

DIN 50159-1



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Supersedes
DIN 50159-1:2015-01

**Metallic materials –
Hardness testing with the UCI method –
Part 1: Test method,
English translation of DIN 50159-1:2022-06**

Metallische Werkstoffe –
Härteprüfung nach dem UCI-Verfahren –
Teil 1: Prüfverfahren,
Englische Übersetzung von DIN 50159-1:2022-06

Matériaux métalliques –
Essai de dureté après la méthode UCI –
Partie 1: Méthode d'essai,
Traduction anglaise de DIN 50159-1:2022-06

Document comprises 21 pages

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In case of doubt, the German-language original shall be considered authoritative.

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Foreword

This document has been prepared by Working Committee NA 062-01-41 AA “Hardness testing for metals” of *DIN-Normenausschuss Materialprüfung* (DIN Standards Committee Materials Testing).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. DIN shall not be held responsible for identifying any or all such patent rights.

DIN 50159 consists of the following parts, under the general title *Metallic materials — Hardness testing with the UCI method*:

- *Part 1: Test method*
- *Part 2: Verification and calibration of the testing devices*

For current information on this document, please go to DIN’s website (www.din.de) and search for the document number in question.

Amendments

This document differs from DIN 50159-1:2015-01 as follows:

- a) the Introduction has been updated;
- b) the Scope has been limited;
- c) Clause 3 “Terms and definitions” has been added;
- d) the symbol for the coating thickness has been renamed “*d*”;
- e) a correlation between surface roughness and abrasive grain size for steels has been added in 9.3;
- f) requirements for conducting the test have been added;
- g) the designation of the device has been updated;
- h) the definition of the coupling method has been made more precise;
- i) a description of averaging more than three measured values has been added;
- j) the standard has been editorially revised.

Previous editions

DIN 50159-1: 2008-10, 2015-01

DIN 50159-1:2022-06

Introduction

Portable hardness testing devices allow hardness testing on specimens that are too large or too heavy to be tested on stationary hardness testing machines. Since the classic hardness testing methods such as Rockwell, Vickers, Brinell and others are not realizable or are only realizable with difficulty in portable devices, various manufacturers have developed new testing methods based on the classic methods, which can also be used in portable devices. UCI (Ultrasonic Contact Impedance) hardness testing devices determine hardness values by means of frequency shifting through interpolation in a previously determined adjustment curve in Vickers hardness units. The hardness values determined in this way are output as HV (UCI) values to distinguish them from the HV values from stationary hardness testing devices. The application of UCI hardness testing devices is essentially limited only by the accessibility of the test position by the indenter. The functioning and mode of operation of this measuring method are the subjects of this document.

1 Scope

This part of DIN 50159 specifies the procedure for hardness testing by the UCI method for metallic materials and hard metal.

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.

DIN 50159-2:2022-06, *Metallic materials — Hardness testing with the UCI method — Part 2: Verification and calibration of the testing devices*

DIN ISO EN 6507-2:2018-07, *Metallic materials — Vickers hardness test — Part 2: Verification and calibration of testing machines (ISO 6507-2:2018)*

DIN EN ISO 6507-3, *Metallic materials — Vickers hardness test — Part 3: Calibration of reference blocks*

3 Terms and definitions

No terms and definitions are listed in this document.

DIN and DKE provide terminology databases for use in standardization at the following addresses:

- DIN-TERMinology Portal: available at <https://www.din.de/en/services/din-term>
- DKE-IEV: available at <https://www.dke.de/DKE-IEV>

4 Principle

With the Ultrasonic Contact Impedance (UCI) measurement method, a vibrating rod vibrating at an ultrasonic frequency, with a Vickers indenter at its lower end, is pressed onto the specimen with a defined test force. Its resonant frequency increases as soon as it is brought into contact with the specimen during the creation of the indentation. The resonance frequency shift Δf is determined under the test force. It depends on the size of the contact area, the test force, as well as the effective modulus of elasticity E_{eff} . Using specimens of known hardness (e. g. hardness reference blocks), the frequency shift Δf is allocated to the corresponding Vickers hardness via appropriate instrument adjustment.

5 Symbols

For the purposes of this document, the symbols and designations in Table 1 apply.

