

Experiences with the determination of uncertainty

Brinell Hardness, PC program

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Abstract

After the next revision of the Standards for hardness testing [1-3], a determination of uncertainty has to be [4]. part of the Standards. In the following text two methods for the determination, proposed for the ISO Standards of hardness, are described and the implementation of both methods in an Excel-based file is explained.

General remarks

A worldwide accepted base for the determination of uncertainty is the “Guide to the expression of uncertainty in measurement” (GUM) [6]. All parts of this article are based on the GUM.

The European Union (SMT) supported in 2000 the research of determination of uncertainty of testing machines. Binder and Gabauer published as part of the EU project COP 14 [7] concerning hardness testing machines. The determination of the uncertainty is based on the indirect verification of the hardness testing machines i.e. among other on the use of hardness reference blocks (CRM).

Determination according to the UNCERT report

This determination, according to the UNCERT report, is indicated in the table 1 as A1. It is proposed as a simplified method for the standards, which can be used without knowledge of the systematic error of the hardness testing machine.

$$U = 2 * \sqrt{u_E^2 + u_{X_{CRM}}^2 + u_{CRM}^2 + u_H^2 + u_x^2} \quad (A1)$$

The used abbreviations and formulas are indicated in the table. The example in the last row concerning HBW is determined on the hardness reference block MPA NRW 25401.52001 with the calibrated value 247 HBW 2,5/187,5. The data for the different sources of uncertainty are also indicated in the table.

One change was made from the original equation to the ISO proposal:

It concerns the step 1, the error of the hardness testing machine (u_E). In the original UNCERT report, the value overtaken from the Standard is assumed to be of a 2σ part of the distribution. To take (u_E) as source in the calculation the division by 2 is used. According to ISO 5725, a 1σ distribution is assumed. To take (u_E) as source in the calculation, the division by 2,8 is used for the proposal described in this paper.

Table 1: Determination of the expanded uncertainty according to method (A1) and (A2)

Step	Sources of uncertainty	Abbreviation	Formula	References/Certificate	Example [.] = HBW 2,5/187,5
1 A1	Standard uncertainty according to the (1σ) maximum permissible error	u_E	$u_E = \frac{\bar{x}_{CRM}}{2,8}$	$u_{E,2r}$ according to ISO 6506-2, Table 2	$u_E = \frac{0,02 * 246,8}{2,8} = 1,763$
2 A1 A2	Uncertainty (1σ) of the standardizing machine for calibration of CRM	$u_{\bar{x}_{CRM}}$	$u_{\bar{x}_{CRM}} = \frac{u_{\bar{x}_{CRM},2\sigma}}{2}$	$u_{\bar{x}_{CRM},2\sigma}$ according to calibration certificate of CRM	$u_{\bar{x}_{CRM}} = \frac{2,0}{2} = 1,0$
3 A1 A2	Mean value and standard deviation of the calibration of CRM	\bar{x}_{CRM} , $\chi^2_{n-1,95\%}$	$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$ $s_{X_{ZRM}} = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_{i(CRM)} - \bar{X}_{CRM})^2}$	X_i according to calibration certificate of CRM	$\bar{X}_{CRM} = 246,8$ $s_{X_{CRM}} = 0,84$
4 A1 A2	Standard uncertainty of CRM	u_{CRM}	$u_{CRM} = \frac{t^* s_{X_{CRM}}}{\sqrt{n}}$	t=1,15 (Student factor) for n=5	$u_{CRM} = \frac{1,15 * 0,84}{\sqrt{5}} = 0,43$
5 A1 A2	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 6506-2 clause 5.6	Single values (1) 246,0–245,0–246,0–246,0–246,0 $\bar{H}_1 = 245,8 / s_H = 0,45$ (2) 245,0–246,0–247,0–246,0–247,0 $\bar{H}_2 = 246,2 / s_H = 0,84$
6 A1 A2	Standard uncertainty of hardness testing machine when measuring CRM	$u_{\bar{H}}$	$u_{\bar{H}} = \frac{t^* s_H}{\sqrt{n}}$	t=1,15 (Student factor) for n=5 and α = 68,3	$u_{\bar{H}} = \frac{1,15 * 0,45}{\sqrt{5}} = 0,23$

