr} = (\bar{x} + \bar{b}) \pm U_{corr} \quad (G.4)$$

or by

$$\overline{X}_{\text{ucorr}} = \overline{x} \pm (U_{\text{corr}} + |\overline{b}|) \qquad \text{(G.5)}$$

depending on whether the bias (error) $\overline{b}$ is thought to be part of the mean value or of the uncertainty.

G.5 Expression of the result of measurement

For the expression of the result of measurement, the method used should be indicated. In general, as a result of the measurement, method 1 [Equation (G.2)] should be used (see also Table G.1, step 12).

Table G.1 — Determination of the expanded uncertainty according to methods M1 and M2

Step Method	Sources of uncertainty	Symbols	Formula	Literature/Certificate	Example [..] = HRC
1 M1	Standard uncertainty according to the (1σ) maximum permissible error	u_E	$u_E = \frac{u_{E,2r}}{2,8}$	Permissible error $u_{E,2r}$ according to ISO 6508-2:2005, Table 5 See Note 1.	$u_E = \frac{1,5}{2,8} = 0,54$
2 M1 M2	Standard uncertainty and mean value of hardness of the CRM (for detailed calculation see ISO 6508-3:2005, Table B.4)	u_{CRM}, $\bar{X}_{CRM}$	$u_{CRM} = \frac{U_{CRM}}{2}$	U_{CRM}, $\bar{X}_{CRM}$ according to calibration certificate of CRM See Note 2.	$u_{CRM} = \frac{0,3}{2} = 0,15$, $\bar{X}_{CRM} = 60,82$
3 M1 M2	Mean value and standard deviation of the measurement on CRM	$\bar{H}$, s_H	$\bar{H} = \frac{\sum_{i=1}^{n} H_i}{n}$ $s_H = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(H_i - \bar{H})^2}$	H_i according to ISO 6508-2:2005, 5.4.1 For the calculation of s_H the larger value of s_{H1} and s_{H2} will be taken.	Single measurements: (1) 60,9 – 61,0 – 61,1 – 61,1 – 60,7 $\bar{H}_1 = 60,96$: $s_{H1} = 0,17$ (2) 60,7 – 60,8 – 61,1 – 61,0 – 60,8 $\bar{H}_2 = 60,88$: $s_{H2} = 0,16$
4 M1 M2	Standard uncertainty of hardness testing machine when measuring CRM	$u_{\bar{H}}$	$u_{\bar{H}} = \frac{t \cdot s_H}{\sqrt{n}}$	$t = 1,14$ for $n = 5$	$u_{\bar{H}} = \frac{1,14 \cdot 0,17}{\sqrt{5}} = 0,09$
5 M1 M2	Mean value and standard deviation of the testing of a test piece	$\bar{x}$, s_x	$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ $s_x = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$	$n = 5$ 5 measurements on the test piece See Note 3. If $n = 1$, $s_x = 0$. The certificate should state that the uncertainty applies only to the specific reading, not to the test piece as a whole	Single values 62,1 – 61,5 – 61,2 – 63,1 – 60,3 $\bar{x} = 61,64$ $s_x = 1,04$

Table G.1 (*continued*)