Table 1 — Symbols, their designations and units

Symbol	Designation	Unit
A	Contact area	mm^2
E_{eff}	Effective modulus of elasticity	N/mm^2
F	Test force	N
h	Indentation depth	μm
k	Coverage factor	—
HV	Vickers hardness	—
HV (UCI)	Hardness determined according to the UCI method	—
R_a	Surface roughness	μm
d	Coating thickness	μm
Δf	Frequency shift	Hz

6 Indication of hardness according to the UCI method

The UCI hardness value is based on a frequency shift and is typically given in the Vickers hardness scale, taking into account the test force used; see the following example in Figure 1:

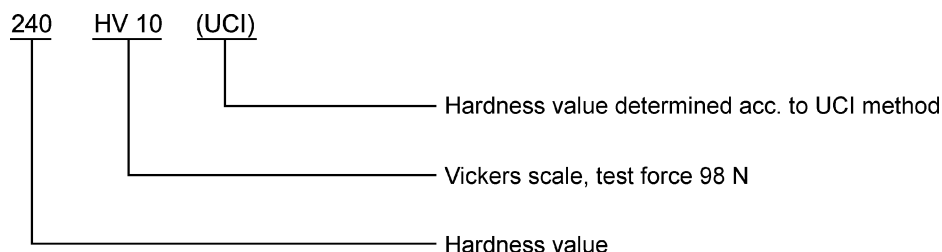


Figure 1 — Example of the indication of hardness according to the UIC method

7 Designation

The designation of a test according to DIN 50159-1 is as follows:

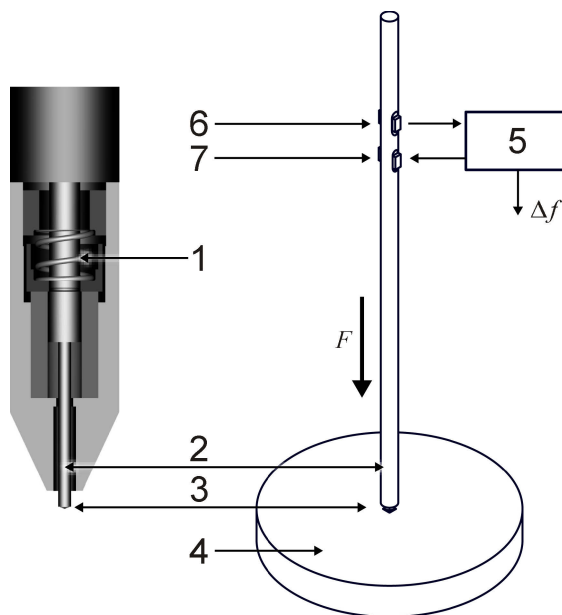
Test DIN 50159-1

8 Test device

8.1 The testing device for UCI hardness testing consists of a probe (see Figure 2) and an electronic measuring and display unit for determining the frequency shift. It is also possible for all measurement information to be integrated into the probe itself and transmitted digitally to a PC or display instrument.

8.2 Essentially, a UCI probe consists of a vibrating rod that is excited to vibrate longitudinally. This vibrating rod consists of a metal rod with the indenter attached to the lower end.

If a defined test force of the UCI probe used acts on the specimen, applied via a metal spring, a corresponding shift in the resonance frequency occurs. The basis for UCI hardness testing is the relationship between the frequency shift and the hardness of the tested material.

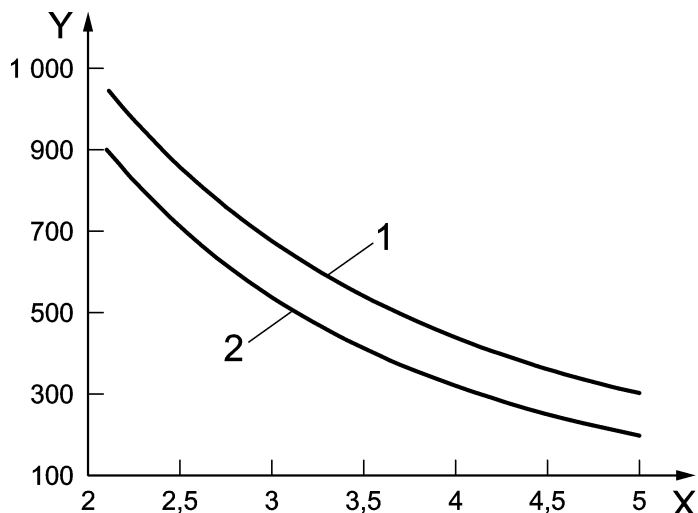


Key

- 1 metal spring for applying the test force
- 2 vibrating rod
- 3 indenter
- 4 specimen
- 5 resonance amplifier
- 6 receiving piezo transducer
- 7 transmitting piezo transducer

