**RMO SC COMPARISON**
**COOMET.M.H-S3**

**Final Report**

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Abstract:
This report describes the results of comparison COOMET.M.H-S3. The comparison measurements between the five participants NSC “IM” (pilot laboratory), PTB, CMI, BelGIM, KazInSt were started in December 2014 and ended in December 2016.
In the RMO SC, one set of hardness reference blocks were used consisting of 6 (six) blocks of the Superficial-Rockwell scales and hardness levels 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47–53 HR30TW, 70-82 HR30TW. Agreement between results of participants is good.

## 1. Introduction

The present supplementary comparisons of Superficial-Rockwell hardness scales were organized by the COOMET and registered in BIPM under the cipher COOMET.M.H-S3. This regional comparison was between hardness laboratories of the national metrological institutes of Germany, Ukraine, Belarus, Kazakhstan and Czech Republic.

## 2. Organization

In December 2014 during TC 1.6 COOMET meeting (Kharkiv, Ukraine) it was decided to entrust the organization of the comparisons on Super-Rockwell hardness scales to the National Scientific Centre “Institute of Metrology” (NSC-IM, Ukraine) as a pilot laboratory. Dr. Vladimir Skliarov (NSC-IM, Ukraine) was appointed the coordinator of the comparisons.

The draft of the technical protocol was agreed upon between the participants of the comparison in 2014. The comparison started in November 2014 and ended in May 2016.

### 2.1 Participants

The list of participants is given in table 1.

Table 1– Participants of comparisons

| № | NMI | Address for sending the sample | Acronym | Contact person |
|---|---|---|---|---|
| 1 | National Scientific Centre “Institute of Metrology” ***(pilot laboratory)*** | 42, Myronosytska str., Kharkiv, 61002, Ukraine | NSC IM | V. Skliarov<br>vladimir.skliarov@gmail.com |
| 2 | Physikalisch-Technische Bundesanstalt | 100, Bundesallee, Braunschweig, 38116, Germany | PTB | F. Menelao<br>febo.menelao@ptb.de |
| 3 | Czech metrology institute | 4, V Botanice 15072 Praha 5 Czech Republic | CMI | J. Borovský<br>jborovsky@cmi.cz |
| 4 | Belarusian State Institute of Metrology | 93, Starovilensky trakt, Minsk,220053, Belarus | BelGIM | N. Kamkova<br>kamkova@belgim.by<br>E. Obozny<br>obozny@belgim.by |
| 5 | Kazakhstan institute of standardization and certification | 22/2, Angerskaja str., Karaganda, 100009, Kazakhstan, | KazInSt | M. Zhamanbalin<br>m.zhamanbalin@ksm.kz |

### 2.2 Time schedule

Table 2 shows the scheduled measuring time.

**Table 2** -Time schedule

| **Institute/Country** | **Date of measurements** |
|---|---|
| NSC-IM, Ukraine | November 2014 |
| PTB, Germany | January 2015 |
| CMI, Czech Republic | May 2015 |
| BelGIM, Belarus | June 2015 |
| KazInSt, Kazakhstan | December 2015 |
| NSC-IM, Ukraine | May 2016 |

## 3 Transfer standards

### 3.1 Description

In the RMO SC, one set of hardness reference blocks were used consisting of 6 (six) blocks of the Superficial-Rockwell scales and hardness levels 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47–53 HR30TW, 70-82 HR30TW. (fig. 1).


**Figure 1** Set of Superficial-Rockwell hardness reference blocks

Hardness blocks are manufactured by “Centre “MET” Ltd (Russia) and have a length of 60 mm, width of 40 mm and a thickness of 10 mm (fig. 2).

The upper surface of the block, which is the measurement surface, is finished. The measurement area is defined to be within an engraved grid. A grid (5.5 mm x 5.5 mm) is engraved on the block surface in order to define the coordinates of the test locations. The sizes of the test area and grid allow 49 possible test locations. (fig. 3).

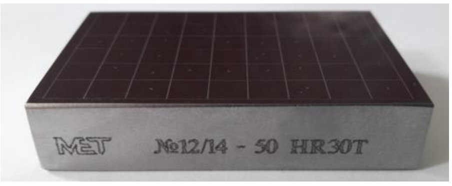


**Figure 2** Hardness reference blocks used for the HRTW with the logo of the manufacturer

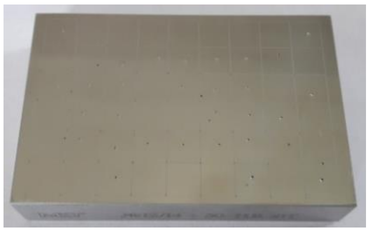

**Figure 3** Layout of the grid on the measurement surface of the hardness reference blocks

### 3.2 Transportation and Handling

The pilot laboratory was responsible for purchasing the blocks for the regional comparison, while each participating institute assumed the costs for transport, customs and related administrative fees.

The pilot laboratory made measurements at the beginning and at the end of the RMO SC in order to evaluate the stability of the hardness reference blocks used in the RMO SC.

It was recommended for each institute to clean the blocks after unpacking with alcohol and then mark all fields reserved for the institute with a fibre pen on the left top corner. After the measurement all dots on the blocks were to be removed before packing in order to avoid corrosion.

## 4. Measurand

The measurements were carried out following the Superficial-Rockwell scale definition developed for adoption by National Metrology Institutes (NMIs). Before conducting the measurements, each participant was required to carry out the calibration of the primary hardness machine.

Each participant made 5 (five) measurement indentations on each hardness reference block. Each indentation was to be made at the center of the open square within the engraved grid lines such that the indentation does not contact an engraved line. The 5 (five) indentations were used to evaluate the stochastic deviations occurring during the measurements, including the evaluation of the in homogeneity of the hardness distribution across the test surface of the hardness reference blocks.

In addition to the 5 (five) measurement locations, two additional test locations were allocated to each institute to be used for a test measurement or in case a measurement error occurs and the measurement must be repeated. The additional two test locations were indicated as “repeat measurements”. For result each participant show only 5 (five) correct measurements exclude test and/or error indentations.

Due to the number of fields on the hardness block surface (35) and the number of indentations to be carried out by each laboratory (5 plus two), the maximum number of participants for each regional comparison is 5 (35/5=5+2 for possible errors or test indentation). The Pilot laboratory performed the measurements twice but for correct results show only measurements at the end of comparisons.

## 5 Methods of measurement

Short descriptions with pictures of the Superficial-Rockwell Primary Hardness Standard Machines (PHSM) used for the measurements by the participants are described in Appendix A.

## 6 Stability of the standards

In order to evaluate the stability of the standards the pilot laboratory carried out measurements at the beginning and at the end of the comparison. The results are summarised in table 3.

**Table 3 -** Measurement results at the beginning and at the end of the comparison by the pilot laboratory

| Measurand, HR | Result at the begin (1), HR | Result at the end (2), HR | Diff. $\Delta_{2-1}$, HR | Meas. Unc. U, HR | $\lvert\Delta_{2-1}\rvert$/ U, HR |
|---|---|---|---|---|---|
| 90 – 94 HR15N | 90,92 | 91,53 | -0,24 | 0,35 | 0,68 |
| 40 – 50 HR30N | 47,44 | 47,82 | 0,38 | 0,42 | 0,9 |
| 76 – 84 HR30N | 81,2 | 80,89 | -0,31 | 0,33 | 0,93 |
| 43 – 54 HR45N | 51,81 | 51,62 | -0,19 | 0,32 | 0,59 |
| 47 – 53 HR30TW | 53,11 | 52,99 | -0,12 | 0,47 | 0,25 |
| 70 – 82 HR30TW | 78,43 | 78,73 | 0,30 | 0,55 | 0,54 |

In the last row the difference between the first and the second measurement $_{2-1}$ is compared to the measurement uncertainty. If the difference is $\lvert\Delta_{2-1}\rvert/U > 1$, it means that the difference $\Delta_{2-1}$ cannot be explained by the uncertainty but can be traced back to any change of the hardness reference blocks during the period of the comparison. Since $\lvert\Delta_{2-1}\rvert/U < 1$ for each of the reference blocks, the drift of the test blocks did not significantly influence the uncertainty of measurement results and can be omitted while processing the comparison results.

Therefore, one can conclude that the used hardness reference blocks remained stable.

## 7 Measurement results

In the following table 4 the results for the hardness reference blocks with hardness levels of 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47–53 HR30TW, 70-82 HR30TW. are summarised. The results are expressed by mean values, the standard deviations $S_5$ of each set of 5 repetition measurements and the standard deviations between the institutes $S_{Inst}$.

**Table 4** - Results of the measurements for the hardness reference blocks with hardness level 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47 – 53 HR30TW, 70-82 HR30TW.

| Institute | 90 – 94 HR15N | | 40 – 50 HR30N | | 76 – 84 HR30N | | 43 – 54 HR45N | | 47 – 53 HR30TW | | 70 – 82 HR30TW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean value | Std. dev | Mean value | Std. dev | Mean value | Std. dev | Mean value | Std. dev | Mean value | Std. dev | Mean value | Std. dev |
| NSC IM | 91,53 | 0,13 | 47,82 | 0,13 | 80,89 | 0,15 | 51,62 | 0,19 | 52,99 | 0,15 | 78,73 | 0,21 |
| PTB | 91,41 | 0,19 | 48,34 | 0,18 | 80,71 | 0,07 | 51,44 | 0,25 | 53,15 | 0,4 | 79,04 | 0,09 |
| CMI | 91,24 | 0,14 | 47,49 | 0,12 | 80,24 | 0,10 | 51,04 | 0,07 | 52,85 | 0,18 | 78,39 | 0,14 |
| BelGIM | 91,23 | 0,23 | 47,98 | 0,35 | 80,19 | 0,05 | 50,68 | 0,22 | 52,36 | 0,25 | 78,2 | 0,09 |
| KazInSt | 91,54 | 0,18 | 47,68 | 0,14 | 80,43 | 0,24 | 51,12 | 0,11 | 52,33 | 0,42 | 79,05 | 0,24 |
| Mean value | 91,19 | | 47,72 | | 80,49 | | 50,98 | | 52,54 | | 78,68 | |
| Std.dev, $S_i$ | 0,55 | | 0,40 | | 0,84 | | 0,64 | | 0,73 | | 0,38 | |

## 8 Uncertainty budgets

### 8.1 Calculation scheme

The calculation of uncertainty for all the participants was carried out according to [1-4].
The calculation scheme can be seen from the example in table 5 and table 6.

Table 5 - Calculation scheme for HRN scales for the unified estimation of the measurement uncertainty

| Quantity, $X_i$ | Symbol, Unit | Estimated value, $\Delta x_i$ | Standard uncertantiy, $u(x_i)=\frac{\Delta x_i}{\sqrt{3}}$ | Sensitivity coefficient, $c_i=\frac{\Delta H}{\Delta x_i}$ | Single hardness deviation, $\Delta H_i=\Delta x_i \cdot c_i$, HR | Uncertainty contribution, $u_i(H)=c_i \cdot u(x_i)$ HR | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,16 | 0,032 | 0,031 | 1,04988 E-07 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,08 | -0,12 | -0,121 | 2,40128 E-05 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,1 | 0,058 | 0,13 | 0,013 | 0,008 | 3,52646 E-10 |
| Indenter radius | $R_\alpha$, $\mu m$ | 1,0 | 0,577 | 0,13 | 0,13 | 0,075 | 3,52646 E-06 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 0,5 | 0,05 | 0,029 | 7,71695 E-08 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,021 | -0,0147 | -0,008 | 5,76548 E-10 |
| Preliminary test force duration time | $T_p$, c | 0,2 | 0,115 | 0,04 | 0,008 | 0,005 | 5,05738 E-11 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total test force duration time | $T_{df}$, c | 0,2 | 0,115 | 0,04 | 0,008 | 0,005 | 5,05738 E-11 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 6,25073 E-06 |
| Total | | | | | 0,256 | 0,109 | |
| Combined standard uncertainty, $u(H)=\sqrt{\sum_i u_i^2(H)}$, HRN | | | | | | 0,173 | |
| Coverage factor $k$ for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertantiy $U = k \cdot u(H)$, HRN | | | | | | 0,345 | |

Table 6 - Calculation scheme for HRTW scale for the unified estimation of the measurement uncertainty

| Quantity, $X_i$ | Symbol, Unit | Estimated value, $\Delta x_i$ | Standard uncertainty, $u(x)_i = \frac{\Delta x_i}{\sqrt{3}}$ | Sensitivity coefficient, $c_i = \frac{\Delta H}{\Delta x_i}$ | Single hardness deviation, $\Delta H_i = \Delta x_i \cdot c_i$ ,HRBW | Uncertainty contribution, $u_i(H) = c_i \cdot u(x_i)$ HRBW | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,31 | 0,062 | 0,036 | 1,82445 E-07 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | 0,15 | 0,225 | 0,130 | 3,16443 E-05 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 1,0 | 0,577 | 0,15 | 0,15 | 0,087 | 6,25073 E-06 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 0,5 | 0,05 | 0,029 | 7,71695 E-08 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,2 | -0,14 | -0,081 | 4,74327 E-06 |
| Preliminary test force duration time | $T_p$, $s$ | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,97554 E-09 |
| Total test force duration time | $T_{df}$, $s$ | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,97554 E-09 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 6,25073 E-06 |
| Total | | | | | 0,537 | 0,310 | |
| Combined standard uncertainty, $u(H)=\sqrt{\sum_i u_i^2(H)}$, HRTW | | | | | | 0,202 | |
| Coverage factor $k$ for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertantiy $U = k \times u(H)$, HRTW | | | | | | 0,404 | |

From the influencing quantities $X_i$ measurement deviations $\Delta \chi_i$ and uncertainties in the form of standard deviation $S_i$ (type A) and $A_i$ (type B) are considered.