7 A1 A2	Mean value and standard deviation of the testing of a sample	u_{CR} $\frac{1}{\sqrt{5}}$	$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$ $s_x = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2}$	x_i : measurements on the sample	Single values 288–290–285–285-282 $\bar{x} = 286,0$ $s_x = 3,08$
8 A1 A2	Standard uncertainty when measuring a sample	u_x	$u_x = \frac{t * s_x}{\sqrt{n}}$	t=1,15 (Student factor) for n=5	$u_x = \frac{1,15 * 3,08}{\sqrt{5}} = 1,59$
9 A2	Standard uncertainty according to the resolution of the length measuring system	u_{ms}	$u_{ms} = \frac{ms}{\sqrt{3}}$	ms=1 μm	$u_{ms} = \frac{1}{\sqrt{3}} = 0,58$
10 A2	Deviation of hardness testing machine from calibration value	b	$B = \bar{H} - \bar{X}_{CRM}$	Steps 3 and 5	b₁ = 245,8-247 = -1,2 b₂ = 246,2-247 = -0,8
11 A2	Standard deviation of the deviation b	s_b	$s_b = \sqrt{\frac{1}{n_m - 1} \sum_{i=1}^{n_i} (b_i - \bar{b})^2}$	Step 10	0,28
12 A2	Standard uncertainty of the determination of b . Can be determined only after the second set of measurements	u_b	$u_b = \sqrt{\frac{n_m - 1}{\chi^2_{n_m - 1, 95\%}}} * s_b$	$\chi^2_{n_m - 1, 95\%} = 0,41$ for m=2	$u_b = \sqrt{\frac{2}{0,41}} * 0,28 = 0,44$
13 A1	Determination of the expanded uncertainty	U	$U = 2 * \sqrt{u_E^2 + u_{X_{CRM}}^2 + u_{CRM}^2 + u_H^2 + u_x^2}$	Step 1 to 8	$U = 2 * \sqrt{1,76^2 + 1,0^2 + 0,39^2 + 0,23^2 + 1,59^2}$ $U = 5,2$
14 A1	Result of the measurement		$\bar{X} = \bar{x} \pm U$		$\bar{X} = 286,0 \pm 5,2$
15 A2	Determination of the corrected expanded uncertainty	U_{corr}	$U_{corr} = 2 * \sqrt{u_{X_{CRM}}^2 + u_{CRM}^2 + u_H^2 + u_x^2 + u_{ms}^2 + u_b^2}$	Step 2 to 9 and 12	$U_{corr} = 2 * \sqrt{1,0^2 + 0,39^2 + 0,23^2 + 1,59^2 + 0,58^2 + 0,44^2}$ $U_{corr} = 4,1$
16 A2	Result of the measurement with corrected mean value		$\bar{X} = (\bar{x} + \bar{b}) \pm U_{corr}$		$\bar{X} = 286,8 \pm 4,1$

Kal. Härte: 247 Verfahren: HBW2,5/187,5 Grenzabweichung: 4,94 Gemessene Härtewerte auf Härtevergleichsplatte

Nummer	Prüfer	Datum	Verwendbarkeitsprüfung	Mittlere Härte	Differenz Härte	Grenzabweichung/Wiederholpräzision (GA/WHP)	Wiederholpräzision abs. R	Wiederholpräzision % Rrel	Standardabweichung s	Messung 1 Härtevergleichsplatte	Messung 2 Härtevergleichsplatte	Messung 3 Härtevergleichsplatte	Messung 4 Härtevergleichsplatte	Messung 5 Härtevergleichsplatte
0		Kalibrierung		247	0,00		2,00	0,81	0,84	247	246	246	248	247
1	Pn	02.02.02	OK	246	-1,20	OK	1,00	0,41	0,45	246	245	246	246	246
2	Pn	03.02.02	OK	246	-0,80	OK	2,00	0,81	0,84	245	246	247	246	247

Fig.1 Data from periodic check of a hardness testing machine (Data of the machine in EXCEL file but not in the Fig.)

Namer	Prüfer	Datum	u_H	U^*	u_x	$u_{c(\bar{x})}$	Ergebnis $\bar{X} = \bar{x} \pm U$	Messung 1 Probe	Messung 2 Probe	Messung 3 Probe	Messung 4 Probe	Messung 5 Probe
1	Pn	02.02.02	0,23	4,17								
2	Pn	03.02.02	0,43	4,23	1,59	2,64	286,0 ± 5,29	288,00	290,00	285,00	285,00	282,00

Fig.2 Data determination of uncertainty according to UNCERT Report (Method A1 and A3) (Data of the machine in EXCEL file but not in the Fig.)

Nummer	Prüfer	Datum	u_H	U_{korr}^*	u_x	$u_{c(\bar{x})_{korr}}$	u_b	Messabweichung b	Ergebnis korrigiert $\bar{X}_{korr} = \bar{x}_{korr} \pm U_{korr}$	Messung 1 Probe	Messung 2 Probe	Messung 3 Probe	Messung 4 Probe	Messung 5 Probe
1	Pn	02.02.02	0,23	2,51				-1,20	-					
2	Pn	03.02.02	0,43	2,61	1,59	2,05	0,14	-0,80	286,8 ± 4,11	288,00	290,00	285,00	285,00	282,00

Fig 3. Data determination of uncertainty including correction (Method A2 and A4) (Data of the machine in EXCEL file but not in the Fig.)