Figure 2 — Schematic set-up of a UCI probe

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Key

- X Δf in kHz
- Y HV (UCI)
- 1 adjustment curve for material 1
- 2 adjustment curve for material 2

Figure 3 — Example adjustment curves for the determination of the HV (UCI) hardness from the frequency shift

The frequency shift Δf determined with the UCI probe [Equation (1)] depends on the effective modulus of elasticity E_{eff} and the contact area A of the Vickers indenter with the specimen material and the test force F (see Figure 3).

$$\Delta f = f(E_{\text{eff}}, A, F) \tag{1}$$

The effective modulus of elasticity is a result of the interaction of the material properties of the specimen and the vibrating rod including the indenter.

Based on the adjustment with calibrated hardness reference blocks, the hardness of the specimen material is obtained using Equation (2):

$$\text{HV (UCI)} = f(1/\Delta f) \tag{2}$$

A large contact area with relatively soft material and constant test force leads to a high frequency shift. For the hardness value, the diagonals of the test indentation after removing the load are not determined optically as in conventional Vickers testing, but the contact area is recorded electronically by measuring the frequency shift under the test force.

The test forces of UCI probes range from 1 N to 98 N, with various probe types available in which the test force is applied manually or via motors.

Typical applications depending on the different test forces are given in Table 2.

Table 2 — Typical applications of the UCI method

Nominal test force	Typical applications a
98 N	Forgings, weld testing, testing of the heat-affected zone
49 N	Induction or case-hardened machine parts, e. g. camshafts, turbines, welds, testing of the heat-affected zone
10 N	Ion-nitrided embossing tools and dies, moulds, presses
8 N	Machined precision parts, gears, bearing races
3 N	Coatings, e. g. copper and chrome coatings on steel cylinders ($d \geq 40 \mu\text{m}$), copper-plated gravure cylinders, coatings, hardened coatings ($d \geq 20 \mu\text{m}$)
1 N	Thin coatings with polished surface
For the selection of the test force, the surface condition and any coatings or changes in hardness depending on the indentation depth, in accordance with subclauses 8.3 and 8.4, shall also be taken into account.	

8.3 The indenter is a straight diamond pyramid with a square base having a specified angle between opposite faces of 136° according to DIN EN ISO 6507-2:2018-07, 5.3.

8.4 The testing device shall meet the requirements of DIN 50159-2.

NOTE A method of periodic checking of the testing device by the user is given in the normative Annex A.

9 Specimen

9.1 Shape

UCI hardness testing is possible on specimens of various shapes as long as the probe can be positioned perpendicular to the test surface. It is also possible to measure the hardness of metallic coatings (see 9.4).

9.2 Thickness and mass

Natural vibration of the specimen can influence the UCI hardness test so that without additional measures, such as coupling the specimen, a minimum wall thickness and mass according to the manufacturer's specifications shall be taken into account. Typical values are a minimum wall thickness of 5 mm and a minimum mass of 200 g.

Specimens with masses lower than the specified minimum or specimens with sufficient mass but with areas thinner than the specified minimum thickness can require coupling to a solid body according to the manufacturer's specifications.

The coupling should be performed on flat surfaces with low roughness of the contact surface of the test specimen and the coupled mass.

NOTE 1 Improper coupling leads to incorrect test results.

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Special specimen geometries, e. g. pipes, require additional support of the measuring point so that the required minimum thickness and minimum mass may also be smaller than the values specified above. The minimum radius of curvature that can be tested is 3 mm.

NOTE 2 Small specimens below the minimum mass specified can also be tested when embedded or otherwise decoupled from free vibration.

9.3 Surface preparation

The preparation of the test surface shall be carried out in such a way that changes to the surface, e. g. those caused by heating or cold deformation, are kept to a minimum. Foreign matter such as scale, coatings or other surface irregularities shall be completely removed. In particular, the surface should be free of lubricants. Depending on the test force, the test areas shall not exceed the roughness *Ra* specified in Table 3.

