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Metallic materials — Rockwell hardness test —

Part 3: Calibration of reference blocks

Matériaux métalliques — Essai de dureté Rockwell —

Partie 3: Étalonnage des blocs de référence

Reference number
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Foreword

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 3, *Hardness testing,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 459, *ECISS - European Committee for Iron and Steel Standardization,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fourth edition cancels and replaces the third edition (ISO 6508-3:2015), which has been technically revised.

The main changes are as follows:

— removed all statements of requirements, permissions, and recommendations from the Scope of the document (Clause 1);

— addition of Clause 3, Terms and definitions;

— modification of the requirements for the calibration and verification of the machine and indenter (Clause 5);

— added a performance verification for the calibration machine and indenter (Clause 5);

— added a requirement to conduct a control verification prior to the calibration of reference blocks (Clause 6);

— added a normative Annex D for the control verification of the calibration machine (Annex D).

A list of all parts in the ISO 6508 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html

Metallic materials — Rockwell hardness test —

Part 3:
Calibration of reference blocks

1 Scope

This document specifies a method for the calibration of reference blocks to be used for the indirect and daily verification of Rockwell hardness testing machines and indenters, as specified in ISO 6508-2. This document also specifies requirements for Rockwell machines and indenters used for calibrating reference blocks and specifies methods for their calibration and verification.

Attention is drawn to the fact that the use of hard metal for ball indenters is considered to be the standard type of Rockwell indenter ball.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 376, *Metallic materials — Calibration of force-proving instruments used for the verification of uniaxial testing machines*

ISO 6508-1:2023, *Metallic materials — Rockwell hardness test — Part 1: Test method*

ISO 6508-2:2023, *Metallic materials — Rockwell hardness test — Part 2: Verification and calibration of testing machines and indenters*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Manufacture of reference blocks

4.1 The block shall be specially manufactured for use as a hardness-reference block.

NOTE Attention is drawn to the need to use a manufacturing process, which will give the necessary homogeneity, stability of structure, and uniformity of surface hardness.

4.2 Each hardness reference block shall be of a thickness not less than 6 mm. To minimize the effect of hardness change with increasing number of indents, thicker blocks should be used.

4.3 The reference blocks shall be free of magnetism. It is recommended that the manufacturer ensures that the blocks, if made of steel, have been demagnetized at the end of the manufacturing process (before calibration).

4.4 The deviation from surface flatness of the top and bottom surfaces shall be ≤0,01 mm. The bottom of the blocks shall not be convex. The deviation from parallelism of the top and bottom surfaces shall be ≤0,02 mm per 50 mm.

4.5 The test surface and bottom surface shall be free from damage, such as notches, scratches, oxide layers, etc., which can interfere with the measurement of the indentations. The surface roughness, *Ra*, shall not exceed 0,3 µm for the test surface and 0,8 µm for the bottom surface. Sampling length is l = 0,8 mm (see ISO 4287:1997, 3.1.9).

4.6 To verify that no material is subsequently removed from the reference block, the thickness at the time of calibration shall be marked on it, to the nearest 0,1 mm, or an identifying mark shall be made on the test surface [see 9.1 e)].

5 Calibration machine and calibration indenter

5.1 General

5.1.1 Calibrations and verifications of Rockwell calibration machines and calibration indenters shall be carried out at a temperature of (23 ± 5) °C.

5.1.2 The instruments used for calibration and verification shall be traceable to national standards.

5.2 Direct verification of the calibration machine

5.2.1 In addition to fulfilling the conditions in ISO 6508-2:2023, Clause 4, the calibration machine shall also meet the requirements given in 5.2.2, 5.2.3, 5.2.4, 5.2.5, 5.2.6 and 5.2.7 determined by the procedures specified in ISO 6508-2:2023, Clause 5.

5.2.2 The machine shall be directly verified annually, not to exceed 13 months. Direct verification involves calibration and verification of the following:

a) test force;

b) measuring system;

c) testing cycle; if this is not possible, at least the force versus time behaviour.

d) machine hysteresis test.

5.2.3 The test force shall be measured by means of an elastic proving device (according to ISO 376) class 0,5 or better and calibrated for reversibility, or by another method having the same or better accuracy.

Evidence should be available to demonstrate that the output of the force-proving device does not vary by more than 0,1 % in a period of 1 s to 30 s, following a stepped change in force.

5.2.4 Each test force shall be measured and shall agree with the nominal preliminary test force, F_0, to within ±0,2 % and the nominal total test force, F, to within ±0,1 %.