Sensitivity coefficients:

| $c_i = \dfrac{\Delta H}{\Delta x_i}$ | Quantity, $X_i$ | Symbol, Unit |
|---|---|---|
| $\dfrac{\Delta HR}{\Delta F_0}$ | Preliminary test force | $F_0$, $N$ |
| $\dfrac{\Delta HR}{\Delta F}$ | Total test force | $F$ , $N$ |
| $\dfrac{\Delta HR}{\Delta \alpha}$ | Indenter cone angle | $\alpha$ , ° |
| $c_i = \dfrac{\Delta H}{\Delta x_i}$ | Quantity, $X_i$ | Symbol, Unit |
| $\dfrac{\Delta HR}{\Delta R_\alpha}$ | Indenter radius | $R_\alpha$ , $\mu m$ |
| $\dfrac{\Delta HR}{\Delta R_\beta}$ | Indenter ball diametr | $R_\beta$ $\mu m$ |
| $\dfrac{\Delta HR}{\Delta l}$ | Indentation depth | $l$ , $\mu m$ |
| $\dfrac{\Delta HR}{\Delta V_{fis}}$ | Indentation velocity | $V_{fis}$ , $\mu m \cdot s^{-1}$ |
| $\dfrac{\Delta HR}{\Delta T_p}$ | Preliminary test force duration time | $T_p$ , $s$ |
| $\dfrac{\Delta HR}{\Delta T_{df}}$ | Total test force duration time | $T_{df}$ , $s$ |

Single hardness deviation:

$$\Delta H_i = c_i \cdot \Delta x_i \, , \tag{1}$$

where $\Delta x_i$ - estimated value

Variances:

$$u^2(y_i) = c_i^2 u^2(x_i) \tag{2}$$

Combined standard uncertainty:

$$u(H) = \sqrt{\sum_{i=1}^{n} u^2(y_i)} \tag{3}$$

Sum of hardness deviations:

$$\Delta H = \sum_{i=1}^{n} \Delta H_i \tag{4}$$

Effective degrees of freedom, according to the Welch-Satterthwaite formula:

$$\nu_{eff} = \frac{u^4(y)}{\sum_{i=1}^{\nu} \frac{u_i^4(y)}{\nu_i}} \tag{5}$$

Coverage factor:

$$k = f(\nu_{eff}, P) \tag{6}$$

Expanded standard uncertainty:

$$U(H) = k \cdot u(H) \tag{7}$$

According to this unified procedure for the estimation of measurement uncertainty, the following measurement uncertainties for the participants were received.

## 8.2 Calculation of measurement uncertainty

As a basis for the determination of the measurement uncertainty the draft guideline to the estimation of the uncertainty of the Superficial-Rockwell measuring method was recommended [1-6].

The uncertainty budgets of the participants based on a unified procedure as presented in clause 8.1 appear in Appendix B. Table 7 shows mean values of hardness measurements and expanded uncertainties of the measurement results for hardness level 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47 – 53 HR30TW, 70-82 HR30TW.

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Table 7 – Mean hardness values and expanded uncertainties.

| Institutes | 90 -94 HR15N | | 40 -50 HR30N | | 76 -84 HR30N | | 43 -54 HR45N | | 47 – 53 HR30TW | | 70 - 82 HR30TW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert |
| NSC IM | 91,53 | 0,71 | 47,82 | 0,76 | 80,89 | 0,65 | 51,62 | 0,69 | 52,99 | 0,66 | 78,73 | 0,71 |
| PTB | 91,41 | 0,45 | 48,34 | 0,44 | 80,71 | 0,41 | 51,44 | 0,48 | 53,15 | 0,83 | 79,04 | 0,80 |
| CMI | 91,24 | 0,53 | 47,49 | 0,54 | 80,24 | 0,58 | 51,04 | 0,45 | 52,85 | 0,65 | 78,39 | 0,66 |
| BelGIM | 91,23 | 0,53 | 47,98 | 0,60 | 80,19 | 0,44 | 50,68 | 0,55 | 52,36 | 0,83 | 78,20 | 0,63 |
| KazInSt | 91,54 | 0,70 | 47,68 | 0,70 | 80,43 | 0,70 | 51,12 | 0,70 | 52,33 | 1,20 | 79,05 | 1,20 |

## 9. Analyzing Method of Comparison Results

The measurement results are used to compute the degree of equivalence in Comparison Reference Value (CRV) and $E_n$ ratio. The calculation is shown in following formulas:

a) calculation of CRV, the Pilot laboratory determined CRV by calculating the weighted mean of measurements of all participants ( $x_{ref}$ ):

$$x_{ref} = \frac{x_1/u^2(x_1) + x_2/u^2(x_2) + ... + x_n/u^2(x_n)}{1/u^2(x_1) + 1/u^2(x_2) + ... + 1/u^2(x_n)}; \tag{8}$$

b) the uncertainty of the CRV was calculated by following expression:

$$\frac{1}{u^2(x_{ref})} = \frac{1}{u^2(x_1)} + \frac{1}{u^2(x_2)} + ... + \frac{1}{u^2(x_n)} , \tag{9}$$

where $x_i$ - the measured value of participating institute $i$ $(i = 1,2,...,n)$;

$u(x_i)$ - the standard uncertainty of $x_i$ .

Table 8 – Mean hardness values and expanded uncertainties with $x_{ref}$

| Institutes | 90 -94 HR15N | | 40 -50 HR30N | | 76 -84 HR30N | | 43 -54 HR45N | | 47- 53 HR30TW | | 70 - 82 HR30TW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert. | Mean value | Exp. uncert |
| NSC IM | 91,53 | 0,71 | 47,82 | 0,76 | 80,89 | 0,65 | 51,62 | 0,69 | 52,99 | 0,66 | 78,73 | 0,71 |
| PTB | 91,41 | 0,45 | 48,34 | 0,44 | 80,71 | 0,41 | 51,44 | 0,48 | 53,15 | 0,83 | 79,04 | 0,80 |
| CMI | 91,24 | 0,53 | 47,49 | 0,54 | 80,24 | 0,58 | 51,04 | 0,45 | 52,85 | 0,65 | 78,39 | 0,66 |
| BelGIM | 91,23 | 0,53 | 47,98 | 0,60 | 80,19 | 0,44 | 50,68 | 0,55 | 52,36 | 0,83 | 78,20 | 0,63 |
| KazInSt | 91,54 | 0,70 | 47,68 | 0,70 | 80,43 | 0,70 | 51,12 | 0,70 | 52,33 | 1,20 | 79,05 | 1,20 |
| $x_{ref}$ | 91,36 | | 47,93 | | 80,48 | | 51,16 | | 52,81 | | 78,57 | |
| $\frac{1}{u^2(x_{ref})}$ | 16,15 | | 15,12 | | 18,50 | | 16,66 | | 8,27 | | 9,06 | |
| $u^2(x_{ref})$ | 0,06 | | 0,07 | | 0,05 | | 0,06 | | 0,12 | | 0,11 | |
| $u(x_{ref})$ | 0,25 | | 0,26 | | 0,23 | | 0,24 | | 0,35 | | 0,33 | |

In Figures 4-8 reference values $x_{ref}$ are shown by a red line, the dashed blue line shows the expanded uncertainty of the reference value $x_{ref}$ . Expanded uncertainties are shown by black vertical bars. The total length of black vertical bars equals 2U.

Figure 4 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 90 -94 HR15N.