Table 3 — Maximum permissible surface roughness *Ra*

Nominal test force	Maximum permissible surface roughness
	<i>Ra</i> µm
98 N	1
49 N	0,8
10 N	0,5
8,6 N	0,5
3 N	0,3
1 N	0,1

Insufficient surface preparation will increase the separation of the measured values. It is recommended that the test area be machined and finely ground to achieve the required roughness. Very small test forces such as 3 N or 1 N usually require a finely ground or polished surface, as may be present on electrolytically produced surfaces. The relationship between the grain size of the grinding medium and the achievable surface roughness *Ra* depends on the material. For steels, the following relationship can be approximated (see Table 4).

Table 4 — Relationship of surface roughness to grinding medium grain size for steels

Grain sizes according to FEPA (Federation of the European Producers of Abrasives)	120	180	240
<i>Ra</i>	about 1,2 µm	about 1,0 µm	about 0,6 µm

9.4 Hardness testing on metallic coatings

For measurements on thin layers or coatings, the indentation depth h of the Vickers indenter shall be taken into account. According to Equation (3), it depends on the test force and the hardness of the specimen:

$$h = 0,062 \cdot \sqrt{\frac{F}{HV}} \quad (3)$$

The minimum coating thickness d should not be less than $10 h$, see [1]. The properties of the base material can influence the hardness value.

9.5 Adjustment

The Vickers hardness value of the reference materials is determined from at least 5 measurements. The mean hardness value of a UCI device, determined from at least 10 measurements evenly distributed over the reference material, is then set to the reference value of the material. In modern devices, this setting can be stored for different materials.

UCI hardness testing is a comparative method, since the frequency shift of a UCI probe depends mainly on the contact area with the specimen material as well as its elastic properties (modulus of elasticity, Poisson's ratio, etc.). Typically, UCI hardness testing devices are adjusted with a set of unalloyed steel hardness reference blocks. When testing a different material, a reference material of this material with known hardness is required, with which the device shall be adjusted before measurement. The hardness of the reference material should lie in the range of the expected measured value.

10 Procedure

10.1 Testing shall be carried out at an ambient temperature between 10 °C and 35 °C. For temperatures outside this range, the temperature shall be specified in the test report. The specimen temperature can influence the UCI hardness test.

10.2 It shall be ensured that the specimen does not shift during the test procedure. If necessary, a suitable holding device shall be used for this purpose. The contact surfaces shall be clean and free of foreign matter (scale, lubricants, dirt, etc.).

10.3 The test force is to be applied steadily increasing, shock-free and along the vibrating rod. Vibrations of the specimen or probe during the UCI hardness test can influence the result and shall be avoided.

10.4 The test shall be performed perpendicular to the test surface. Deviations > 5° from the perpendicular to the test surface lead to errors that cannot be disregarded.

10.5 Before starting a series of measurements, check the device on a hardness reference block to ensure that it displays the calibrated hardness value.

10.6 After manual or automatic application of the test force perpendicular to the prepared test surface, the measurement is triggered. The frequency shift is automatically detected by the measuring or display unit, and the hardness value is determined.

10.7 For the determination of the UCI hardness, the arithmetic mean of at least three measured values shall be determined. Depending on the process history and surface condition, significantly more measurements than three can also be necessary for determining the mean. In these cases, the individual results are to be summarized in a suitable list of results and checked for significance. If individual outliers are identified, the exclusion of measured values from the results list is only permissible if a corresponding test

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specification is available for this purpose. The excluded measured values shall be logged and be available for subsequent evaluation.

10.8 The distance of the centre of each test indentation from the edge of the specimen shall be at least 5 mm. In the case of embedded specimens or specimens otherwise decoupled from free vibration, the distance to the specimen edge may be selected to be significantly smaller.

10.9 The distance between the centres of two adjacent test indents shall be at least 1 mm for materials such as steel, copper and copper alloys and at least 3 mm for soft materials such as light metals, lead, tin and their alloys.

10.10 The place where the test is carried out shall be free from vibrations and strong magnetic fields, such as those occurring in the vicinity of induction furnaces and electric welding equipment.

11 Measurement uncertainty of results

The measurement uncertainty of the results depends on various parameters, which can be divided into two categories:

- Sources depending on the UCI hardness testing device (including the uncertainty of measurement for the direct calibration of the testing device) and the calibration of hardness reference blocks;
- Sources depending on the test methods used and on different test conditions, for example, contact angle, surface roughness or inhomogeneities in the test specimen.