5.2.5 The measuring system shall have a resolution of ±0,000 1 mm and a maximum expanded uncertainty of 0,000 2 mm, when calculated with a confidence level of 95 % over its working range.

5.2.6 The testing cycle shall be timed with an uncertainty less than ±0,5 s and shall conform to the testing cycle of Clause 6.

5.2.7 The average of the last three tests when evaluating the hysteresis of the calibration machine shall indicate a hardness number of (130 ± 0,5) Rockwell units when the regular Rockwell ball scales B, E, F, G, H, and K are used, or within (100 ± 0,5) Rockwell units when any other Rockwell scale is used.

5.3 Calibration diamond indenter

5.3.1 The geometric shape and performance of calibration diamond indenters shall be calibrated as specified below. Direct verification of the geometric shape shall be made before first use. The condition of the diamond shall be checked at frequent intervals using appropriate optical devices (microscope, magnifying glass, etc.) as specified in ISO 6508-1:2023, Annex F.

Verification of the indenter performance, as specified in 5.3.3, shall be made before first use and annually, not to exceed 13 months.

5.3.2 The diamond indenter shall be measured on at least eight unique axial section planes equidistant from each other (e.g. the eight cross-sections will be spaced approximately 22,5° apart at 0°, 22,5°, 45°, 67,5°, 90°, 112,5°, 135°, 157,5°), and shall meet the following requirements.

a) The cone angle shall be measured adjacent to the blend. The diamond cone shall have a mean included angle of (120 ± 0,1)°. In each measured axial section, the included angle shall be (120 ± 0,17)°.

b) The mean deviation from straightness of the generatrix of the diamond cone adjacent to the blend shall not exceed 0,000 5 mm over a minimum length of 0,4 mm. In each measured section, the deviation shall not exceed 0,000 7 mm.

c) The radius of the spherical tip of the diamond shall be measured adjacent to the blend. The tip shall have a mean radius of (0,200 ± 0,005) mm. In each measured section, the radius shall be within (0,200 ± 0,007) mm and local deviations from a true radius shall not exceed 0,002 mm.

   NOTE The tip of the diamond indenter is usually not truly spherical, but often varies in radius across its surface. Depending on the crystallographic orientation of the diamond stone with respect to the indenter axis, diamond tends to preferentially polish away more easily or with more difficulty at the tip, producing an increasingly flat or sharp surface in the central indenter axis region. The sphericity of the diamond tip can be better evaluated by measuring multiple measurement windows of varying width. The measurement window would be bounded by widths measured along a line normal to the indenter axis. For example, the following window sizes can be evaluated:

   — between ±80 µm from the indenter axis;

   — between ±60 µm from the indenter axis;

   — between ±40 µm from the indenter axis.

d) The surfaces of the cone and the spherical tip shall blend in a smooth tangential manner. The location where the spherical tip and the cone of the diamond blend together will vary depending on the values of the tip radius and cone angle. Ideally for a perfect indenter geometry, the blend point is located at 100 µm from the indenter axis measured along a line normal to the indenter axis. To avoid including the blend area in the measurement of the tip radius and cone angle, the portion of the diamond surface between 90 µm and 110 µm should be ignored.

e) The inclination of the axis of the diamond cone to the axis of the indenter holder (normal to the seating surface) shall be within 0,3°.

5.3.3 Calibration diamond indenters shall be performance verified by performing comparison tests with reference diamond indenter(s) that meet the requirements of Annex C. Calibration diamond indenters can be verified for use on either regular or superficial Rockwell diamond scales or both. The test blocks used for the comparison testing shall meet the requirements of Clause 4 and be calibrated at the hardness levels given in Table 1, Table 2, Table 3, or Table 4, depending on the scales for which the indenter is verified. The testing shall be carried out in accordance with ISO 6508-1.

NOTE The alternate hardness levels given in Table 2 are provided to accommodate indenters calibrated to other International Standards. It is believed that calibrations conducted to Table 1 or Table 2 will yield equivalent results.

For each block, the mean hardness value of three indentations made using the calibration diamond indenter to be verified shall not differ from the mean hardness value of three indentations obtained with a reference diamond indenter by more than ±0,4 Rockwell units. The indentations made with the calibration diamond indenter to be verified and with the reference diamond indenter should be adjacent.