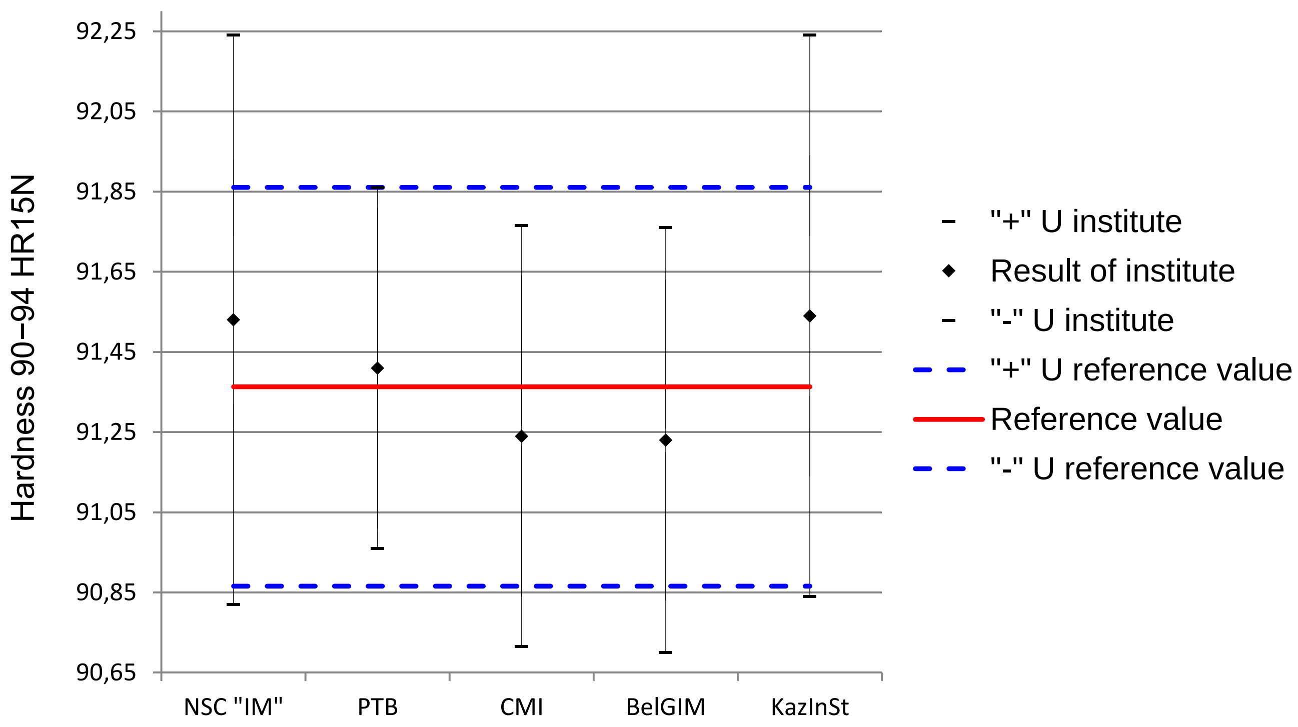


Figure 4 Comparisons results for hardness level 90−94 HR15N

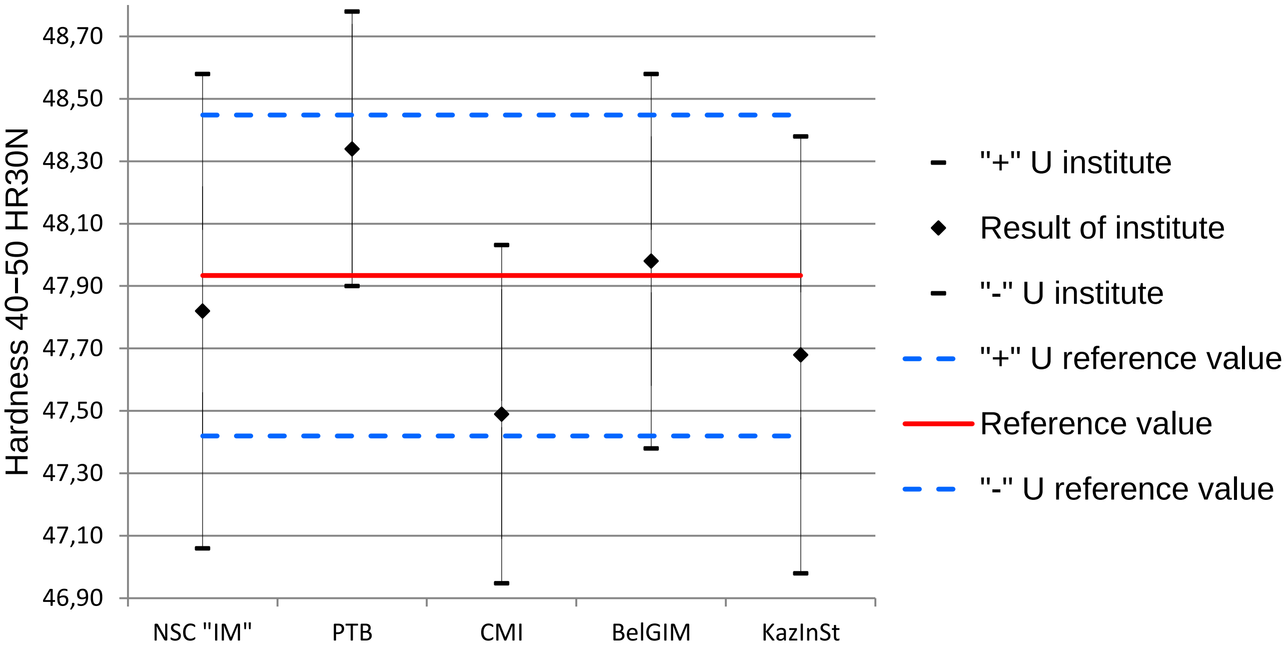


Figure 5 Comparisons results for hardness level 40−50 HR30N

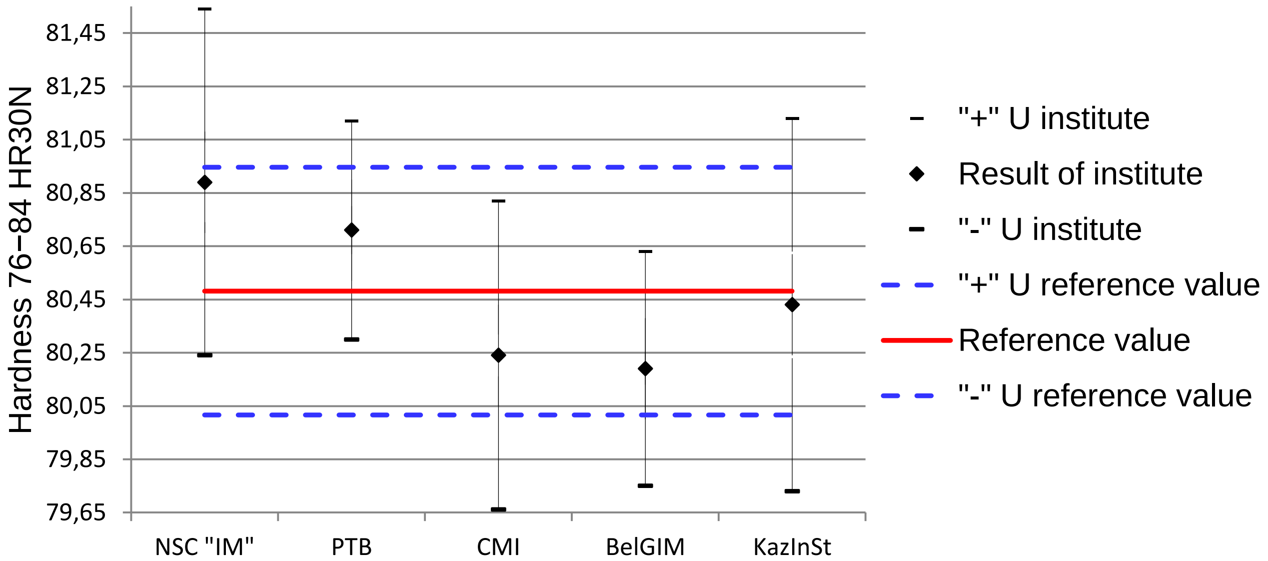


Figure 6 Comparisons results for hardness level 76−84 HR30N

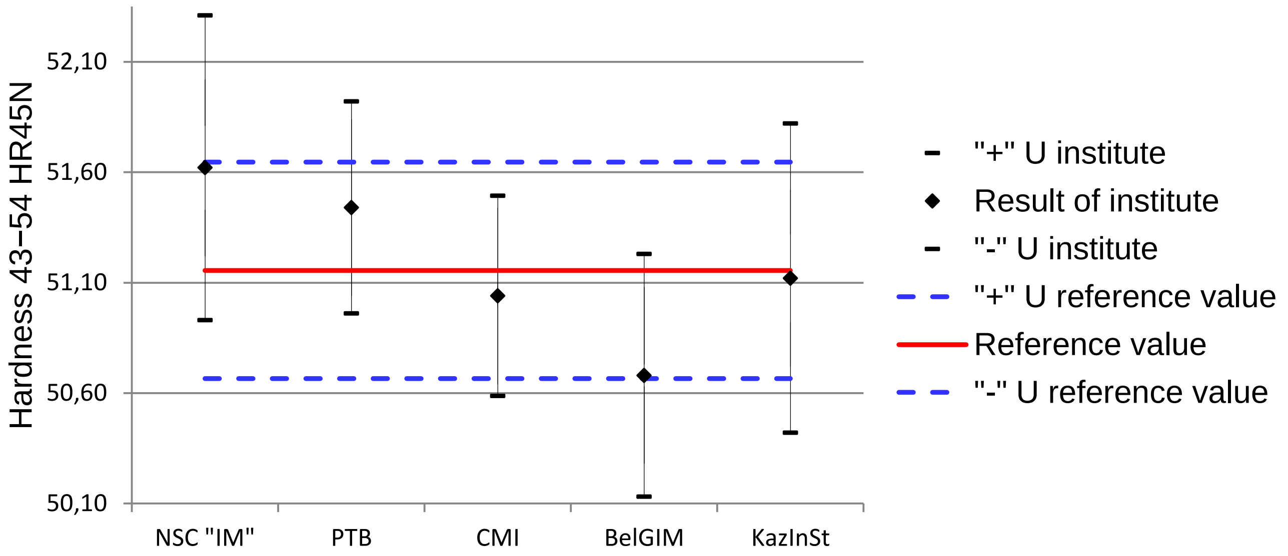


Figure 7 Comparisons results for hardness level 43−54 HR45N

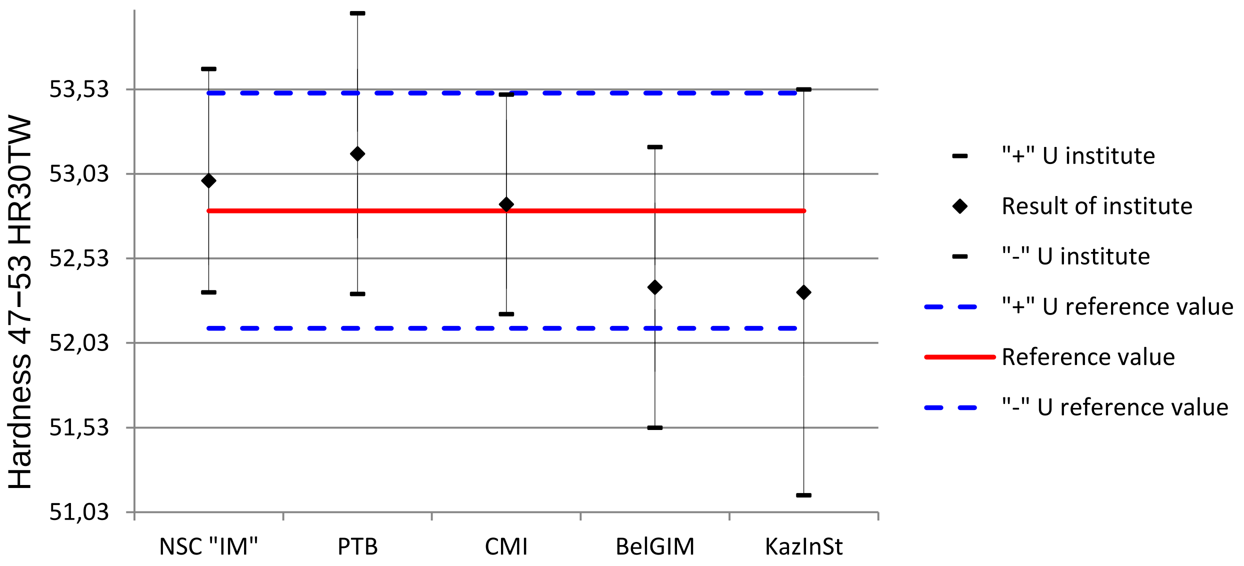


Figure 8 Comparisons results for hardness level 47−53 HR30TW

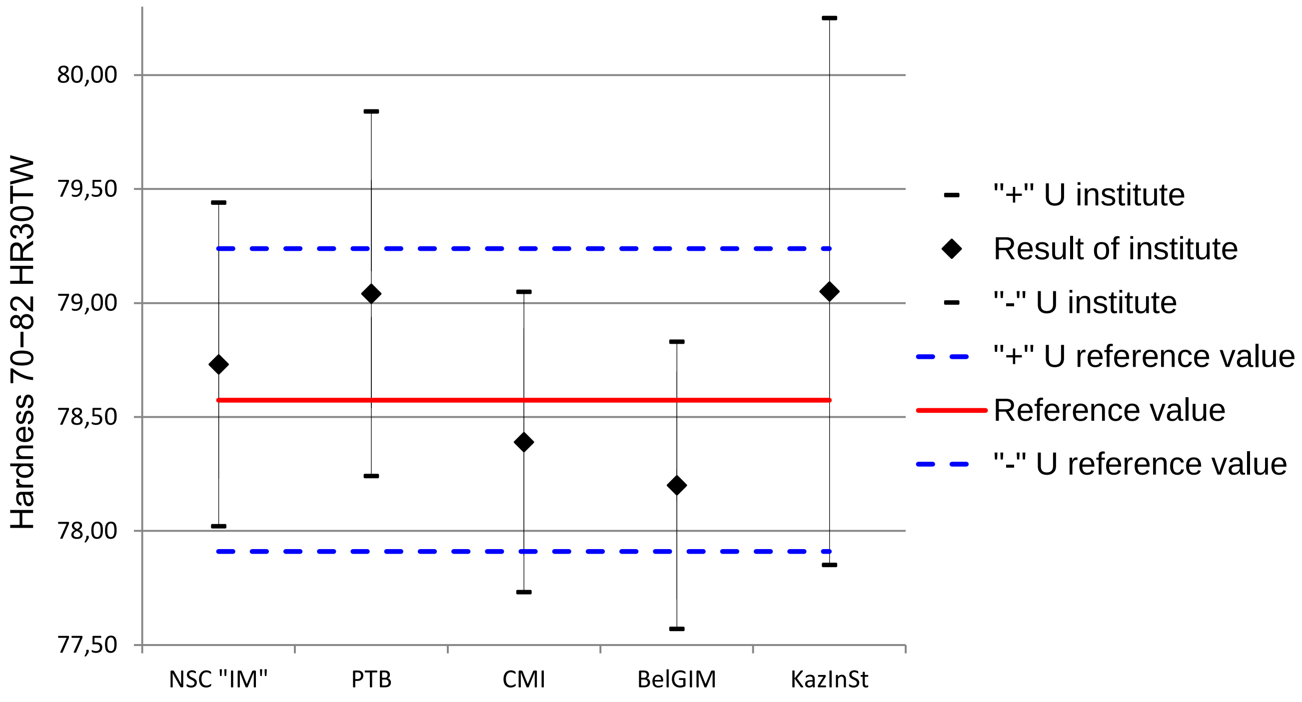


Figure 9 Comparisons results for hardness level 70−82 HR30TW

The results shown in Figure 4 to 9 indicate that the measurement results obtained by the majority of the comparisons participants correlate well with mean hardness values.

c) The deviation from CRV:

$$d_i = x_i - x_{ref} \tag{10}$$

d) The uncertainty of this deviation at a 95% level of confidence:

$$U(d_i) = k \cdot u(d_i) \quad , \tag{11}$$

where $u(d_i)$ was given by ( $k = 2$ )

$$u(d_i) = \sqrt{u^2(x_i) + u^2(x_{ref})} \tag{12}$$

e) Evaluation of Coefficient $E_n$ :

the equivalence between the measurements of participating institutes was expressed by coefficient $E_n$ as well:

$$E_n = \left| \frac{x_i - x_{ref}}{\sqrt{U^2(x_i) + U^2(x_{ref})}} \right| \quad , \tag{13}$$

where

$$U(x_i) = k \cdot u(x_i),$$
$$U(x_{ref}) = k \cdot u(x_{ref}) \quad . \qquad (15)$$

The $x_i$ is considered equivalent with the CRV $x_{ref}$ at 95% confidence level, if $|E_n| \le 1$.

Table 9 show the intermediate result for next Table 10 and evaluation the deviations.

Table 9 – The intermediate results for further evaluations

| | | 90 -94 HR15N | 40 -50 HR30N | 76 -84 HR30N | 43 -54 HR45N | 47-53 HR30TW | 70 - 82 HR30TW |
|---|---|---|---|---|---|---|---|
| NMIs | $U(x_{ref}) = k \cdot u(x_{ref})$ | 0,50 | 0,51 | 0,46 | 0,49 | 0,70 | 0,66 |
| | $U^2(x_{ref})$ | 0,25 | 0,26 | 0,22 | 0,24 | 0,48 | 0,44 |
| NSC IM | $U(x_1) = k \cdot u(x_1)$ | 0,71 | 0,76 | 0,65 | 0,69 | 0,66 | 0,71 |
| | $U^2(x_1)$ | 0,50 | 0,58 | 0,42 | 0,48 | 0,44 | 0,50 |
| PTB | $U(x_2) = k \cdot u(x_2)$ | 0,45 | 0,44 | 0,41 | 0,48 | 0,83 | 0,80 |
| | $U^2(x_2)$ | 0,20 | 0,19 | 0,17 | 0,23 | 0,69 | 0,64 |
| CMI | $U(x_3) = k \cdot u(x_3)$ | 0,53 | 0,54 | 0,58 | 0,45 | 0,65 | 0,66 |
| | $U^2(x_3)$ | 0,28 | 0,29 | 0,34 | 0,21 | 0,42 | 0,43 |
| BelGIM | $U(x_4) = k \cdot u(x_4)$ | 0,53 | 0,60 | 0,44 | 0,55 | 0,83 | 0,63 |
| | $U^2(x_4)$ | 0,28 | 0,36 | 0,19 | 0,30 | 0,69 | 0,40 |
| KazInSt | $U(x_5) = k \cdot u(x_5)$ | 0,70 | 0,70 | 0,70 | 0,70 | 1,20 | 1,20 |
| | $U^2(x_5)$ | 0,49 | 0,49 | 0,49 | 0,49 | 1,44 | 1,44 |

## 10. Comparison Results

The comparison results, comparison reference value (CRV), the deviation value of each NMIs from CRV as well as their uncertainty and $E_n$ ratio, are calculated and shown in Table 11, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13 and Figure 14 for Super-Rockwell scale with hardness level 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47 – 53 HR30TW, 70-82 HR30TW.