Determination correlated with the conduct of a control chart

As an alternative, the method A2 is proposed as part of the ISO Standards. The method is correlated with the conduct of a control chart.

$$U_{corr} = 2 * \sqrt{u_{X_{CRM}}^2 + u_{CRM}^2 + u_H^2 + u_x^2 + u_{ms}^2 + u_b^2} \quad (A2)$$

The procedure for the determination of U_{corr} is explained in the table. The differences between A1 and A2 are also indicated in the table. In most cases (u_E) is the biggest source. Therefore it is reasonable to discuss whether it can be taken out of the calculation or replaced. In the publication of Gabauer [8] the source (u_E) is by a factor 6 bigger than the next biggest source. The most important difference between the two methods is that the source (u_E) is in the calculation A1 but not in that of A2. (u_E).

The value of combined uncertainty becomes smaller; therefore additional sources become relevant. (mentioned in the table only with A2 in the first column).

One source of uncertainty is u_b , describing the uncertainty due to the determination of b (step 10 in the table). The determination of b is done with each determination of uncertainty and they are characterised by b_i . The determination of u_b is dependent as well on all determinations before.

As a further source of uncertainty u_{ms} was introduced concerning the single step (ms). The measured value of a hardness testing machine is displayed numerically. The smallest single step of the display is connected with the quantification of the resolved value (step 11,12 in the table).

When using U_{corr} , all determined hardness values have to be corrected by b [11,12].

Determinations only taking into account the influence of the machine

Not proposed to be part of the standards are the two determinations A3 and A4 to get U^* and U^*_{corr} which are derived from A1 and A2 but do not take into account the influences of the material under discussion but only the influences of the machine itself.

$$U^* = 2 * \sqrt{u_E^2 + u_{X_{CRM}}^2 + u_{CRM}^2 + u_x^2} \quad (A3)$$

$$U^* = 2 * \sqrt{1,76^2 + 1,0^2 + 0,39^2 + 0,23^2} = 4,1 \quad (A3)$$

$$U^*_{corr} = 2 * \sqrt{u_{X_{CRM}}^2 + u_{CRM}^2 + u_H^2 + u_{ms}^2 + u_b^2} \quad (A4)$$

$$U^*_{corr} = 2 * \sqrt{1,0^2 + 0,39^2 + 0,23^2 + 0,58^2 + 0,44^2} = 2,63 \quad (A4)$$

The implementation of determination of uncertainty in an Excel-based file

The results of determination of the uncertainty method A1 and A3 are shown in fig. 2, of method A2 and A4 in fig.3. Both figures are part of an Excel-file for (fig.1) periodic cheque [9,10]. To shorten the figures, the information of the tested machine and the sources depending on the reference block, which are part of the Excel file, are not in the figures. The file is generated for each hardness reference block and consists of:

- page 1 hints to the user
- page 2 data of the periodic check of the machine (partly in Fig. 1)
- page 3 Figure of hardness differences
- page 4 Figure repeatability (R_{rel})
where the range of the single values is given, the allowed range is the borderline.
- page 5 Uncertainty according to UNCERT COP 14 (partly in Fig. 2)

- page 6 Uncertainty considering the deviation **b** (partly in Fig. 3)
- page 7 Table of the meanings of the sources (see the table of this publication)

The file can be overtaken by download over the URL <http://mpanrw.de/crm> of the calibration lab when introducing the number of the hardness reference block and the hardness values [9-12]. Test versions are available when introducing "demo" on both positions. The file is the first determination of uncertainty, which is part of delivery of a reference material.

Literature

- [1] ISO 6507: (1/98) Metallic materials, Vickers hardness test
 Part 1: Test method
 Part 2: Verification of the testing machine
 Part 3: Calibration of reference blocks
- [2] ISO 6506: (10/99); Metallic materials, Brinell hardness test
 Part 1: Test method
 Part 2: Verification and calibration of the testing machine
 Part 3: Calibration of reference blocks
- [3] ISO 6508: (10/99) Metallic materials, Rockwell hardness test
 (scales A, B, C, D, E, F, G, H, K, N, T)
 Part 1: Test method
 Part 2: Verification and calibration of the testing machine
 Part 3: Calibration of reference blocks
- [4] ISO/IEC 17025 (99) General requirements for the competence of testing and calibration laboratories
- [5] ISO 5725: (11/97) Precision of test methods and results
- [6] Guide to the Expression of Uncertainty in Measurement (1995)
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- [8] Gabauer W., Binder O., Abschätzung der Messunsicherheit in der Härteprüfung unter Verwendung der indirekten Kalibriermethode, DVM Werkstoffprüfung, Tagungsband 2000, S. 255-261
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- [10] Polzin, T., Schwenk, D., Fengler, M., Änderung der Normen Brinell und Rockwell HTM 56 (2001) S. 232-235
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- [12] Frenz H., Polzin T., Vogt C., Determination of uncertainty for hardness testing, proposed methods for ISO Standards of hardness testing, Practical Metallography, -to be published in 2002

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