Table 1 — Hardness levels for indenters to be used for calibrating Rockwell regular and superficial scale test blocks (A, C, D, and N)

Scale	Nominal hardness	Ranges
HRC	23	20 to 26
HRC	55	52 to 58
HR45N	43	40 to 46
HR15N	91	88 to 94

Table 2 — Alternate hardness levels for indenters to be used for calibrating Rockwell regular and superficial scale test blocks (A, C, D, and N)

Scale	Nominal hardness	Ranges
HRC	25	22 to 28
HRC	63	60 to 65
HR30N	64	60 to 69
HR15N	91	88 to 94

Table 3 — Hardness levels for indenters to be used for calibrating Rockwell regular scale test blocks only (A, C, and D)

Scale	Nominal hardness	Ranges
HRC	25	22 to 28
HRC	45	42 to 50
HRC	63	60 to 65
HRA	81	78 to 84

Table 4 — Hardness levels for indenters to be used for calibrating Rockwell superficial scale test blocks only (N)

Scale	Nominal hardness	Ranges
HR15N	91	88 to 94
HR30N	64	60 to 69
HR30N	46	42 to 50
HR45N	25	22 to 29

5.4 Calibration ball indenter

5.4.1 The calibration tungsten carbide composite ball shall be replaced at a frequency no greater than 13 months.

5.4.2 Calibration tungsten carbide composite balls shall meet the requirements of ISO 6508-2, with the exception of the following tolerances for the ball diameter:

— ±0,002 mm for the ball of diameter 1,587 5 mm;

— ±0,003 mm for the ball of diameter 3,175 mm.

5.5 Performance verification of the calibration machine and indenter

5.5.1 Performance verification involves verification of the calibration machine with the calibration indenter by performing comparisons with laboratories having measurement capabilities with lower or equivalent uncertainties. The comparisons shall be made by one or more of the following procedures:

— tests on primary reference blocks calibrated by National Metrology Institutes;

— intercomparisons with National Metrology Institutes;

— intercomparisons with other Rockwell calibration laboratories having lower or equivalent stated measurement uncertainties, such as part of a Proficiency Testing (PT) program.

5.5.2 The calibration laboratory shall schedule the performance verification comparisons such that, at a minimum, the following number of Rockwell scales are compared during each performance verification interval depending on the reference blocks calibrated by the laboratory. Comparisons are only required for the scales that blocks will be calibrated in the future.

— One (1) regular Rockwell diamond scale (A, C, D)

— One (1) superficial Rockwell diamond scale (15N, 30N, 45N)

— One (1) 1,587 5 mm ball scale (B, F, G)

— One (1) 3,175 mm ball scale (E, H, K)

5.5.3 For each Rockwell scale to be compared, comparison tests shall be made at hardness levels within each of the hardness ranges specified by ISO 6508-2:2023, Table 1 (i.e. three hardness levels for each Rockwell scale except two hardness levels for the HRHW scale).

5.5.4 For each subsequent performance verification interval, the Rockwell scales chosen to be compared shall be different scales than compared previously for each category listed in 5.5.2 until all applicable scales are compared. Additional comparisons of previously compared scales can also be included in addition to the required comparisons.

5.5.5 Performance verification of the calibration machine with the calibration indenter shall be performed at least once annually, not to exceed 13 months. The verification measurements shall be carried out at a temperature of (23 ± 5) °C.

5.5.6 The results of each comparison shall be evaluated by appropriate statistical techniques, including calculating the normalized error, E_n, according to Formula (1):

$$E_n = \frac{H_{Lab} - H_{Ref}}{\sqrt{U_{Lab}^2 + U_{Ref}^2}} \quad (1)$$

where

H_{Lab} is the measurement result of the calibration laboratory;

H_{Ref} is the measurement result of the reference laboratory;

U_{Lab} is the expanded uncertainty of the calibration laboratory's measurement result;

U_{Ref} is the expanded uncertainty of the reference laboratory's measurement result.

5.5.7 The comparison results are considered satisfactory when the value of $|E_n| \leq 1$ (i.e. greater than or equal to -1 and less than or equal to +1).

6 Reference block calibration procedure

6.1 The calibration machine shall undergo control verifications as specified in Annex D and be determined to be in-control prior to calibrating reference blocks.

6.2 The reference blocks shall be calibrated in a calibration machine as specified in Clause 5, at a temperature of (23 ± 5) °C, using the general procedure specified in ISO 6508-1.

During calibration, the thermal drift should not exceed 1 °C.

6.3 The velocity of the indenter, when it comes into contact with the surface, shall not exceed 1 mm/s.

The velocity of the indenter, when it comes into contact with the surface, should not exceed 0,3 mm/s for undamped systems.

