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UNCERTAINTY EVALUATION OF THE REFERENCE HARDNESS STANDARD OF SLOVENIA

Anton Štibler[1)], Konrad Herrmann[2)]

1) ZAG Ljubljana, Slovenia, 2) PTB Braunschweig, Germany

Abstract - A commercial hardness testing machine has been provided to represent a reference hardness standard in Slovenia. Various hardness scales which are important for calibration purposes are realized on this machine. The evaluation of measurement uncertainty is one of the most important tasks for establishing this reference standard. Therefore the influence quantities contributing to the uncertainty are determined and the calibration of the machine by direct and indirect method is carried out. Calculations of measurement uncertainties for Brinell, Vickers and Rockwell hardness scales are presented.

The hardness scales for Brinell HBW 2,5/187,5; HBW 2,5/62,5; HBW 2,5/31,25, Vickers HV 30 and Rockwell are subject of uncertainty determination in this paper.

Keywords: Hardness of metals, hardness standard, measurement uncertainty

1. UNCERTAINTY CALCULATION FOR DIRECT CALIBRATION

At first the main sources of measurement uncertainties are determined and then they are evaluated by measurement.
The main parameters which have an effect on measurement uncertainty are those defining the measurement process. They are stipulated and given by the standards EN ISO 6506, EN ISO 6507 and EN ISO 6508.

1.1. Test force

The test force is applied by a servo controlled motor drive system. Such system leads to two main error sources:

- measurement of the applied force
- measurement of the maintenance of the applied force

The applied force was calibrated with load cells. Several series of measurement were carried out in accordance with the recognized standards.
The maintenance of the applied force was assessed by analysing data obtained during the force calibration.

The uncertainty of measurement of the test force is evaluated in two steps:

- determination of the combined relative standard uncertainty of the reference value of the force transfer standard:

$$u_{FRS} = \sqrt{u_{TS}^2 + u_T^2 + u_S^2 + u_D^2}$$

u_{TS} relative uncertainty of the transfer standard
u_T relative uncertainty due to the temper. deviation
u_S relative long term stability
u_D relative interpolation deviation

- determination of the measurement uncertainty of each force.
  Each force was measured three times in three different indentation positions.

Fig. 1. Hardness reference machine

The uncertainty of measurement of the test force is calculated by use of the following formula.:

$$u_F = \sqrt{u_{FRS}^2 + u_{FHTM}^2 + u_{main}^2}$$

u_{FHTM} uncertainty of measurement of the test force – normal distribution
u_{main} uncertainty of maintainance of the test force – rectangular distribution

Expanded uncertainty:

$$U_F = k \times u_F$$

TABLE I. Results of measurement uncertainty evaluation

Force N	ΔF_{rel} %	U^*_F %	U_F %
98,07	1,29	0,46	-
294,2	0,32	0,33	1,33
306,5	0,04	0,45	1,20
612,9	0,04	0,24	0,42
1471	0,06	0,20	0,22
1839	0,02	0,24	0,29

ΔF_{rel} relative deviation of the test force
U^*_F relative expanded uncertainty of the test force without considering of force maintenance; k=2
U_F relative expanded uncertainty of the test force; k=2

1.2. Length

1.2.1 Optical length measuring system

Brinell and Vickers indentations are measured using the optical length measuring system. The main sources of uncertainty are due to the:

- identification of the edges/vertices of the indentation
- measurement of the distance between the two opposite edges/vertices of the indentation

Identification of the edges/vertices of the indentation depends on the person carrying out the measurement. Measurement of the distance between the two opposite edges/vertices is assessed by calibration using Zeiss stage micrometer.
Uncertainty of length measurement is calculated as follows:

$$u_L = \sqrt{u_{LRS}^2 + u_{ms}^2 + u_{LHTM}^2}$$

u_{LRS} relative uncertainty of the transfer standard
u_{ms} relative uncertainty due to the resolution
u_{LHTM} relative standard uncertainty of measurement results

Expanded uncertainty:

$$U_L = k \times u_L$$

TABLE II. Results of measurement uncertainty evaluation

Length mm	ΔL_{rel} %	U_L %
0,2 – 0,9	0,48	0,40

ΔL_{rel} maximum relative deviation of the length
U_L maximum expanded uncertainty of the length; k=2

1.2.2. Depth measuring system

Rockwell indentation is measured using the depth measuring system. Calibration of the depth measuring system is carried out using special calibration device made by Co. Bareiss Prüfgerätebau GmbH in Oberdischingen, Germany. The calibration procedure is described in a separate paper.

1.3. Test cycles

All phases of the test cycle are adjustable at the panel of the machine and they are in the tolerances required by the standards. Calibration of test time is carried out using a stop watch.

2. UNCERTAINTY CALCULATION FOR INDIRECT CALIBRATION

Indirect calibration is carried out using a high quality reference hardness blocks made by Co. Buderus, Germany.