Table 10 – Comparison results for evaluation

| NMIs | *Nominal* | 90 -94 HR15N | 40 -50 HR30N | 76 -84 HR30N | 43 -54 HR45N | 47-53 HR30TW | 70 - 82 HR30TW |
|---|---|---|---|---|---|---|---|
| | *CRV* $x_{ref}$ | 91,36 | 47,93 | 80,48 | 51,16 | 52,81 | 78,57 |
| | $u^2(x_{ref})$ | 0,06 | 0,07 | 0,05 | 0,06 | 0,12 | 0,11 |
| NSC IM | *deviation from CRV* $d_i = x_i - x_{ref}$ | 0,17 | -0,11 | 0,41 | 0,46 | 0,18 | 0,16 |
| | $U(d_i) = k \cdot u(d_i)$ | 0,71 | 0,76 | 0,65 | 0,69 | 0,66 | 0,71 |
| | *Evaluation of Coefficient* $E_n$ | 0,19 | -0,12 | 0,51 | 0,55 | 0,19 | 0,16 |
| PTB | *deviation from CRV* $d_i = x_i - x_{ref}$ | 0,05 | 0,41 | 0,23 | 0,28 | 0,34 | 0,47 |
| | $U(d_i) = k \cdot u(d_i)$ | 0,45 | 0,44 | 0,41 | 0,48 | 0,83 | 0,80 |
| | *Evaluation of Coefficient* $E_n$ | 0,07 | 0,60 | 0,37 | 0,41 | 0,31 | 0,45 |
| CMI | *deviation from CRV* $d_i = x_i - x_{ref}$ | -0,12 | -0,44 | -0,24 | -0,12 | 0,04 | -0,18 |
| | $U(d_i) = k \cdot u(d_i)$ | 0,53 | 0,54 | 0,58 | 0,45 | 0,65 | 0,66 |
| | *Evaluation of Coefficient* $E_n$ | -0,17 | -0,59 | -0,32 | -0,17 | 0,04 | -0,20 |
| BelGIM | *deviation from CRV* $d_i = x_i - x_{ref}$ | -0,13 | 0,05 | -0,29 | -0,48 | -0,45 | -0,37 |
| | $U(d_i) = k \cdot u(d_i)$ | 0,53 | 0,60 | 0,44 | 0,55 | 0,83 | 0,63 |
| | *Evaluation of Coefficient* $E_n$ | -0,18 | 0,06 | -0,45 | -0,65 | -0,42 | -0,41 |
| KazInSt | *deviation from CRV* $d_i = x_i - x_{ref}$ | 0,18 | -0,25 | -0,05 | -0,04 | -0,48 | 0,48 |
| | $U(d_i) = k \cdot u(d_i)$ | 0,70 | 0,70 | 0,70 | 0,70 | 1,20 | 1,20 |
| | *Evaluation of Coefficient* $E_n$ | 0,21 | -0,29 | -0,06 | -0,04 | -0,35 | 0,35 |