6.4 Bring the indenter into contact with the test surface and apply the preliminary test force, F_0, without shock or vibration and without oscillation or overload of the test force. The application time, T_a, of the preliminary test force, F_0, shall not exceed 2 s.

The duration, T_p, of the preliminary test force, F_0, shall be equal to (3 ± 1) s, as shown in Formula (2):

$$T_p = T_a/2 + T_{pm} = (3 \pm 1)\ \text{s} \tag{2}$$

where

T_p is the preliminary test force time;

T_a is the application time of preliminary test force;

T_{pm} is the duration time of preliminary test force prior to measuring the initial indentation depth.

For testing machines that apply the preliminary test force in less than 1 s (T_a), T_p can be calculated as being equal to T_{pm}.

6.5 Bring the measuring system to its datum position, and without shock, vibration, oscillation, or overload, apply the additional test force, F_1.

For the regular Rockwell scale tests, apply the additional test force, F_1, in 7^{+1}_{-6} 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. During the final stage of the indentation process (approximately in the range of 0,8 F to 0,99 F), the indentation speed should be in the range of 0,015 mm/s to 0,04 mm/s.

6.6 The duration of the application of the total force, F, shall be equal to (5 ± 1) s.

6.7 The final reading shall be made (4 ± 1) s after removing the additional test force, F, and returning to the preliminary test force, F_0.

7 Number of indentations

On each reference block, at least five indentations shall be made, uniformly distributed over the test surface. The arithmetic mean of the hardness values characterizes the hardness value of the block.

To reduce the measurement uncertainty, more than five indentations should be made.

8 Uniformity of hardness

8.1 For each reference block, let H_1, H_2, H_3, H_4, ... H_n be the values of the measured hardness, arranged in increasing order of magnitude.

The mean hardness value of all the indentations is defined according to Formula (3):

$$\overline{H} = \frac{H_1 + H_2 + H_3 + H_4 + \ldots + H_n}{n} \quad (3)$$

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.

The non-uniformity, R, of the block in Rockwell units, under the particular conditions of calibration, is characterized by Formula (4):

$$R = H_n - H_1 \quad (4)$$

8.2 The maximum permissible value of non-uniformity, R, of a reference block in Rockwell units is given in Table 5 and is graphically presented in Annex A.

Table 5 — Maximum permissible value of non-uniformity

Rockwell hardness scale	Maximum permissible value of non-uniformity, R [a]
A	0,015 (100 - $\overline{H}$) or 0,4 HRA Rockwell units
B	0,020 (130 - $\overline{H}$) or 1,0 HRBW Rockwell units
C	0,010 (100 - $\overline{H}$) or 0,4 HRC Rockwell units
D	0,010 (100 - $\overline{H}$) or 0,4 HRD Rockwell units
E	0,020 (130 - $\overline{H}$) or 1,0 HREW Rockwell units
F	0,020 (130 - $\overline{H}$) or 1,0 HRFW Rockwell units
G	0,020 (130 - $\overline{H}$) or 1,0 HRGW Rockwell units
H	0,020 (130 - $\overline{H}$) or 1,0 HRHW Rockwell units
K	0,020 (130 - $\overline{H}$) or 1,0 HRKW Rockwell units
15N, 30N, 45N	0,020 (100 - $\overline{H}$) or 0,6 HR-N Rockwell units
15T, 30T, 45T	0,030 (100 - $\overline{H}$) or 1,2 HR-TW Rockwell units

[a] The greater of the two values shall apply.

8.3 The uncertainty of measurement of the hardness reference blocks shall be calculated. An example method is given in Annex B.

9 Marking

9.1 Each reference block shall be marked with the following:

a) arithmetic mean of the hardness values found in the calibration test. For example, 66,3 HRC;

b) name or mark of the supplier or manufacturer;

c) serial number;

d) name or mark of the calibration agency;

e) thickness of the block, or an identifying mark on the test surface (see 4.6);

f) year of calibration, if not indicated in the serial number.

9.2 Any mark put on the side of the block shall be upright when the test surface is the upper face.

10 Calibration certificate

Each delivered reference block shall be accompanied with a document giving at least the following information:

a) reference to this document (i.e. ISO 6508-3:2023);

b) identity of the block;

c) date of calibration;

d) individual calibration results;

e) arithmetic mean of the hardness values;

f) value characterizing the non-uniformity of the block (see 8.1);

g) statement of uncertainty.

11 Validity

The hardness reference block is only valid for the scale for which it was calibrated.