Step Method	Sources of uncertainty	Symbols	Formula	Literature/Certificate	Example [..] = HRC
6 M1 M2	Standard uncertainty when measuring a test piece	$u_{\bar{x}}$	$u_{\bar{x}} = \frac{t \cdot s_x}{\sqrt{n}}$	t = 1,14 for n = 5	$u_{\bar{x}} = \frac{1,14 \times 1,04}{\sqrt{5}} = 0,53$
7 M2	Standard uncertainty according to the resolution of the length measuring system	u_{ms}	$u_{\text{ms}} = \frac{\delta_{\text{ms}}}{2\sqrt{3}}$	δ_{ms} = 0,1 HRC	$u_{\text{ms}} = \frac{0,1}{2 \times \sqrt{3}} = 0,03$
8 M2	Deviation of hardness testing machine from calibration value	$\bar{b}$	$\bar{b} = \bar{H} - \bar{X}_{\text{CRM}}$	Steps 2 and 3 See Note 4.	$b_1 = 60,96 - 60,82 = 0,14$ $b_2 = 60,88 - 60,82 = 0,06$
9 M2	Standard deviation of the deviation b	s_b	$\bar{b} = \frac{1}{n_{\text{m}}} \sum_{i=1}^{n_{\text{m}}} b_i$ $s_{\text{b}} = \sqrt{\frac{1}{n_{\text{m}} - 1} \sum_{i=1}^{n_{\text{m}1}} (b_{\text{i}} - \bar{b})^2}$	Step 8 for n_{m} = 2 number of measurement series	$\bar{b} = 0,10$ $s_b = 0,056\ 5$
10 M2	Standard uncertainty of the determination of b. Can be determined only after the second series of measurements	u_b	$u_b = \frac{t \cdot s_b}{\sqrt{n_{\text{m}}}}$	Step 9 t = 1,84 for n_{m} = 2 See Note 5.	$u_b = \frac{1,84 \times 0,056\ 5}{\sqrt{2}} = 0,07$
11 M1	Determination of the expanded uncertainty	U	$U = k \cdot \sqrt{u_{\text{E}}^2 + u_{\text{CRM}}^2 + u_{\bar{H}}^2 + u_{\bar{x}}^2 + u_{\text{ms}}^2}$	Step 1 to 7 $k = 2$	$U = 2 \times \sqrt{0,54^2 + 0,15^2 + 0,08^2 + 0,53^2 + 0,03^2}$ U = 1,55 HRC
12 M1	Result of the measurement	$\bar{X}$	$\bar{X} = \bar{x} \pm U$	Steps 5 and 11	$\bar{X}$ = (61,6 ± 1,6) HRC (M1)

Table G.1 (*continued*)

Step Method	Sources of uncertainty	Symbols	Formula	Literature/Certificate	Example [..] = HRC
13 M2	Determination of the corrected expanded uncertainty	U_{corr}	$U_{\text{corr}} = k \cdot \sqrt{u_{\text{CRM}}^2 + u_{\bar{H}}^2 + u_{\bar{x}}^2 + u_{\text{ms}}^2 + u_{b}^2}$	Step 2 to 7 and 10 $k = 2$	$U_{\text{corr}} = 2 \times \sqrt{0{,}15^2 + 0{,}08^2 + 0{,}53^2 + 0{,}03^2 + 0{,}07^2}$ $U_{\text{corr}} = 1{,}13\ \text{HRC}$
14 M2	Result of the measurement with corrected mean value	$\bar{X}_{\text{corr}}$	$\bar{X}_{\text{corr}} = (\bar{x} + \bar{b}) \pm U_{\text{corr}}$	Steps 5, 8 and 13	$\bar{X}_{\text{corr}} = (61{,}7 \pm 1{,}1)\ \text{HRC}$ (M2)
15 M2	Result of the measurement with corrected uncertainty	$\bar{X}_{u\text{corr}}$	$\bar{X}_{u\text{corr}} = (\bar{x} \pm U_{\text{corr}} + \lvert\bar{b}\rvert)$	Steps 5, 8 and 13	$\bar{X}_{u\text{corr}} = (61{,}6 \pm 1{,}2)\ \text{HRC}$ (M2)

NOTE 1 The factor 2,8 is derived from the determination of the standard uncertainty for a rectangular distribution.

NOTE 2 If necessary, the hardness change of the CRM has to be considered.

NOTE 3 If between the measurement of CRM and test piece the optics of the device are changed, the corresponding influence should be considered.

NOTE 4 If $0{,}8\ u_{\text{E},2r} < b < 1{,}0\ u_{\text{E},2}$, the relationship of hardness values between CRM and sample should be considered.

NOTE 5 Because, for $n_{\text{m}} = 2$, in the uncertainty u_b the influence of the long-term change of b is not contained, for critical applications it may be necessary to raise the number of measurements n_{m}.

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