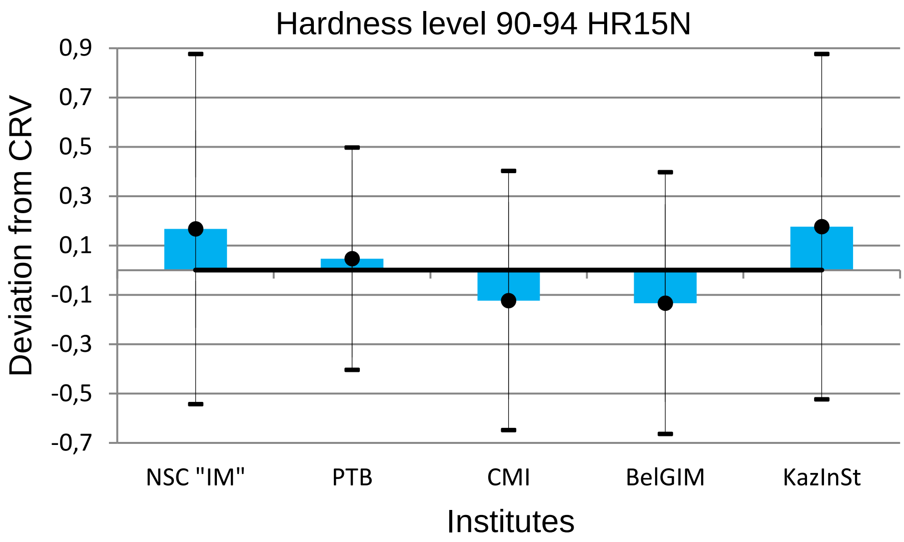


Figure 9 Deviation from reference value of 90-94 HR15N measurement comparison

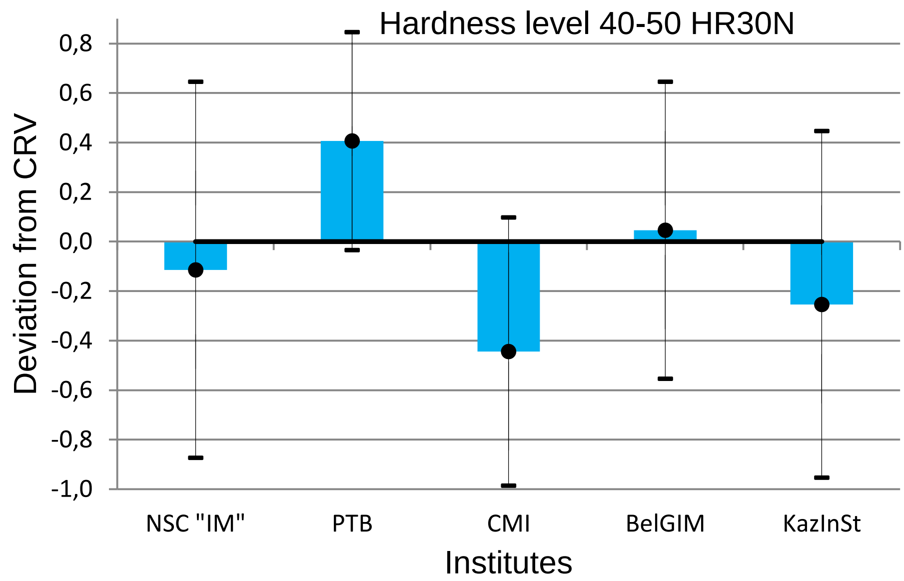


Figure 10 Deviation from reference value of 40-50 HR30N measurement comparison

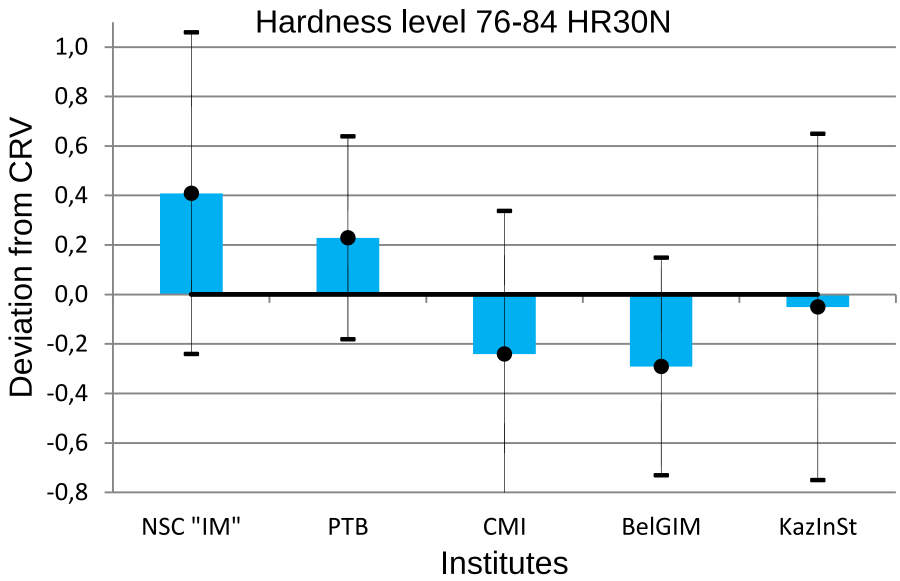


Figure 11 Deviation from reference value of 76-84 HR30N measurement comparison

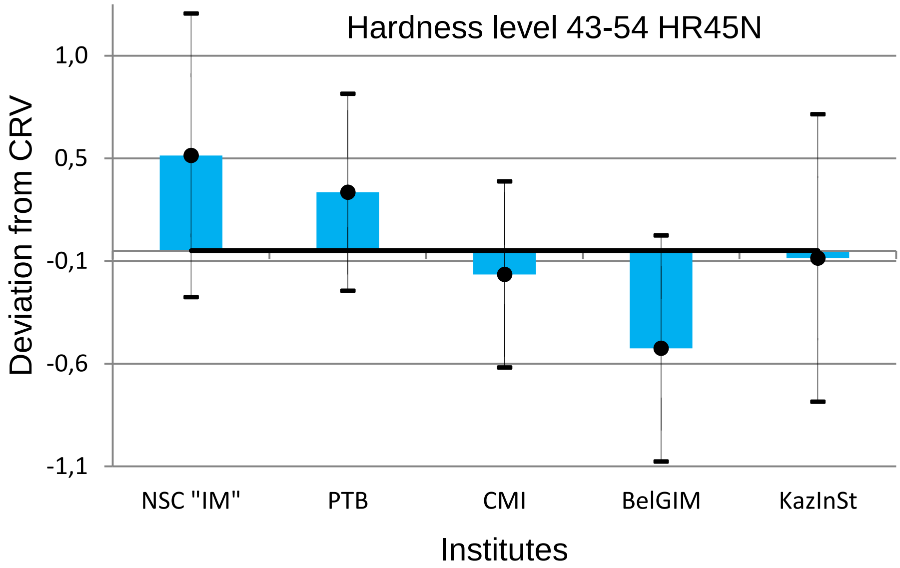


Figure 12 Deviation from reference value of 43-54 HR45N measurement comparison

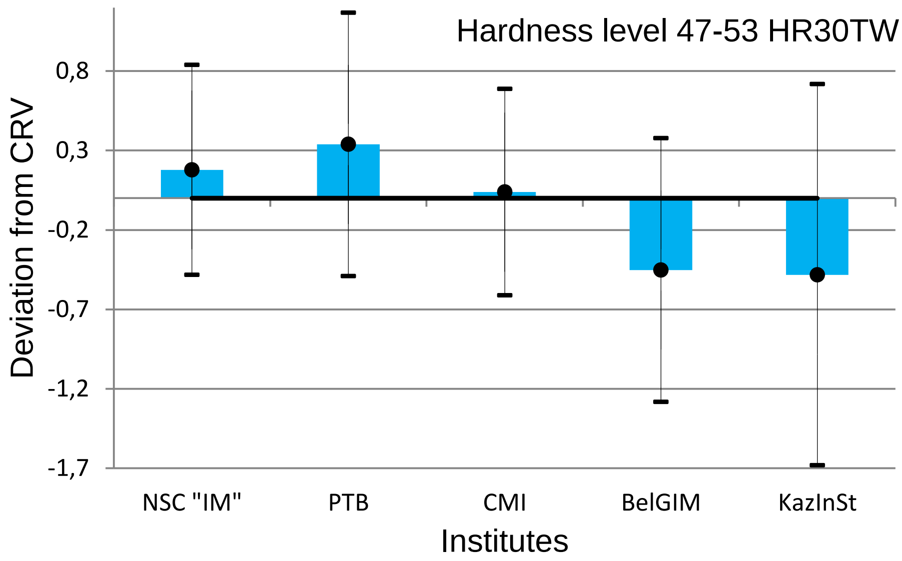


Figure 13 Deviation from reference value of 47-53 HRTW30 measurement comparison

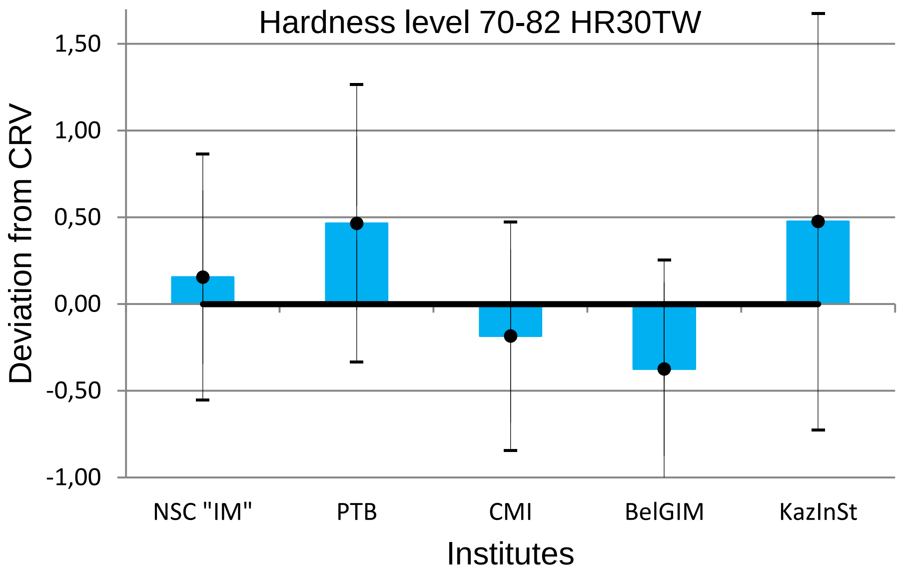


Figure 14 Deviation from reference value of 70-82 HR30TW measurement comparison

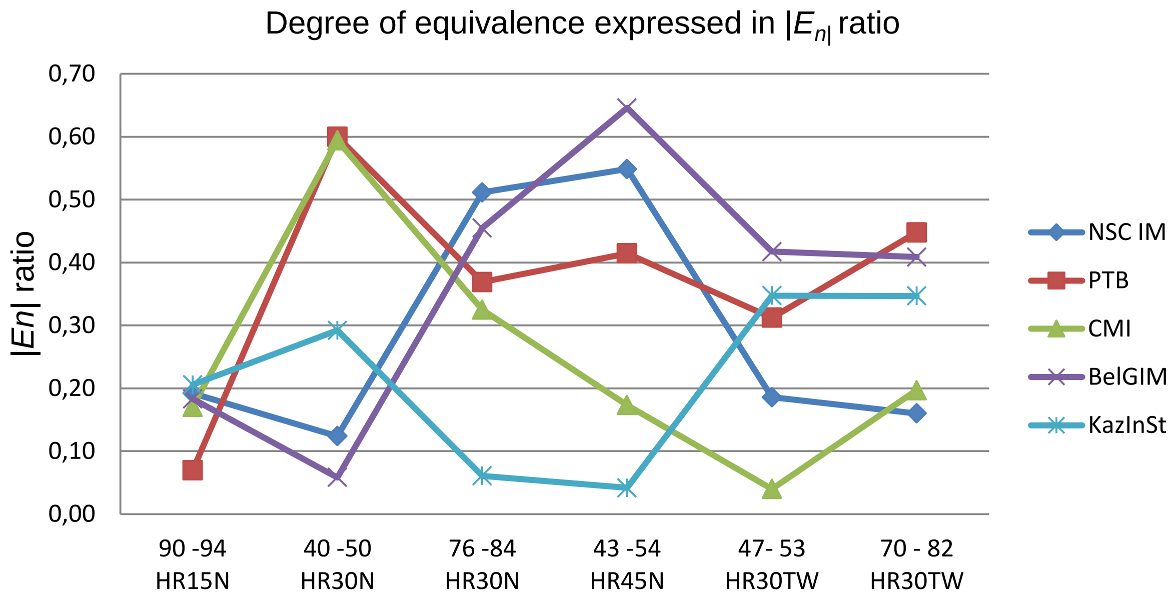


Figure 14 $\left|E_n\right|$ ratio of hardness level 90-94 HR15N, 40-50 HR30N, 76-84 HR30N, 43-54 HR45N, 47 – 53 HR30TW, 70-82 HR30TW measurement comparison

## 11. Discussions, conclusions and remarks

The COOMET.M.H-S3 comparison can be considered as a successful metrological exercise. At present, Superficial-Rockwell hardness reference blocks with high time-dependent stability and high local homogeneity, including high surface quality are available.

The contribution of this comparison would be quite important because other COOMET countries need the confirmation of traceability by a key comparison.

## 12. References

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2 R. Samuel, Low: Rockwell Hardness Measurement of Metallic Materials, NIST Recommended Practice Guide, Special Publication 960-5, 2001.

3 G. Barbato, S. Desogus, A. Germak, "Hardness measurement from empiricism to metrology an application to Rockwell C scale". -In: "Basic metrology and applications", Ed. Levrotto& Bella, 1994, pp. 112-117.

4 L. Brice, F. Davis, A. Crawshaw, "Uncertainty in hardness measurement", NPL Report CMAM 87, April 2003 (http://www.npl.co.uk/engineering-measurements/mass-force-pressure/hardness/rockwell-hardness-sensitivity-coefficients).

5 W. Bich, M.G. Cox, W.T. Estler, L. Nielsen, W. Woeger: Proposed guidelines for the evaluation of key comparison data, BIPM (2003).

6 J.-F. Song, S. Low, D. Pitchure, A. Germark, S. Desogus, T. Polzin, H.-Q. Yang, H.Ishida and G. Barbato, "Establishing a world-wide unified Rockwell hardness scale with metrological traceability", Metrologia34 (1997) 331-342.

AppendixA

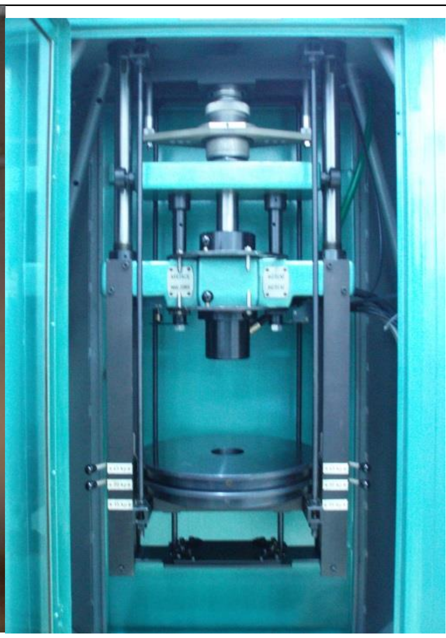
## Description of the Primary Hardness Standard Machine (PHSM)

NSC “Institute of Metrology”

<table>
<tr><td>Name</td><td colspan="3">National primary standards according to Superficial-Rockwell, hardness scales</td></tr>
<tr><td>Manufacturer</td><td colspan="3">NSC “Institute of Metrology”</td></tr>
<tr><td>Model</td><td colspan="3">DETU 02-04-99</td></tr>
<tr><td>S/n</td><td colspan="3">DETU 02-04-99</td></tr>
<tr><td>Year of construction (and following significant upgrades)</td><td colspan="3">1999</td></tr>
<tr><td>Hardness Scales</td><td colspan="3">Superficial-Rockwell scales</td></tr>
<tr><td rowspan="2">HR, $U_{95\%}$</td><td>scale</td><td>measured</td><td>uncertainty</td></tr>
<tr><td>90 -94 HR15N<br>40 -50 HR30N<br>76 -84 HR30N<br>43 -54 HR45N<br>47 – 53 HR30TW<br>70 - 82 HR30TW</td><td>91,53 HR15N<br>47,82 HR30N<br>80,89 HR30N<br>51,62 HR45N<br>52,99 HR30TW<br>78,73 HR30TW</td><td>0,71 HR15N<br>0,76 HR30N<br>0,65 HR30N<br>0,69 HR45N<br>0,66 HR30TW<br>0,71 HR30TW</td></tr>
<tr><td>Force generation system and $U_{95\%}$</td><td colspan="3">Dead weight, 0,28 N</td></tr>
<tr><td>Depth measuring system and $U_{95\%}$</td><td colspan="3">0,058µm</td></tr>
<tr><td>Indenter (manufacturer, model, s/n)</td><td colspan="3">“Instrument Service” (Ukraine), model NC, s/n 2111</td></tr>
<tr><td>Picture</td><td colspan="3"></td></tr>
</table>

Czech metrology institute

**Primary Hardness Standard Machine (PHSM) CMI**

<table>
<tr><td>Name</td><td colspan="4">National primary standards according to Rockwell hardness</td></tr>
<tr><td>Manufacturer</td><td colspan="4">PGH –Kraftmessgeräte, Germany</td></tr>
<tr><td>Model</td><td colspan="4">RNGT 150</td></tr>
<tr><td>S/n</td><td colspan="4">007/1962</td></tr>
<tr><td>Year of construction (and following significant upgrades)</td><td colspan="4">1962, the last general overhaul and reconstruction in 2003, replacing the measuring system in 2014</td></tr>
<tr><td>Year of construction (and following significant upgrades)</td><td colspan="4">Rockwell scales</td></tr>
<tr><td rowspan="7">HR,$U_{95\%}$<br>(with own indenter, as results from Annex C)</td><td>scale</td><td>measured</td><td>uncertainty</td><td>inhomogeneity</td></tr>
<tr><td>92 HR15N</td><td>90,24 HR15N</td><td>0,51 HR15N</td><td>0,49 HR15N</td></tr>
<tr><td>45 HR30N</td><td>47,49 HR30N</td><td>0,53 HR30N</td><td>0,69 HR30N</td></tr>
<tr><td>80 HR30N</td><td>80,24 HR30N</td><td>0,57 HR30N</td><td>0,38 HR30N</td></tr>
<tr><td>49HR45N</td><td>50,04 HR45N</td><td>0,42 HR45N</td><td>0,48 HR45N</td></tr>
<tr><td>50 HR30TW</td><td>52,85 HR30TW</td><td>0,56 HR30TW</td><td>0,80 HR30TW</td></tr>
<tr><td>76 HR30TW</td><td>78,39 HR30TW</td><td>0,57 HR30TW</td><td>0,63 HR30TW</td></tr>
<tr><td>Force generation system and $U_{95\%}$</td><td colspan="4">Dead weight, 0,20 N</td></tr>
<tr><td>Depth measuring system and $U_{95\%}$</td><td colspan="4">0,20µm</td></tr>
<tr><td>Indenter (manufacturer, model, s/n)</td><td colspan="4">Manufacturer Zeiss, s/n 5417</td></tr>
<tr><td>Pictures (two maximum)</td><td colspan="4"> </td></tr>
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Kazakhstan institute of standardization and certification

<table>
<tr><td>Name</td><td colspan="3">National primary standards according to Rockwell and Superficial Rockwell hardness scales</td></tr>
<tr><td>Manufacturer</td><td colspan="3">Indentec Hardness Testing Machines Ltd, United Kindom</td></tr>
<tr><td>Model</td><td colspan="3">8150TK</td></tr>
<tr><td>S/n</td><td colspan="3">032808</td></tr>
<tr><td>Year of construction (and following significant upgrades)</td><td colspan="3">2003</td></tr>
<tr><td>Hardness Scales</td><td colspan="3">Superficial Rockwell N, T scales</td></tr>
<tr><td rowspan="6">HR, $U_{95\%}$</td><td>90 -94 HR15N</td><td>91,54 HR15N</td><td>0,70 HR15N</td></tr>
<tr><td>40 -50 HR30N</td><td>47,68 HR30N</td><td>0,70 HR30N</td></tr>
<tr><td>76 -84 HR30N</td><td>80,43 HR30N</td><td>0,70HR30N</td></tr>
<tr><td>43 -54 HR45N</td><td>51,12 HR45N</td><td>0,70 HR45N</td></tr>
<tr><td>47 – 53 HR30TW</td><td>52,33 HR30TW</td><td>1,20 HR30TW</td></tr>
<tr><td>70 - 82 HR30TW</td><td>79,05 HR30TW</td><td>1,20 HR30TW</td></tr>
<tr><td>Force generation system and $U_{95\%}$</td><td colspan="3">Dead weight, 0,28 N</td></tr>
<tr><td>Depth measuring system and $U_{95\%}$</td><td colspan="3">0,289μm</td></tr>
<tr><td>Indenter (manufacturer, model, s/n)</td><td colspan="3">Indentec Hardness Testing Machines Ltd, United Kindom, s/n 23672</td></tr>
<tr><td>Picture</td><td colspan="3"></td></tr>
</table>

Physikalisch-Technische Bundesanstalt

| | |
|---|---|
| Name | National primary standards Superficial-Rockwell hardness scales. |
| Manufacturer | Wazau |
| Model | RNG3 |
| S/n | |
| Year of construction (and following significant upgrades) | 1969 |
| Hardness Scales | Superficial-Rockwell scales |
| HR, $U_{95\%}$ (with own indenter, as results from Annex C) | 92±2 HR15N = 91,41 HR15N ± 0,45 HR15N<br>45±5 HR30N= 48,43 HR30N ± 0,44 HR30N<br>80±4 HR30N = 80,71 HR30N ± 0,41 HR30N<br>49±6 HR45N = 51,44 HR45N ± 0,48 HR45N<br>50±5 HR30TW = 53,15 HR30TW ± 0,80 HR30TW<br>76±6 HR30TW = 79,04 HR30TW ± 0,45 HR30TW |
| Force generation system and $U_{95\%}$ | Dead weight, 0,03 N |
| Depth measuring system and $U_{95\%}$ | 0,01 µm |
| Indenter (manufacturer, model, s/n) | Stroh, s/n840 |
| Pictures (two maximum) |  |