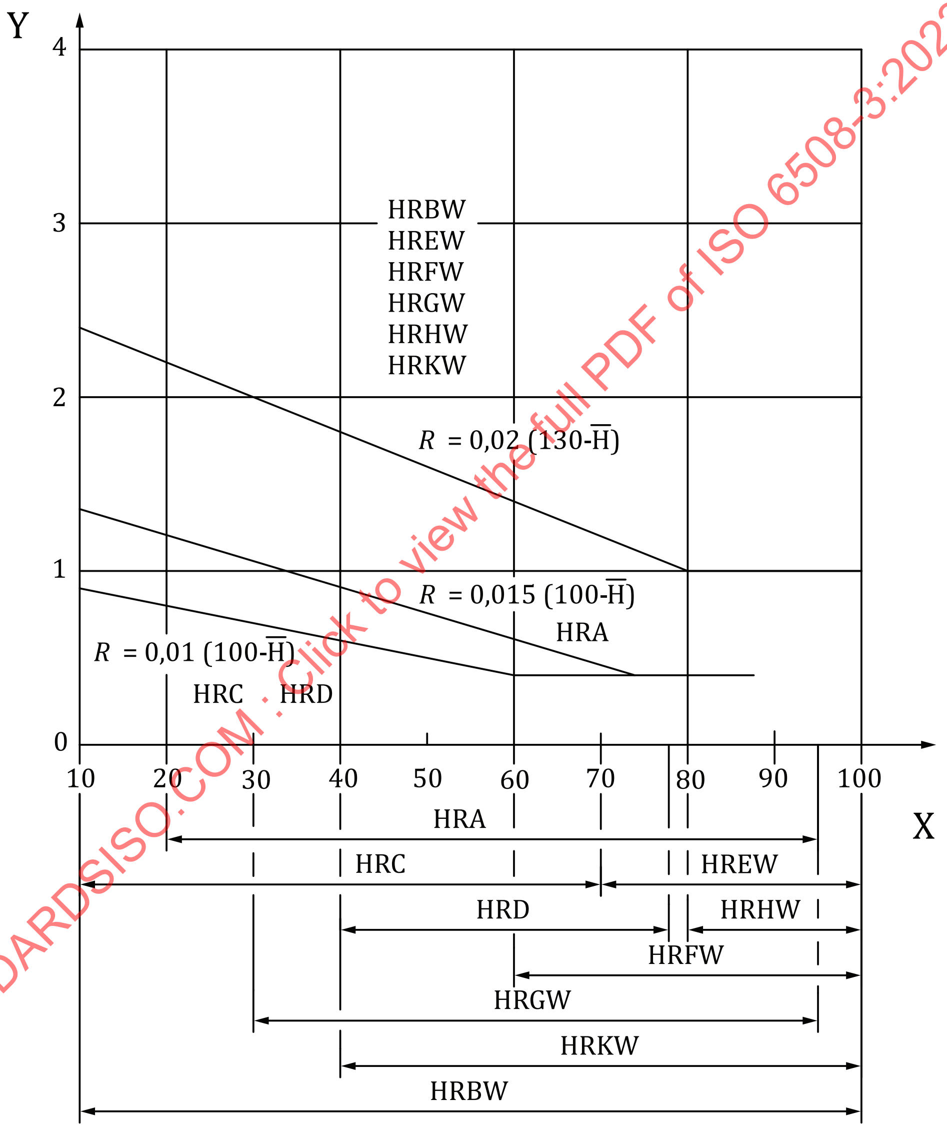
The calibration validity should be limited to a duration of five years. Attention is drawn to the fact that, for Al-alloys and Cu-alloys, the calibration validity could be reduced to three years.

The calibration result is only valid for the reference block at the time of calibration. The hardness of the block can be changed by repeated test on the block and attention shall be drawn to the fact that it might not be negligible when the number of indentations is large.

Annex A
(informative)

Uniformity of reference blocks

Maximum permissible values of non-uniformity, *R*, in Rockwell units are given in Figure A.1 and Figure A.2.