A complete evaluation of the measurement uncertainty should be carried out following the "ISO Guide to the expression of uncertainty in measurement (GUM)" [2].

NOTE It is not always possible to quantify all identified aspects that contribute to measurement uncertainty. An estimate of the measurement uncertainty is obtained in each case from the statistical analysis of several measurements on the specimen.

An example of estimating the measurement uncertainty of the measured hardness values is given in Annex B.

12 Test report

The test report shall include at least the following information:

- a) reference to DIN 50159-1:2022-06;
- b) all details necessary for identifying the specimen;
- c) information on the testing device used (test force);
- d) measurement result obtained and number of single values upon which it is based;
- e) all essential details of the test which are not specified in DIN 50159-1 or which were optionally applied, e. g. type of coupling, test location on the specimen;
- f) reference material used;
- g) details of any events that may have affected the measurement result, e. g. the ambient temperature and the temperature of the specimen if outside the range specified in 9.1, and whether any measured values were excluded (see 10.7);
- h) measurement uncertainty of the hardness values;

- i) name of tester;
- j) test date.

There is no generally applicable method for accurately converting UCI hardness to hardness values from other hardness testing methods or to tensile strength. Conversions should therefore be avoided if there is no reliable basis for conversion through comparative testing.

Annex A **(normative)**

Periodic checking of the testing device by the user

A simple check of the testing device shall be performed each day the device is used, in each hardness range used.

The check consists of at least three indentations on a hardness reference block calibrated according to DIN EN ISO 6507-3. If the difference between the mean value of the read-off hardness and the hardness of the reference block is less than or equal to the limit deviation in Table A.1, the testing device can be considered to be satisfactory. If not, a complete indirect calibration shall be carried out.

Table A.1 — Limit deviations

Hardness scale	Limit deviation			
	%			
	< 250 HV	250 HV to < 500 HV	500 HV to 800 HV	> 800 HV
HV 0,1	6	7	8	9
HV 0,3	6	7	8	9
HV 0,8	5	5	6	7
HV 1	5	5	6	7
HV 5	5	5	5	5
HV 10	5	5	5	5

A record of these results should be kept to determine the reproducibility and indication error of the testing device.

Annex B (informative)

Measurement uncertainty of the measured hardness values

B.1 General

The approach to uncertainty determination considers only those uncertainties associated with the overall metrological function of the hardness testing device in the context of hardness reference blocks (referred to below as CRM). The uncertainties of the functioning reflect the combined effect of all individual uncertainties (indirect calibration). Because of this approach, it is important that the individual machine components operate within the tolerances. It is strongly recommended that this procedure be used no longer than one year after successfully passing the direct calibration.