Belarusian State Institute of Metrology

| | |
|---|---|
| Name | Hardness tester |
| Manufacturer | Indentec |
| Model | 8150SK |
| S/n | 063266 |
| Year of construction (and following significant upgrades) | 2006 |
| Hardness Scales | Superficial-Rockwell scales |
| HR, $U_{95\%}$ | 92±2 HR15N = 91,23 HR15N ± 0,53 HR15N<br>45±5 HR30N= 47,28 HR30N ± 0,60 HR30N<br>80±4 HR30N  = 79,19 HR30N ± 0,44 HR30N<br>49±6 HR45N = 50,68 HR45N ± 0,55 HR45N<br>50±5 HR30TW = 51,46 HR30TW± 0,83 HR30TW<br>76±6 HR30TW = 78,20 HR30TW± 0,63 HR30TW |
| Force generation system and $U_{95\%}$ | According to the verification scheme in accordance with GOST 8.064-94 for hardness comparator standardized SεΣ = 0,2. The accuracy of load and indentation depth measurement system is not monitored. |
| Depth measuring system and $U_{95\%}$ | |
| Indenter (manufacturer, model, s/n) | Indentec, № 06194 |
| Picture |  |

Appendix B

## Uncertainty budgets of the participants based on a unified procedure

NSC "Institute of Metrology"; hardness level 90-94 HR15N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,6 | 0,12 | 0,069 | 2,3E-05 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,06 | -0,09 | -0,052 | 7,29E-06 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,1 | 0,058 | 0,45 | 0,045 | 0,026 | 4,56E-07 |
| Indenter radius | $R_\alpha$, $\mu m$ | 1,0 | 0,577 | 0,45 | 0,45 | 0,260 | 0,004557 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 1 | 0,1 | 0,058 | 1,11E-05 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,35 | -0,202 | 0,001668 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 5,63E-05 |
| Total | | | | | 0,465 | 0,268 | |
| Standard uncertainty | | | | | | 0,357 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,714** | |

NSC "Institute of Metrology"; hardness level 40-50 HR30N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,7 | 0,14 | 0,081 | 4,269E-05 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,2 | -0,3 | -0,173 | 0,001 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,1 | 0,058 | -0,41 | -0,041 | -0,024 | 3,140E-07 |
| Indenter radius | $R_\alpha$, $\mu m$ | 1,0 | 0,577 | -0,41 | -0,41 | -0,237 | 0,003 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 1 | 0,1 | 0,058 | 1,111E-05 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,35 | -0,202 | 0,0017 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,778E-08 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,778E-08 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 5,626E-05 |
| Total | | | | | -0,671 | -0,387 | |
| Standard uncertainty | | | | | | 0,381 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,762** | |

NSC “Institute of Metrology”; hardness level 76-84 HR30N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,45 | 0,09 | 0,052 | 7,290E-06 |
| Total test force | $F$ , $N$ | 1,5 | 0,866 | 0,08 | 0,12 | 0,069 | 2,304E-05 |
| Indenter cone angle | $\alpha_m$ ,$^0$ | 0,1 | 0,058 | 0,38 | 0,038 | 0,022 | 2,317E-07 |
| Indenter radius | $R_\alpha$ , $\mu m$ | 1,0 | 0,577 | 0,38 | 0,38 | 0,219 | 0,002 |
| Indentation depth | $l$ , $\mu m$ | 0,1 | 0,058 | 1 | 0,1 | 0,058 | 1,111E-05 |
| Indentation velocity | $V_{fis}$ , $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,35 | -0,202 | 0,002 |
| Preliminary test force duration time | $T_p$ , s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,778E-08 |
| Total test force duration time | $T_{df}$ , s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,778E-08 |
| Deformation of frame | $d$ , $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 5,626E-05 |
| Total | | | | | 0,568 | 0,328 | |
| Standard uncertainty | | | | | | 0,329 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,657** | |

NSC “Institute of Metrology”; hardness level 43-54 HR45N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,47 | 0,094 | 0,054 | 8,676E-06 |
| Total test force | $F$ , $N$ | 1,5 | 0,866 | -0,25 | -0,375 | -0,217 | 0,002 |
| Indenter cone angle | $\alpha_m$ ,$^0$ | 0,1 | 0,058 | 0,41 | 0,041 | 0,024 | 3,140E-07 |
| Indenter radius | $R_\alpha$ , $\mu m$ | 1,0 | 0,577 | 0,41 | 0,41 | 0,237 | 0,003 |
| Indentation depth | $l$ , $\mu m$ | 0,1 | 0,058 | 1 | 0,1 | 0,058 | 1,111E-05 |
| Indentation velocity | $V_{fis}$ , $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,08 | -0,056 | -0,032 | 1,093E-06 |
| Preliminary test force duration time | $T_p$ , s | 0,2 | 0,115 | -0,2 | -0,04 | -0,023 | 2,845E-07 |
| Total test force duration time | $T_{df}$ , s | 0,2 | 0,115 | -0,2 | -0,04 | -0,023 | 2,8445E-07 |
| Deformation of frame | $d$ , $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 5,626E-05 |
| Total | | | | | 0,284 | 0,164 | |
| Standard uncertainty | | | | | | 0,345 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,691** | |

NSC “Institute of Metrology”; hardness level 47–53 HR30TW

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRTW | $u_i(H)$, HRTW | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,35 | -0,525 | -0,303 | 0,008442 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 1,0 | 0,577 | -0,085 | -0,085 | -0,049 | 5,8E-06 |
| Indentation depth | $l$, $\mu m$ | 0,5 | 0,289 | 1 | 0,1 | 0,058 | 1,11E-05 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,2 | -0,14 | -0,081 | 4,27E-05 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 5,63E-05 |
| Total | | | | | -0,440 | -0,254 | |
| Standard uncertainty | | | | | | 0,335 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,669** | |

NSC “Institute of Metrology”; hardness level 70-82 HR30TW

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRTW | $u_i(H)$, HRTW | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,085 | 0,017 | 0,010 | 9,28E-09 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,38 | -0,57 | -0,329 | 0,01173 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 1,0 | 0,577 | -0,07 | -0,07 | -0,040 | 2,67E-06 |
| Indentation depth | $l$, $\mu m$ | 0,5 | 0,289 | 1 | 0,1 | 0,058 | 1,11E-05 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,2 | -0,14 | -0,081 | 4,27E-05 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,1 | 0,02 | 0,012 | 1,78E-08 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,15 | 0,087 | 5,63E-05 |
| Total | | | | | -0,473 | -0,273 | |
| Standard uncertainty | | | | | | 0,357 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,715** | |

Kazakhstan institute of standardization and certification. Uncertainty budget for 90-94 HR15N

| Influencing Quantity, $X_i$ | Symbol,Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $u_i(H)$, HRN |
|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,670 | 0,077 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | 0,2 | 0,173 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,1 | 0,058 | 0,350 | 0,020 |
| Indenter radius | $R_\alpha$, $\mu m$ | 1,0 | 0,577 | 0,350 | 0,202 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 0,9 | 0,052 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,202 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,1 | 0,012 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,1 | 0,012 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,087 |
| Standard uncertainty | | | | | 0,359 |
| Coverage factor k for confidence level p=0,95 | | | | | 2 |
| Expanded uncertainty | | | | | **0,717** |

Kazakhstan institute of standardization and certification. Uncertainty budget for 40-50 HR30N

| Influencing Quantity, $X_i$ | Symbol,Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $u_i(H)$, HRN |
|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,670 | 0,077 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | 0,2 | 0,173 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,1 | 0,058 | 0,350 | 0,020 |
| Indenter radius | $R_\alpha$, $\mu m$ | 1,0 | 0,577 | 0,350 | 0,202 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 0,9 | 0,052 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,202 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,1 | 0,012 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,1 | 0,012 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,5 | 0,087 |
| Standard uncertainty | | | | | 0,359 |
| Coverage factor k for confidence level p=0,95 | | | | | 2 |
| Expanded uncertainty | | | | | **0,717** |

Kazakhstan institute of standardization and certification. Uncertainty budget for 76-84 HR30N

| Influencing Quantity, $X_i$ | Symbol,Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $u_i(H)$, HRN |
|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,670 | 0,077 |
| Total test force | $F$ , $N$ | 1,5 | 0,866 | 0,2 | 0,173 |
| Indenter cone angle | $\alpha_m$ ,$^0$ | 0,1 | 0,058 | 0,350 | 0,020 |
| Indenter radius | $R_\alpha$ , $\mu m$ | 1,0 | 0,577 | 0,350 | 0,202 |
| Indentation depth | $l$ , $\mu m$ | 0,1 | 0,058 | 0,9 | 0,052 |
| Indentation velocity | $V_{fis}$ , $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,202 |
| Preliminary test force duration time | $T_p$ , s | 0,2 | 0,115 | 0,1 | 0,012 |
| Total test force duration time | $T_{df}$ , s | 0,2 | 0,115 | 0,1 | 0,012 |
| Deformation of frame | $d$ , $\mu m$ | 0,3 | 0,173 | 0,5 | 0,087 |
| Standard uncertainty | | | | | 0,359 |
| Coverage factor k for confidence level p=0,95 | | | | | 2 |
| Expanded uncertainty | | | | | **0,717** |

Kazakhstan institute of standardization and certification. Uncertainty budget for 43-54 HR45N

| Influencing Quantity, $X_i$ | Symbol,Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $u_i(H)$, HRN |
|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,670 | 0,077 |
| Total test force | $F$ , $N$ | 1,5 | 0,866 | 0,2 | 0,173 |
| Indenter cone angle | $\alpha_m$ ,$^0$ | 0,1 | 0,058 | 0,350 | 0,020 |
| Indenter radius | $R_\alpha$ , $\mu m$ | 1,0 | 0,577 | 0,350 | 0,202 |
| Indentation depth | $l$ , $\mu m$ | 0,1 | 0,058 | 0,9 | 0,052 |
| Indentation velocity | $V_{fis}$ , $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,5 | -0,202 |
| Preliminary test force duration time | $T_p$ , s | 0,2 | 0,115 | 0,1 | 0,012 |
| Total test force duration time | $T_{df}$ , s | 0,2 | 0,115 | 0,1 | 0,012 |
| Deformation of frame | $d$ , $\mu m$ | 0,3 | 0,173 | 0,5 | 0,087 |
| Standard uncertainty | | | | | 0,359 |
| Coverage factor k for confidence level p=0,95 | | | | | 2 |
| Expanded uncertainty | | | | | **0,717** |

Kazakhstan institute of standardization and certification. Uncertainty budget for 47–53 HR30TW

| Influencing Quantity, $X_i$ | Symbol,Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $u_i(H)$, HRTW |
|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,1 | 0,012 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,6 | -0,520 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 1,0 | 0,577 | -0,09 | -0,052 |
| Indentation depth | $l$, $\mu m$ | 0,5 | 0,289 | 0,9 | 0,260 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,2 | -0,081 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,08 | 0,009 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,05 | 0,006 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,05 | 0,009 |
| Standard uncertainty | | | | | 0,589 |
| Coverage factor k for confidence level p=0,95 | | | | | 2 |
| Expanded uncertainty | | | | | **1,178** |

Kazakhstan institute of standardization and certification. Uncertainty budget for 70-82 HR30TW

| Influencing Quantity, $X_i$ | Symbol,Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $u_i(H)$, HRTW |
|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,115 | 0,1 | 0,012 |
| Total test force | $F$, $N$ | 1,5 | 0,866 | -0,6 | -0,520 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 1,0 | 0,577 | -0,09 | -0,052 |
| Indentation depth | $l$, $\mu m$ | 0,5 | 0,289 | 0,9 | 0,260 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | -0,2 | -0,081 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | 0,08 | 0,009 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,05 | 0,006 |
| Deformation of frame | $d$, $\mu m$ | 0,3 | 0,173 | 0,05 | 0,009 |
| Standard uncertainty | | | | | 0,589 |
| Coverage factor k for confidence level p=0,95 | | | | | 2 |
| Expanded uncertainty | | | | | **1,178** |

Czech metrology institute; hardness level 90-94 HR15N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,2 | 0,087 | 0,693 | 0,104 | 0,060 | 1,3E-05 |
| Total test force | $F$, $N$ | 1,2 | 0,693 | 0,110 | 0,132 | 0,076 | 3,37E-05 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,1 | 0,058 | 0,180 | 0,018 | 0,010 | 1,17E-08 |
| Indenter radius | $R_\alpha$, $\mu m$ | 1,0 | 0,577 | 0,300 | 0,300 | 0,173 | 0,0009 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 1,000 | 0,100 | 0,058 | 1,11E-05 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,7 | 0,404 | 0,293 | 0,205 | 0,118 | 0,000197 |
| Preliminary test force duration time | $T_p$, s | 0,2 | 0,115 | -0,905 | -0,181 | -0,105 | 0,000119 |
| Total test force duration time | $T_{df}$, s | 0,2 | 0,115 | 0,128 | 0,026 | 0,015 | 4,77E-08 |
| Deformation of frame | $d$, $\mu m$ | 0,2 | 0,087 | 0,120 | 0,048 | 0,028 | 5,9E-07 |
| Total | | | | | 0,752 | 0,434 | |
| Standard uncertainty | | | | | | 0,262 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,525** | |

Czech metrology institute; hardness level 40-50 HR30N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,15 | 0,087 | 0,534 | 0,080 | 0,046 | 4,574E-06 |
| Total test force | $F$, $N$ | 1,20 | 0,693 | 0,241 | 0,289 | 0,167 | 0,0001 |
| Indenter cone angle | $\alpha_m$, $^0$ | 0,20 | 0,115 | 0,180 | 0,036 | 0,021 | 1,866E-07 |
| Indenter radius | $R_\alpha$, $\mu m$ | 0,90 | 0,520 | 0,300 | 0,270 | 0,156 | 0,001 |
| Indentation depth | $l$, $\mu m$ | 0,1 | 0,058 | 1,000 | 0,100 | 0,058 | 1,11E-05 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,90 | 0,520 | 0,144 | 0,130 | 0,075 | 3,135E-05 |
| Preliminary test force duration time | $T_p$, s | 0,20 | 0,115 | 0,822 | 0,164 | 0,095 | 8,117E-05 |
| Total test force duration time | $T_{df}$, s | 0,20 | 0,115 | 0,060 | 0,012 | 0,007 | 2,304E-09 |
| Deformation of frame | $d$, $\mu m$ | 0,40 | 0,231 | 0,120 | 0,048 | 0,028 | 5,899E-07 |
| Total | | | | | 1,129 | 0,652 | |
| Standard uncertainty | | | | | | 0,271 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,542** | |