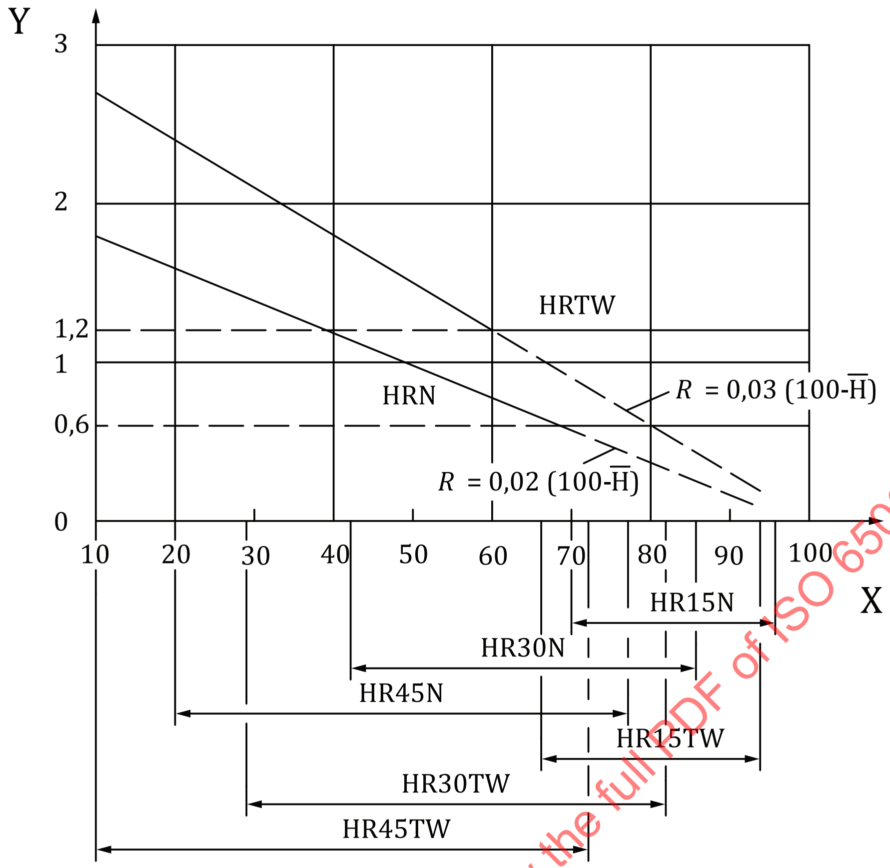


Key

X Rockwell hardness

Y non-uniformity, *R*

Figure A.1 — Rockwell hardness (scales A, B, C, D, E, F, G, H, and K)



Key

X Rockwell hardness

Y non-uniformity, *R*

Figure A.2 — Rockwell superficial hardness (scales N and T)

Annex B
(informative)

Uncertainty of the mean hardness value of hardness-reference blocks

B.1 General

Measurement uncertainty analysis is a useful tool to help determine sources of error and to understand differences between measured values. This annex gives guidance on uncertainty estimation, but the methods contained are for information only, unless specifically instructed otherwise by the customer. The criteria specified in this document for the calibration requirements of the reference block have been developed and refined over a significant period of time. When determining a specific tolerance that the reference block needs to meet, the uncertainty associated with the use of measuring equipment has been incorporated within this tolerance and therefore, it would be inappropriate to make any further allowance for this uncertainty, for example, by reducing the tolerance by the measurement uncertainty. This applies to all measurements associated with the manufacture and calibration of the reference blocks and also to all measurements made when performing a verification of the calibration machine. In each case, it is simply the measured value resulting from the use of the specified measuring equipment that is used to assess compliance with this document. 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.

NOTE The metrological chain necessary to define and disseminate hardness scales is shown in ISO 6508-1.

B.2 Direct verification - uncertainty of calibration of machine components

B.2.1 Calibration and verification of the test force and depth-measuring system

Refer to ISO 6508-2 for information on the uncertainty of measurement of the calibration results of the hardness testing machine.

B.2.2 Verification of the indenter and test cycle

Refer to ISO 6508-2 for information on the uncertainty of measurement of the calibration results of the hardness testing machine.

B.3 Indirect verification - uncertainty of calibration of calibration machine

NOTE 1 In this annex, the index “CRM-P (certified reference material-primary)” means “primary hardness reference block”.

NOTE 2 The result of indirect verification is used for the evaluation of the uncertainty of calibration of the hardness calibration machine.

By indirect verification with primary hardness-reference blocks, the overall function of the hardness-calibration machine is checked. The repeatability of the hardness-calibration machine and the deviation of the hardness-calibration machine’s measurement of hardness from the true hardness value are determined. For the indirect verification of the hardness-calibration machine, the difference, or bias, b_{HCM}, between the average hardness of the primary hardness-reference block measured by the hardness-calibration machine and the corresponding certified value of the primary hardness-reference block is calculated and reported. The indirect verification verifies whether the bias is within specified maximum permissible limits. Consequently, the following is a procedure to calculate the uncertainty of the bias value of the hardness-calibration machine measurement with respect to the true average hardness of the primary hardness-reference block.