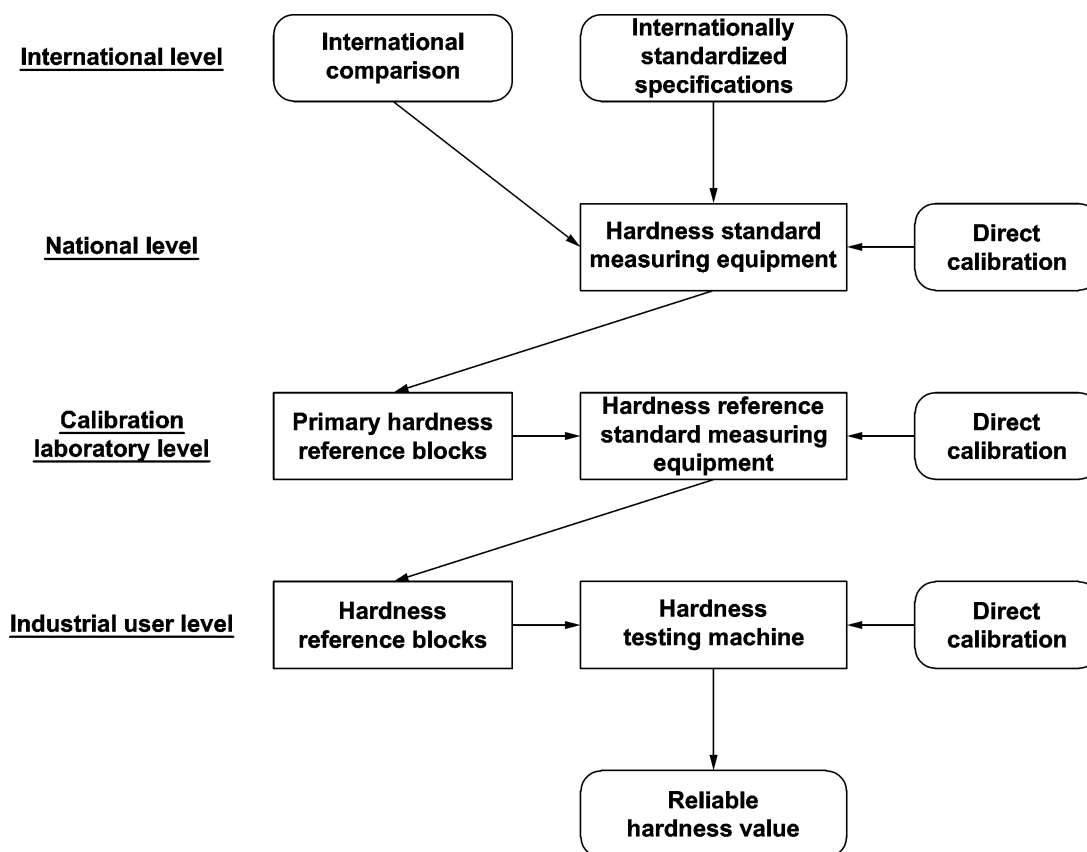


Figure B.1 — Structure of the metrological chain for the definition and transfer of hardness scales

Figure B.1 shows the structure of the metrological chain with the four levels necessary to define and pass on the hardness scales. The chain begins at the international level, where the international definitions of the various hardness scales are established in order to make international comparisons. There are a number of primary hardness standard measuring machines at the national level, and primary hardness comparison blocks for use by calibration laboratories. Of course, direct calibration and testing of these devices should be done with the highest possible accuracy.

B.2 Uncertainty of measurement for hardness testing

B.2.1 Procedure without error (method 1)

Method 1 (referred to below as M1) is a simplified method that can be used without considering the systematic errors of the hardness testing device.

In M1, the limit deviation, i. e. the range in which the hardness testing device is allowed to deviate from the reference standard, is used to define the uncertainty source u_E . There is no correction of the hardness values with respect to this deviation.

The procedure for determining U is explained in Table B.1 [2], [3].

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

Thus the measurement result is given by

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

NOTE M1 has been used in order to be in accordance with the standards of stationary hardness testers (DIN EN ISO 6506-1 [7], DIN EN ISO 6507-1 [8], DIN EN ISO 6508-1 [10] and DIN EN ISO 4545-1 [11]).

B.2.2 Representation of the measurement result

When representing the measurement result, the method used should be indicated. In general, method 1 [Equation (B.2)] should be used for the measurement result (see also Table B.1, step 9).

Table B.1 — Determination of the expanded uncertainty using method M1

Step	Source of uncertainty	Symbol	Equation	Literature/certificate	Example [..] = HV 1 (UCI)
1 M1	Uncertainty due to the limit deviation	u_E	$u_E = \frac{u_{E,2r} \cdot \bar{X}_{CRM}}{2,8}$	Limit deviation $u_{E,2r}$ as in DIN 50159-2:2022-06, Table 1. \bar{X}_{CRM} from the calibration certificate. See Note 1.	$u_E = \frac{0,06 \cdot 554}{2,8} = 11,87$
2 M1	Uncertainty and mean value of CRM hardness (for detailed calculation see DIN EN ISO 6507-3:2006-03, Table A.4)	u_{CRM} , \bar{X}_{CRM}	$u_{CRM} = \frac{U_{CRM}}{2}$	U_{CRM} , \bar{X}_{CRM} from the calibration certificate for the CRM. See Note 2.	$u_{CRM} = \frac{8}{2} = 4$ $\bar{X}_{CRM} = 553,81$
3 M1	Mean value and standard deviation when measuring the CRM	\bar{H} , s_H	$\bar{H} = \frac{\sum_{i=1}^n H_i}{n}$ $s_H = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (H_i - \bar{H})^2}$	n = number of measurements i = sequential number	Single measurements: 556-550-557-554-559 $\bar{H} = 555,2$ $s_H = 3,4$
4 M1	Uncertainty of the hardness testing device when measuring the CRM	$u_{\bar{H}}$	$u_{\bar{H}} = \frac{t \cdot s_H}{\sqrt{n}}$	$t = 1,14$ for $n = 5$ $t = t$ -Test	$u_{\bar{H}} = \frac{1,14 \cdot 3,4}{\sqrt{5}} = 1,73$
5 M1	Mean value and standard deviation when measuring a specimen	\bar{x} , s_x	$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$ $s_x = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2}$	$n = 5$ measurements on the specimen If $n = 1$, $s_x = 0$ then the test report should contain a note that the measurement uncertainty refers only to this measurement recording but not to the entire specimen.	Single values: 530-525-537-528-532 $\bar{x} = 530,4$ $s_x = 4,5$
6 M1	Standard uncertainty when measuring a specimen	$u_{\bar{x}}$	$u_{\bar{x}} = \frac{t \cdot s_x}{\sqrt{n}}$	$t = 1,14$ for $n = 5$	$u_{\bar{x}} = \frac{1,14 \cdot 4,5}{\sqrt{5}} = 2,29$