Czech metrology institute; hardness level 76-84 HR30N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0,\ N$ | 0,15 | 0,087 | 0,656 | 0,098 | 0,057 | 1,04181E-05 |
| Total test force | $F\ ,\ N$ | 1,20 | 0,693 | 0,291 | 0,349 | 0,202 | 0,001652363 |
| Indenter cone angle | $\alpha_m\ ,^0$ | 0,20 | 0,115 | 0,180 | 0,036 | 0,021 | 1,86646E-07 |
| Indenter radius | $R_\alpha\ ,\ \mu m$ | 0,90 | 0,520 | 0,300 | 0,270 | 0,156 | 0,000590559 |
| Indentation depth | $l\ ,\ \mu m$ | 0,1 | 0,058 | 1,000 | 0,100 | 0,058 | 1,11E-05 |
| Indentation velocity | $V_{fis}\ ,\ \mu m \cdot s^{-1}$ | 0,90 | 0,520 | 0,202 | 0,182 | 0,105 | 0,00012139 |
| Preliminary test force duration time | $T_p$ , s | 0,20 | 0,115 | -0,001 | 0,000 | 0,000 | 1,77799E-16 |
| Total test force duration time | $T_{df}$ , s | 0,20 | 0,115 | -0,034 | -0,007 | -0,004 | 2,37599E-10 |
| Deformation of frame | $d\ ,\ \mu m$ | 0,40 | 0,231 | 0,120 | 0,048 | 0,028 | 5,89893E-07 |
| Total | | | | | 1,076 | 0,621 | |
| Standard uncertainty | | | | | | 0,289 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,579** | |

Czech metrology institute; hardness level 43-54 HR45N

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRN | $u_i(H)$, HRN | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0,\ N$ | 0,15 | 0,087 | 0,171 | 0,0257 | 0,015 | 4,81014E-08 |
| Total test force | $F\ ,\ N$ | 1,20 | 0,693 | 0,129 | 0,1548 | 0,089 | 6,38105E-05 |
| Indenter cone angle | $\alpha_m\ ,^0$ | 0,10 | 0,058 | 0,180 | 0,0180 | 0,010 | 1,16654E-08 |
| Indenter radius | $R_\alpha\ ,\ \mu m$ | 1,00 | 0,577 | 0,300 | 0,3000 | 0,173 | 0,000900106 |
| Indentation depth | $l\ ,\ \mu m$ | 0,15 | 0,087 | 1,000 | 0,1500 | 0,087 | 5,62566E-05 |
| Indentation velocity | $V_{fis}\ ,\ \mu m \cdot s^{-1}$ | 1,00 | 0,577 | 0,118 | 0,1180 | 0,068 | 2,15445E-05 |
| Preliminary test force duration time | $T_p$ , s | 0,20 | 0,115 | 0,032 | 0,0064 | 0,004 | 1,86435E-10 |
| Total test force duration time | $T_{df}$ , s | 0,20 | 0,115 | -0,082 | -0,0164 | -0,009 | 8,03866E-09 |
| Deformation of frame | $d\ ,\ \mu m$ | 0,40 | 0,231 | 0,120 | 0,0480 | 0,028 | 5,89893E-07 |
| Total | | | | | 0,804 | 0,464 | |
| Standard uncertainty | | | | | | 0,227 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,453** | |

Czech metrology institute; hardness level 47–53 HR30TW

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRTW | $u_i(H)$, HRTW | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,15 | 0,087 | 0,161 | 0,0242 | 0,014 | 3,78E-08 |
| Total test force | $F$, $N$ | 1,20 | 0,693 | 0,144 | 0,1728 | 0,100 | 9,91E-05 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 2,00 | 1,155 | 0,200 | 0,4000 | 0,231 | 0,002845 |
| Indentation depth | $l$, $\mu m$ | 0,30 | 0,173 | 1,000 | 0,3000 | 0,173 | 0,0009 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,90 | 0,520 | 0,200 | 0,1800 | 0,104 | 0,000117 |
| Preliminary test force duration time | $T_p$, s | 0,20 | 0,115 | 0,100 | 0,0200 | 0,012 | 1,78E-08 |
| Total test force duration time | $T_{df}$, s | 0,20 | 0,115 | -0,017 | -0,0034 | -0,002 | 1,48E-11 |
| Deformation of frame | $d$, $\mu m$ | 0,40 | 0,231 | 0,120 | 0,0480 | 0,028 | 5,9E-07 |
| Total | | | | | 1,142 | 0,659 | |
| Standard uncertainty | | | | | | 0,324 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,649** | |

Czech metrology institute; hardness level 70-82 HR30TW

| Influencing Quantity, $X_i$ | Symbol, Unit | $\Delta x_i$ | $u(x_i)$ | $c_i$ | $\Delta H_i$, HRTW | $u_i(H)$, HRTW | $u_i^4(H)/\nu_i$ |
|---|---|---|---|---|---|---|---|
| Preliminary test force | $F_0$, $N$ | 0,15 | 0,087 | 0,066 | 0,010 | 0,006 | 1,07E-09 |
| Total test force | $F$, $N$ | 1,20 | 0,693 | 0,261 | 0,313 | 0,181 | 0,001069 |
| Indenter ball diameter | $R_\beta$, $\mu m$ | 2,00 | 1,155 | -0,160 | -0,320 | -0,185 | 0,001165 |
| Indentation depth | $l$, $\mu m$ | 0,30 | 0,173 | 1,000 | 0,3000 | 0,173 | 0,0009 |
| Indentation velocity | $V_{fis}$, $\mu m \cdot s^{-1}$ | 0,90 | 0,520 | 0,200 | 0,180 | 0,104 | 0,000117 |
| Preliminary test force duration time | $T_p$, s | 0,20 | 0,115 | 0,125 | 0,025 | 0,014 | 4,34E-08 |
| Total test force duration time | $T_{df}$, s | 0,20 | 0,115 | -0,017 | -0,003 | -0,002 | 1,48E-11 |
| Deformation of frame | $d$, $\mu m$ | 0,40 | 0,231 | 0,120 | 0,048 | 0,028 | 5,9E-07 |
| Total | | | | | 0,553 | 0,319 | |
| Standard uncertainty | | | | | | 0,330 | |
| Coverage factor k for confidence level p=0,95 | | | | | | 2 | |
| Expanded uncertainty | | | | | | **0,659** | |

**Belarusian State Institute of Metrology**

The uncertainty value of the hardness reference blocks has been calculated according to the calibration procedure MRP MK 47 03.29-2013, which was developed by BelGIM on the basis of ISO 6508-3:2005. The use of a custom BelGIM calibration procedure is due to the fact that ISO 6508-3:2005 is currently not implemented in the Republic of Belarus and hence it cannot be applied directly.

Since BelGIM does not possess appropriate equipment to realize hardness units on its own, the calibration was conducted by using both reference hardness blocks calibrated at the VNIIFTRI and hardness comparators. For the same reason, the calibration procedure specified above was used instead of the one given in the technical report (any direct calibration of our hardness machines makes no sense, because they are being adjusted against the reference hardness blocks).

As the hardness value of the reference block under calibration a median value was taken inclusive of an appropriate correction obtained by using a 1st class reference hardness block.

A rather large expanded uncertainty was resulting from the uncertainty value specified in the calibration certificate for the relevant 1st class hardness block.

National standards for hardness units, which are planned to be established in 2017-2019, will allow avoiding the use of hardness comparators and provide means for our stand-alone realization of hardness units with the smallest uncertainty value.

The measurement results for each hardness block together with their uncertainty calculation are presented below.

| № hardness block | Result |
|---|---|
| 7/14 HR15N | 91,23 ± 0,53 |
| 9/14 HR30N | 47,98±0,60 |
| 8/14 HR30N | 80,19 ± 0,44 |
| 10/14 HR45N | 50,68± 0,55 |
| 12/14 HR30TW | 52,36 ± 0,83 |
| 11/14 HR30TW | 78,20 ± 0,63 |

**Measurements for hardness block №** 7/14 HR15N

Measurements on a reference hardness block 1st category

| | | |
|---|---|---|
| Actual value of the hardness block 1st category, $H_d$, HRN | | 90,67 |
| Results of measurements on hardness block 1st category, $H_{1i}$, HRN | 1 | 90,1 |
| | 2 | 89,8 |
| | 3 | 90,4 |
| | 4 | 90,1 |
| | 5 | 90,3 |
| arithmetic mean value of hardness, $\overline{H}$, HRN | | 90,14 |
| Standard uncertainty, $u(\overline{H})$, HRN | | 0,10 |
| combined standard uncertainty of hardness block 1st category, *U,* HRN | | **0,45** |
| Standard uncertainty of hardness block 1st category, $u(H_d)$, HRN | | 0,225 |
| Standard uncertainty, $u(\delta_{ms})$, HRN | | 0,03 |

Measurements on calibrated hardness block

m6 – 89,7 HRN – test measurement

m2 – 89,8 HRN– not used in the calculation

| | | | | | | |
|---|---|---|---|---|---|---|
| Number of measurements | | 5 | | | | |
| Measurement results Hi, HRN | | m1 | m7 | m3 | m4 | m5 |
| | | 90,6 | 90,7 | 90,7 | 90,8 | 90,6 |
| Ranging measurements hardness, HRN | 1 | 90,6 | | | | |
| | 2 | 90,6 | | | | |
| | 3 | 90,7 | | | | |
| | 4 | 90,7 | | | | |
| | 5 | 90,8 | | | | |
| Median, $H_{mes}$, HRN | | 90,7 | | | | |
| Value \| $H_i – H_{mes}$ \|, HRN | | 0,1 | 0,1 | 0 | 0 | 0,1 |
| Ranging results \| $H_i – H_{mes}$ \|, HRN | 1 | 0 | | | | |
| | 2 | 0 | | | | |
| | 3 | 0,1 | | | | |
| | 4 | 0,1 | | | | |
| | 5 | 0,1 | | | | |
| Median \| $H_i – H_{mes}$ \| S*, HRN | | 0,1 | | | | |
| Standard deviation, s*,HRN | | 0,15 | | | | |
| Standard uncertainty, $u(H_{mes})$, HRN | | 0,08 | | | | |
| combined standard uncertainty, *u,* HRN | | 0,26 | | | | |
| coverage factor | | 2 | | | | |
| expanded uncertainty, U, HRN | | **0,53** | | | | |
| Range, HRN | | 0,2 | | | | |
| Hardness calibrated block, HRN | | **91,23±0,53** | | | | |

**Measurements for hardness block №** 9/14 HR30N

Measurements on a reference hardness block 1st category

| | | |
|---|---|---|
| Actual value of the hardness block 1st category, $H_d$, HRN | | 46,82 |
| Results of measurements on hardness block 1st category, $H_{1i}$, HRN | 1 | 45,9 |
| | 2 | 46,1 |
| | 3 | 46,2 |
| | 4 | 45,7 |
| | 5 | 45,8 |
| arithmetic mean value of hardness, $\overline{H}$, HRN | | 45,94 |
| Standard uncertainty, $u(\overline{H})$, HRN | | 0,09 |
| combined standard uncertainty of hardness block 1st category, *U,* HRN | | **0,46** |
| Standard uncertainty of hardness block 1st category, $u(H_d)$, HRN | | 0,23 |
| Standard uncertainty, $u(\delta_{ms})$, HRN | | 0,03 |

Measurements on calibrated hardness block

m6 – 46,5 HRN – test measurement

m7 – 46,1 HRN – not used in the calculation

| | | | | | | |
|---|---|---|---|---|---|---|
| Number of measurements | | 5 | | | | |
| Measurement results Hi, HRN | | m1 | m2 | m3 | m4 | m5 |
| | | 46,4 | 46,3 | 46,6 | 46,7 | 45,8 |
| Ranging measurements hardness, HRN | 1 | 45,8 | | | | |
| | 2 | 46,3 | | | | |
| | 3 | 46,4 | | | | |
| | 4 | 46,6 | | | | |
| | 5 | 46,7 | | | | |
| Median, $H_{mes}$, HRN | | 46,4 | | | | |
| Value $\lvert H_i – H_{mes} \rvert$, HRN | | 0,6 | 0,1 | 0 | 0,2 | 0,3 |
| Ranging results $\lvert H_i – H_{mes} \rvert$, HRN | 1 | 0 | | | | |
| | 2 | 0,1 | | | | |
| | 3 | 0,2 | | | | |
| | 4 | 0,3 | | | | |
| | 5 | 0,6 | | | | |
| Median $\lvert H_i – H_{mes} \rvert$ S*, HRN | | 0,2 | | | | |
| Standard deviation, s*,HRN | | 0,2966 | | | | |
| Standard uncertainty, $u(H_{mes})$, HRN | | 0,166 | | | | |
| combined standard uncertainty, *u,* HRN | | 0,30 | | | | |
| coverage factor | | 2 | | | | |
| expanded uncertainty, U, HRN | | 0,60 | | | | |
| Range, HRN | | 0,9 | | | | |
| Hardness calibrated block, HRN | | **47,98 ± 0,60** | | | | |