2.1. Uncertainty of calibration of reference machine

The uncertainty of measurement of indirect verification of the reference hardness testing machine is calculated by the equation:

$$u_{HTM} = \sqrt{u_{CRM}^{*2} + u_H^2 + u_{CRM-D}^2 + u_{ms}^2}$$

u^*_{CRM} calibration uncertainty of the reference block without its inhomogeneity according to the calibration certificate for k=1.
u_H standard uncertainty due to the repeatability of the reference hardness machine
u_{CRM-D} long time drift in hardness of the reference block
u_{ms} relative uncertainty due to the resolution

$$u_H = \frac{t \times s_H}{\sqrt{n}}$$

s_H standard deviation due to the repeatability
t = 1,15 …student factor
n = 5 … number of indentation

Expanded uncertainty:

$$U_{HTM} = k \times u_{HTM}$$

2.2. Uncertainty of calibration of reference blocks

An additional component u_{xCRM} contributes to the uncertainty of measurement of hardness reference blocks. u_{xCRM} represents standard deviation due to the inhomogeneity of the hardness distribution on the surface of the reference block.

$$u_{CRM} = \sqrt{u_{HTM}^2 + u_{xCRM}^2}$$

u_{xCRM} standard uncertainty of hardness value due to the inhomogeneity of the block

Expanded uncertainty:

$$U_{CRM} = k \times u_{CRM}$$

2.3. Example of budget of measurement uncertainty for Rockwell measurement method

Hardness reference block …45,0 HRC
Uncertainty of the reference block..u_{CRM} = ± 0,15 HRC (k=1)
Time drift of the reference block …u_{CRM-D} = 0 HRC

TABLE III Results of the indirect verification

No.	Measured hardness HRC
1	44,8
2	44,7
3	45,0
4	45,0
5	44,8
6	45,0
7	45,0
Mean value	44,90
Standard deviation s_H	0,129
Standard uncertainty of measurement u_H	0,06

TABLE IV. Budget of uncertainty for Rockwell measurement

Quantity X_i	Estimated value x_i	Standard uncert. of measureme $u_{(xi)}$	Distribu tion	Uncertaint y contributi on $u_I(H)$
u_{RB}	45,0 HRC	0,15 HRC	Normal	0,15 HRC
u_{HTM-R}		0,06 HRC	Normal	0,06 HRC
u_{ms}		0,05 HRC	Rectang.	0,04 HRC
s_{RB-D}	0 HRC	0 HRC	Triang.	0 HRC
Combined uncertainty of measurement u_{HTM}				0,17 HRC

Sensitivity coefficients c_i = 1,0.

TABLE V. Determination of the inhomogeneity of the reference hardness blocks

No.	Measured hardness HRC
1	45,84
2	45,95
3	45,88
4	46,07
5	46,01
Mean value	45,95
Standard deviation s_{xCRM}	0,009
Standard uncertainty u_{xCRM}	0,005

2.4. Budget of uncertainty for different hardness scales

In the following table results of evaluation of measurement uncertainty for different hardness scales are presented. Evaluation is done by use of high quality reference hardness blocks with uncertainty of the hardness value noted in the table.

TABLE V. Results of measurement uncertainty evaluation

Hardness scale	Hardness value hardness unit	u^*_{CRM} hardness unit	U_{HTM} hardness unit (k=2)	U_{CRM} hardness unit (k=2)
Rockwell HRC	25	0,15	0,31	0,32
	45	0,15	0,32	0,32
	65	0,15	0,31	0,32
Vickers HV 30	250	1,2	2,7	2,8
	550	2,5	5,3	5,5
	850	4,0	9,0	9,2
Brinell HBW 2,5/31,25	70	0,5	1,1	1,2
	80	0,5	1,5	1,7
HBW 2,5/62,5	100	0,5	1,1	1,3
	180	0,5	1,2	1,5
HBW 2,5/187,5	130	0,5	1,2	1,4
	300	1,0	2,1	2,2

3. CONCLUSION

Results of direct calibration show big influence on the uncertainty of small forces (306,5 N and lower). Maintenance of force should be more stable.
The measurement results given in the table V show that accurate measurement with low uncertainties can be carried out on the reference hardness machine.
Uncertainty contribution due to the repeatability of the reference hardness machine u_H is small. The main influence to the uncertainty of measurement on the machine U_{HTM} arises from the uncertainty of the reference hardness value of the blocks used for the calibration of the machine.
Uncertainty contribution due to the inhomogeniety of the blocks u_{xCRM} is also small as a result of high quality blocks which were used for measurement.
Considering the corrections for a known deviations determined by interlaboratory comparison (see published report on IMEKO T3/5/20 Conference; Celle 2002) we can conclude that the reference hardness machine is suitable for high accurate measurement as well as for calibration of the reference hardness blocks.

REFERENCE

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Authors: Anton Štibler, Slovenian National Building and Civil Engineering Institute, Dimičeva 12, 1000 Ljubljana, Slovenija
Tel: + 386 1 28 04 519; Fax: + 386 1 28 04 484
e-mail: anton.stibler@zag.si
Konrad Herrmann, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
Tel: + 49 531 592 5140; Fax: + 49 531 592 5105
e-mail: konrad.herrmann@ptb.de