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Step	Source of uncertainty	Symbol	Equation	Literature/certificate	Example [..] = HV 1 (UCI)
7 M1	Standard uncertainty due to the resolution of the hardness value display	u_{ms}	$u_{ms} = \frac{\delta_{ms}}{2\sqrt{3}}$	$\delta_{ms} = 5$ HV 1 (UCI)	$u_{ms} = \frac{5}{2 \cdot \sqrt{3}} = 1,44$
8 M1	Determination of the expanded uncertainty	U	$U = k \cdot \sqrt{u_E^2 + u_{CRM}^2 + u_H^2 + u_x^2 + u_{ms}^2}$	Steps 1 to 7 $k = 2$	$U = 2 \cdot \sqrt{11,87^2 + 4^2 + 1,73^2 + 2,29^2 + 1,44^2}$ $U = 25,9$ HV 1 (UCI)
9 M1	Measurement result	\bar{X}	$\bar{X} = \bar{x} \pm U$	Steps 5 and 8	$\bar{X} = (530,4 \pm 25,9)$ HV 1 (UCI) as in DIN 50159-1
NOTE 1	The factor 2,8 is derived from the determination of the standard uncertainty for a rectangular probability distribution.				
NOTE 2	If necessary, the change in hardness of the hardness reference block shall be considered.				

B.2.3 Procedure using the measurement uncertainty of the hardness testing device (method 2)

Method 2 (referred to below as M2) is a method equivalent to M1, in which the quantities u_{CRM} , u_H and u_{ms} are combined to form the measurement uncertainty of the hardness testing device. The measurement uncertainty of the hardness testing device u_{HTM} can be taken from the calibration certificate or the test certificate of the device.

The measurement uncertainty of the hardness test is given by Equation (B.3):

$$U = 2 \sqrt{u_E^2 + u_x^2 + u_{HTM}^2} \tag{B.3}$$

where

u_{HTM} is the measurement uncertainty of the hardness testing device;

u_x is the standard uncertainty due to the inhomogeneity of the hardness distribution on the specimen;

u_E is the measurement uncertainty due to the limit deviation of the hardness testing device.

An example for a device with a Vickers scale is given in Table B.2:

Table B.2 — Determination of the inhomogeneity of the specimen

No.	Measured hardness value HV 1 (UCI)
1	530
2	525 _{min}
3	537 _{max}
4	528
5	532
Mean \bar{H}	530,4
Standard deviation s_x	4,5

$$u_x = \frac{t \times s_x}{\sqrt{n}} \tag{B.4}$$

with $t = 1,14$ and $n = 5$ then:

$$u_x = 2,29 \text{ HV 1 (UCI)}$$

The values

u_{HTM} 4,59 HV 1 (UCI) (from the calibration certificate of the hardness testing device, see DIN 50159-2:2022-06, Table A.2)

u_x 2,29 HV 1 (UCI)

u_E 11,87 HV 1 (UCI)

result in the extended uncertainty of the hardness test:

$U = 25,9$ HV 1 (UCI)

The result is then: $\bar{X} = (530,4 \pm 25,9)$ HV 1 (UCI).

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- [9] DIN EN ISO 6507-3:2006-03, *Metallic materials — Vickers hardness test — Part 3: Calibration of reference blocks (ISO 6507-3:2018)*
- [10] DIN EN ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*
- [11] DIN EN ISO 4545-1, *Metallic materials — Knoop hardness test — Part 1: Test method*