The uncertainty of the measurement of the bias of the hardness-calibration machine is calculated from the indirect verification results using Formula (B.1):

$$u_{HCM} = \sqrt{u_{CRM\text{-}P}^2 + u_{HCRM\text{-}P}^2 + u_{ms}^2} \quad (B.1)$$

where

$u_{CRM\text{-}P}$ is a contribution to the measurement uncertainty due to the calibration uncertainty of the certified value of the primary hardness-reference block, according to the calibration certificate for $k = 1$;

$u_{HCRM\text{-}P}$ is a contribution to the measurement uncertainty due to the lack of measurement repeatability of the hardness-calibration machine and the hardness non-uniformity of the primary hardness-reference block, calculated as the standard deviation of the mean of the hardness measurements when measuring the primary hardness-reference block;

u_{ms} is a contribution to the measurement uncertainty due to the resolution of the hardness-calibration machine.

EXAMPLE Indirect verification of the Rockwell C scale (~ 45 HRC) of the hardness-calibration machine.

Primary-hardness reference block (CRM-P) $H_{CRM\text{-}P}$ = 45,40 HRC

Expanded uncertainty of the certified value of the CRM-P $U_{CRM\text{-}P}$ = 0,24 HRC (from calibration certificate)

Resolution of the hardness-calibration machine δ_{ms} = 0,01 HRC

Five HRC measurements are made on the CRM-P, as shown in Table B.1.

$$b_{HCM} = \overline{H} - H_{CRM\text{-}P} \quad (B.2)$$

$$u_{CRM\text{-}P} = \frac{U_{CRM\text{-}P}}{2} \quad (B.3)$$

$$u_{HCRM\text{-}P} = \frac{t \times s_{HCRM\text{-}P}}{\sqrt{n}} \quad (B.4)$$

$$u_{ms} = \frac{\delta_{ms}}{\sqrt{6}} \quad (B.5)$$

where $s_{HCRM\text{-}P}$ is the standard deviation of the indirect verification measurements.

Table B.1 — Results of the indirect verification

No.	Measured hardness value *H*, HRC[a]
1	45,65
2	45,52
3	45,51
4	45,58
5	45,61

[a] HRC: Rockwell C scale hardness.

Table B.1 *(continued)*

No.	Measured hardness value H, HRC[a]
Mean value, $\overline{H}$	45,57
Standard deviation, $s_{HCRM\text{-}P}$	0,059
Standard uncertainty of measurement, $u_{HCRM\text{-}P}$	0,030
[a] HRC: Rockwell C scale hardness.	

From the given indirect verification parameters and Table B.1:

$$b_{HCM} = \overline{H} - H_{CRM} = (45{,}57 - 45{,}40)\,\text{HRC} = 0{,}17\,\text{HRC}$$

$$u_{CRM-P} = \frac{U_{CRM-P}}{2} = 0{,}12\,\text{HRC}$$

For $n = 5$, $t = 1{,}14$

$$u_{HCRM-P} = \frac{t \times s_{HCRM-P}}{\sqrt{n}} = \frac{1{,}14 \times 0{,}059}{\sqrt{5}} = 0{,}030\,\text{HRC}$$

$$u_{ms} = \frac{1}{\sqrt{6}} \times \delta_{ms} = 0{,}004\,\text{HRC}$$

Table B.2 — Budget of uncertainty of measurement bias

Quantity X_i	Estimated value x_i	Standard uncertainty of measurement $u(x_i)$	Distribution type	Sensitivity coefficient c_i	Standard measurement uncertainty symbol	Uncertainty contribution $u_i(H)$
Certified value of CRM-P	45,40 HRC	0,12 HRC	Normal	1,0	$u_{CRM\text{-}P}$	0,120 HRC
Hardness calibration machine measurement	45,40 HRC	0,030 HRC	Normal	1,0	$u_{HCRM\text{-}P}$	0,030 HRC
Hardness calibration machine resolution	0 HRC	0,004 HRC	Triangular	1,0	u_{ms}	0,004 HRC
Combined uncertainty of bias value, u_{HCM}						0,124 HRC
Expanded uncertainty of bias value, U_{HCM} (k = 2)						0,247 HRC