**Measurements for hardness block №** 8/14 HR30N

Measurements on a reference hardness block 1st category

| | | |
|---|---|---|
| Actual value of the hardness block 1st category, $H_d$, HRN | | 78,79 |
| Results of measurements on hardness block 1st category, $H_{1i}$, HRN | 1 | 79,7 |
| | 2 | 79,7 |
| | 3 | 79,7 |
| | 4 | 79,7 |
| | 5 | 79,7 |
| arithmetic mean value of hardness, $\overline{H}$, HRN | | 79,7 |
| Standard uncertainty, $u(\overline{H})$, HRN | | 0,00 |
| combined standard uncertainty of hardness block 1st category, *U,* HRN | | **0,44** |
| Standard uncertainty of hardness block 1st category, $u(H_d)$, HRN | | 0,22 |
| Standard uncertainty, $u(\delta_{ms})$, HRN | | 0,03 |

Measurements on calibrated hardness block

m6 – 80,1 HRN – test measurement

m7 – 80,2 HRN – not used in the calculation

| | | | | | | |
|---|---|---|---|---|---|---|
| Number of measurements | | 5 | | | | |
| Measurement results Hi, HRN | | m1 | m2 | m3 | m4 | m5 |
| | | 80,0 | 80,1 | 80,2 | 80,1 | 80,1 |
| Ranging measurements hardness, HRN | 1 | 80,0 | | | | |
| | 2 | 80,0 | | | | |
| | 3 | 80,1 | | | | |
| | 4 | 80,1 | | | | |
| | 5 | 80,2 | | | | |
| Median, $H_{mes}$, HRN | | 80,1 | | | | |
| Value \| $H_i - H_{mes}$ \|, HRN | | 0,1 | 0,1 | 0 | 0 | 0 |
| Ranging results \| $H_i - H_{mes}$ \|, HRN | 1 | 0 | | | | |
| | 2 | 0 | | | | |
| | 3 | 0 | | | | |
| | 4 | 0,1 | | | | |
| | 5 | 0,1 | | | | |
| Median \| $H_i - H_{mes}$ \| S*, HRN | | 0 | | | | |
| Standard deviation, s*,HRN | | 0,00 | | | | |
| Standard uncertainty, $u(H_{mes})$, HRN | | 0,00 | | | | |
| combined standard uncertainty, *u,* HRN | | 0,22 | | | | |
| coverage factor | | 2 | | | | |
| expanded uncertainty, U, HRN | | 0,44 | | | | |
| Range, HRN | | 0,1 | | | | |
| Hardness calibrated block, HRN | | **80,19 ± 0,44** | | | | |

**Measurements for hardness block №** 10/14 HR45N

Measurements on a reference hardness block 1st category

| | | |
|---|---|---|
| Actual value of the hardness block 1st category, $H_d$, HRN | | 49,88 |
| Results of measurements on hardness block 1st category, $H_{1i}$ , HRN | 1 | 49,6 |
| | 2 | 49,7 |
| | 3 | 49,4 |
| | 4 | 49,6 |
| | 5 | 49,7 |
| arithmetic mean value of hardness, $\overline{H}$ , HRN | | 49,6 |
| Standard uncertainty, $u(\overline{H})$,HRN | | 0,05 |
| combined standard uncertainty of hardness block 1st category, *U,* HRN | | **0,51** |
| Standard uncertainty of hardness block 1st category, $u(H_d)$, HRN | | 0,26 |
| Standard uncertainty, $u(\delta_{ms})$, HRN | | 0,03 |

Measurements on calibrated hardness block

m6 – 50,6 HRN – test measurement

m7 – 50,3 HRN – not used in the calculation

| | | | | | | |
|---|---|---|---|---|---|---|
| Number of measurements | | 5 | | | | |
| Measurement results Hi, HRN | | m1 | m2 | m3 | m4 | m5 |
| | | 50,7 | 50,5 | 50,1 | 50,4 | 50,4 |
| Ranging measurements hardness, HRN | 1 | 50,1 | | | | |
| | 2 | 50,4 | | | | |
| | 3 | 50,4 | | | | |
| | 4 | 50,5 | | | | |
| | 5 | 50,7 | | | | |
| Median, $H_{mes}$, HRN | | 50,4 | | | | |
| Value \| $H_i - H_{mes}$ \|, HRN | | 0,3 | 0 | 0 | 0,1 | 0,3 |
| Ranging results \| $H_i - H_{mes}$ \|, HRN | 1 | 0 | | | | |
| | 2 | 0 | | | | |
| | 3 | 0,1 | | | | |
| | 4 | 0,3 | | | | |
| | 5 | 0,3 | | | | |
| Median \| $H_i - H_{mes}$ \| S*, HRN | | 0,1 | | | | |
| Standard deviation, s*, HRN | | 0,1483 | | | | |
| Standard uncertainty, $u(H_{mes})$, HRN | | 0,08290222 | | | | |
| combined standard uncertainty, *u,* HRN | | 0,28 | | | | |
| coverage factor | | 2 | | | | |
| expanded uncertainty, U, HRN | | 0,55 | | | | |
| Range, HRN | | 0,6 | | | | |
| Hardness calibrated block, HRN | | **50,68 ± 0,55** | | | | |

**Measurements for hardness block №** 12/14 HR30TW

Measurements on a reference hardness block 1st category

| | | |
|---|---|---|
| Actual value of the hardness block 1st category, $H_d$, HRTW | | 58,34 |
| Resaults of measurements on hardness block 1st category, $H_{1i}$ , HRTW | 1 | 59 |
| | 2 | 58,6 |
| | 3 | 58,7 |
| | 4 | 58,7 |
| | 5 | 58,9 |
| arithmetic mean value of hardness, $\overline{H}$ ,HRTW | | 58,78 |
| Standard uncertainty, $u(\overline{H})$, HRTW | | 0,073 |
| combined standard uncertainty of hardness block 1st category, *U*,HRTW | | **0,8** |
| Standard uncertainty of hardness block 1st category, $u(H_d)$,HRTW | | 0,4 |
| Standard uncertainty, $u(\delta_{ms})$, HRTW | | 0,03 |

Measurements on calibrated hardness block
m6 – 52,2 HRTW – test measurement
m7 – 52,4 HRTW – not used in the calculation

| | | | | | | |
|---|---|---|---|---|---|---|
| Number of measurements | | 5 | | | | |
| Measurement results Hi, HRTW | | m1 | m2 | m3 | m4 | m5 |
| | | 51,8 | 51,5 | 52,2 | 51,9 | 51,9 |
| Ranging measurements hardness, HRTW | 1 | 51,5 | | | | |
| | 2 | 51,8 | | | | |
| | 3 | 51,9 | | | | |
| | 4 | 51,9 | | | | |
| | 5 | 52,2 | | | | |
| Median, $H_{mes}$, HRTW | | 51,9 | | | | |
| Value $\lvert H_i – H_{mes} \rvert$, HRTW | | 0,4 | 0,1 | 0 | 0 | 0,3 |
| Ranging results $\lvert H_i – H_{mes} \rvert$, HRTW | 1 | 0 | | | | |
| | 2 | 0 | | | | |
| | 3 | 0,1 | | | | |
| | 4 | 0,3 | | | | |
| | 5 | 0,4 | | | | |
| Median $\lvert H_i – H_{mes} \rvert$ $S^*$, HRTW | | 0,1 | | | | |
| standard deviation, $s^*$, HRTW | | 0,15 | | | | |
| Standard uncertainty, $u(H_{mes})$, HRTW | | 0,08 | | | | |
| combined standard uncertainty, *u*, HRTW | | 0,42 | | | | |
| coverage factor | | 2 | | | | |
| expanded uncertainty, U, HRTW | | **0,83** | | | | |
| Range, HRTW | | 0,7 | | | | |
| Hardness calibrated block, HRTW | | **52,36 ± 0,83** | | | | |

**Measurements for hardness block №** 11/14 HR30TW

Measurements on a reference hardness block 1st category

| | | |
|---|---|---|
| Actual value of the hardness block 1st category, $H_d$, HRTW | | 78,26 |
| Resaults of measurements on hardness block 1st category, $H_{1i}$ , HRTW | 1 | 78,6 |
| | 2 | 78,6 |
| | 3 | 78,7 |
| | 4 | 78,6 |
| | 5 | 78,8 |
| arithmetic mean value of hardness, $\overline{H}$ ,HRTW | | 78,66 |
| Standard uncertainty, $u(\overline{H})$, HRTW | | 0,040 |
| combined standard uncertainty of hardness block 1st category, *U*,HRTW | | **0,6** |
| Standard uncertainty of hardness block 1st category, $u(H_d)$,HRTW | | 0,3 |
| Standard uncertainty, $u(\delta_{ms})$, HRTW | | 0,03 |

Measurements on calibrated hardness block
m6 – 78,5 HRTW – test measurement
m7 – 78,4 HRTW – not used in the calculation

| | | | | | | |
|---|---|---|---|---|---|---|
| Number of measurements | | 5 | | | | |
| Measurement results Hi, HRTW | | m1 | m2 | m3 | m4 | m5 |
| | | 78,6 | 78,6 | 78,5 | 78,7 | 78,7 |
| Ranging measurements hardness, HR | 1 | 78,5 | | | | |
| | 2 | 78,6 | | | | |
| | 3 | 78,6 | | | | |
| | 4 | 78,7 | | | | |
| | 5 | 79,7 | | | | |
| Median, $H_{mes}$, HRTW | | 78,6 | | | | |
| Value \| $H_i – H_{mes}$ \|, HRTW | | 0,1 | 0 | 0 | 0,1 | 0,1 |
| Ranging results\| $H_i – H_{mes}$ \|, HRTW | 1 | 0 | | | | |
| | 2 | 0 | | | | |
| | 3 | 0,1 | | | | |
| | 4 | 0,1 | | | | |
| | 5 | 0,1 | | | | |
| Median \| $H_i – H_{mes}$ \| $S^*$, HRTW | | 0,1 | | | | |
| standard deviation,$s^*$, HRTW | | 0,15 | | | | |
| Standard uncertainty, $u(H_{mes})$, HRTW | | 0,08 | | | | |
| combined standard uncertainty, *u,* HRTW | | 0,32 | | | | |
| coverage factor | | 2 | | | | |
| expanded uncertainty, U, HRTW | | **0,63** | | | | |
| Range, HRTW | | 0,2 | | | | |
| Hardness calibrated block, HRTW | | **78,20 ± 0,63** | | | | |

Physikalisch-Technische Bundesanstalt;

Uncertainty budget for HRN

| Quantity | Estimated value | | Standard uncertainty | Sensitivity coefficient | Uncertainty contribution |
|---|---|---|---|---|---|
| $X_i$ | $\Delta x_i$ | | $u(x_i)=\frac{\Delta x_i}{\sqrt{3}}$ | $C_i$ | $u_i(H)$ |
| Preliminary test force, $F_0$ | 0,01 | N | 0,0058 | 0,47 | 0,0027 |
| Total test force, F | 0,03 | N | 0,0173 | -0,25 | -0,0043 |
| Permanent depth of measuring device, h | 0,01 | µm | 0,0058 | 1,00 | 0,0058 |
| Preliminary test force dwell time, $t_0$ | 0,2 | s | 0,1155 | -0,20 | -0,0231 |
| Indentation velocity, v | 2 | µm/s | 1,1547 | -0,04 | -0,0462 |
| Total test force dwell time, t | 0,2 | s | 0,1155 | -0,20 | -0,0231 |
| Indenter angle, $\alpha$ | 0,1 | ° | 0,0577 | 0,41 | 0,0237 |
| Indenter radius, r | 1 | µm | 0,5774 | 0,30 | 0,1732 |
| Combined uncertainty, $u_c$ | | | | | 0,1839 |
| Expanded uncertainty, Ue | | | | k=2 | 0,37 |

Physikalisch-Technische Bundesanstalt;

Uncertainty budget for HRT

| Quantity | Estimated value | | Standard uncertainty | Sensitivity coefficient | Uncertainty contribution |
|---|---|---|---|---|---|
| $X_i$ | $\Delta x_i$ | | $u(x_i)=\frac{\Delta x_i}{\sqrt{3}}$ | $C_i$ | $u_i(H)$ |
| Preliminary test force, $F_0$ | 0,01 | N | 0,0058 | 0,50 | 0,0029 |
| Total test force, F | 0,03 | N | 0,0173 | 0,30 | 0,0052 |
| Permanent depth of measuring device, h | 0,01 | µm | 0,0058 | 0,50 | 0,0029 |
| Preliminary test force dwell time, $t_0$ | 0,2 | s | 0,1155 | 0,35 | 0,0404 |
| Indentation velocity, v | 2 | µm/s | 1,1547 | 0,32 | 0,3695 |
| Total test force dwell time, t | 0,2 | s | 0,1155 | 0,23 | 0,0266 |
| Indenter diameter, d | 0,1 | µm | 0,0577 | 0,35 | 0,0202 |
| Combined uncertainty, $u_c$ | | | | | 0,3733 |
| Expanded uncertainty, Ue | | | | k=2 | 0,75 |