B.4 Uncertainty of the certified value of hardness-reference blocks

B.4.1 General

The combined expanded uncertainty of the measurement of a calibrated hardness-reference block is calculated using Formula (B.6):

$$U_{CRM} = k \times \sqrt{u_{HCRM}^2 + u_{ms}^2 + u_{HCM}^2} \tag{B.6}$$

When measurements made using the hardness-calibration machine are not corrected for bias, b_{HCM}, then the certified value of the calibrated hardness-reference block, and the associated uncertainty are calculated using Formula (B.7):

$$\overline{H}_{CRM} \pm (U_{CRM} + |b_{HCM}|) \tag{B.7}$$

When measurements made using the hardness-calibration machine are corrected for bias, b_{HCM}, then the certified value of the calibrated hardness-reference block, $\overline{H}_{CRM}$ and the associated uncertainty are calculated using Formula (B.8):

$$\left(\overline{H}_{CRM} - b_{HCM}\right) \pm U_{CRM} \tag{B.8}$$

where

u_{HCRM} is a contribution to the measurement uncertainty due to the lack of measurement repeatability of the hardness-calibration machine and the non-uniformity of the CRM block being calibrated;

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

u_{HCM} is a contribution to the measurement uncertainty due to the standard uncertainty of the bias, $b_{HCM,}$ measurement generated by the hardness-calibration machine [this value is reported as a result of the indirect verification specified above, see Formula (B.1)];

b_{HCM} is the bias between the average hardness of the primary hardness-reference block measured by the hardness-calibration machine and the corresponding certified value of the primary hardness-reference block.

EXAMPLE

Bias of hardness-calibration machine (~ 45 HRC) b_{HCM} = 0,17 HRC

Combined standard uncertainty of bias value (~ 45 HRC) u_{HCM} = 0,124 HRC

Resolution of the hardness-calibration machine δ_{ms} = 0,01 HRC

Five calibration HRC measurements are made on the hardness-reference block, as shown in Table B.3.

$$u_{HCRM} = \frac{t \times s_{HCRM}}{\sqrt{n}} \tag{B.9}$$

$$u_{ms} = \frac{\delta_{ms}}{\sqrt{6}} \tag{B.10}$$

Table B.3 — Results of the calibration of the hardness-reference block

No.	Measured hardness value, H, HRC
1	43,22
2	43,30
3	43,23
4	43,37
5	43,40
Mean value, $\overline{H}_{CRM}$	43,30
Standard deviation, s_{HCRM}	0,081

From the given indirect verification parameters and Table B.3:

$$u_{HCRM} = \frac{t \times s_{HCRM}}{\sqrt{n}} = \frac{1,14 \times 0,081}{\sqrt{5}} = 0,041 \text{ HRC}$$

$$u_{ms} = \frac{1}{\sqrt{6}} \times \delta_{ms} = 0,004 \text{ HRC}$$

B.4.2 Budget of uncertainty of certified value of hardness-reference blocks (see Tables B.4 and B.5)

Table B.4 — Budget of uncertainty of measurement

Quantity X_i	Estimated value x_i	Distribution type	Standard uncertainty of measurement $u(x_i)$	Sensitivity coefficient c_i	Standard measurement uncertainty symbol	Uncertainty contribution u_i
Hardness calibration machine measurement	43,30 HRC	Normal	0,041 HRC	1,0	u_{HCRM}	0,041 HRC
Hardness calibration machine resolution	0 HRC	Triangular	0,004 HRC	1,0	u_{ms}	0,004 HRC
Hardness calibration machine bias	0,17 HRC	Normal	0,124 HRC	1,0	u_{HCM}	0,124 HRC
Standard uncertainty of certified value of a calibrated hardness-reference block, u_{CRM}						0,131 HRC
Expanded uncertainty of certified value of a calibrated hardness-reference block, U_{CRM} (k = 2)						0,261 HRC

Table B.5 — Uncertainty of certified value of the hardness-reference block

Quantity	Certified value of hardness reference block	Expanded uncertainty of measurement U_{CRM}	Hardness calibration machine bias b_{HCM}	Expanded uncertainty of certified value of hardness-reference block
$\overline{H}_{CRM(Uncorr)}$ Uncorrected	43,30 HRC $(\overline{H}_{CRM})$	0,26 HRC	0,17 HRC	0,43 HRC $(U_{CRM} + \lvert b_{HCM} \rvert)$
$\overline{H}_{CRM(Corr)}$ Corrected	43,13 HRC $(\overline{H}_{CRM} - b_{HCM})$	0,26 HRC	0,17 HRC	0,26 HRC (U_{CRM})

