National Research Institute for Physical-Technical and Radio Engineering Measurements (VNIIFTRI)

RMO BRINELL SUPPLEMENTARY COMPARISON
COOMET M.H-S4

Final report

A. Aslanyan(VNIIFTRI), E. Aslanyan (VNIIFTRI), E. Obozniy (BELGIM),
E. Galat (BELGIM), Y. Dovzhenko (NSC IM), M. Zhamanbalin (KAZINMETR)

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Content

1. Introduction

The present supplementary comparisons of Brinell hardness scales were organized by the Regional Metrology Organization COOMET and registered in CIPM under the cipher COOMET.M.H- S4 (old cipher - COOMET.M.H- K2). Status of comparisons and, consequently, the cipher of comparisons has been amended due to the fact that the key comparison of Brinell BIPM CCM with CCM cipher-H. K2, which was the pilot of these comparisons – laboratory of hardness measurements VNIIFTRI has changed the status to pilot.

2. Organization

In March 2005, during TC 1.6 COOMET meeting (Vilnius, Lithuania), it was decided to entrust the organization of the comparisons on Brinell hardness scales to the National Research Institute for Physical-Technical and Radio Engineering Measurements (VNIIFTRI, Russia) as a pilot laboratory. Dr. Edward Aslanyan (VNIIFTRI) was appointed the coordinator of the comparisons.

The draft of the technical protocol was agreed upon between the participants of the comparison in 2006. The comparison started in August 2006 and ended in February 2009.

3. Participants

The list of participants is given in Table 1.

Table 1 – Participants of comparisons

Abbreviation	Institute	Contact person	Contacts
BELGIM, Belarus	Belarus State Institute of Metrology	Evgeny Galat	galat@belgim.by Tel: +37 517-288-0877 Fax: +37 517-288-0877
KAZINMETR Kazakhstan	Karaganda branch of RSE “Kazakhstan Institute of Metrology”	Meirtas Zhamanbalin	zhamanbalin@kazinmetr.kzTel: +7 721 244-22-63 Fax: +7 721 244-22-63
NSC IM, Ukraine	NSC “ Institute of Metrology”	Yakov Dovzhenko	metrology_massa@ukr.net Tel: +38 057-704-9821 Fax: +38 057-704-9821
VNIIFTRI, Russian Federation	Russian Institute for Physical-Technical and Radio Engineering Measurements	Edward Aslanyan, Andrey Aslanyan	aslanyan@vniiftri.ru Tel: :+7 495 5266341 Andrey_aslanyan@vniiftri.ru Tel: +7 495 5266318

Measurement schedule

Table 2 shows the scheduled measuring time.

Table 2: Time schedule

Laboratory	Original schedule
VNIIFTRI	08.2006
KAZINMETR	02.2007
BELGIM	06.2007
NSC IM	08.2008
VNIIFTRI	02.2009

4 Standards

4.1 Description

Brinell comparison was performed for scales HBW 5/250/15; HBW 5/750/15; HBW 10/1000/15; HBW 10/3000/15.

For hardness scales HBW 5/250/15; HBW 10/1000/15, hardness blocks were selected with hardness level 100HBW, and for hardness scales HBW 5/750/15; HBW 10/3000/15; hardness blocks were selected with hardness two hardness levels (200HBW, 400HBW). Test blocks were manufactured by Centre MET, Russia. Comparison number of hardness blocks are shown in Table 3

Table 3 - Brinell hardness blocks used in comparison.

Hardness Level	Hardness scale, HBW			
	5/250	5/750	10/1000	10/3000
100 HBW	№10	-	№13	-
200 HBW	-	№11	-	№14
400 HBW	-	№12	-	№15

The test surface of the hardness blocks are rectangle about 80×100 mm and 16 mm in thickness. The test surface of blocks were polished and were engraved with a 48 (№10-12), 30 (№13,15) or 20(№14) cell measurement grid.

	1	2	3	4	5	6
1						
2						
3						
4						
5						

Fig.1 Layout of the grid on the measurement surface of the Brinell hardness blocks №13, 15.

The area of the measuring fields are different and based on requirements of ISO 6506-3. Rows and columns of grid are numbered. Each grid cell numbered (x,y), first number correspond to row, and second correspond to column.

Each participant of the comparison measured the diameter of the Brinell reference indentation, which was made by the pilot laboratory. The reference indentation has the same coordinates of grid cell on all Brinell hardness blocks (3,3).

4.2 Handling

It was recommended 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 take to be removed before packing in order to avoid corrosion.

5. Measurand

Each participant made five indentations on the designated cell of the blocks №10, №11, 12, №13, №15 and four on the block №14, following the ISO 6506-3 requirements. The assigned measurement cells are given in Tables 4,5 and 6.

Table 4. - Assigned measurement cells on hardness blocks №10, №11, №12

Participants	Location of indentation				
	1	2	3	4	5
VNIIFTRI	2,6	6,4	3,7	4,4	5,5
KAZINMETR	2, 1	1, 6	3, 4	5, 2	4, 6
BELGIM	-	-	-	-	-
NSC IM	2, 4	3, 5	4, 2	5, 3	6, 6

Table 5. - Assigned measurement cells on hardness blocks №13, №15.

Participants	Location of indentation				
	1	2	3	4	5
VNIIFTRI	1, 3	3, 5	4, 2	5, 4	5, 5
KAZINMETR	2, 3	2, 5	3, 4	4, 5	5, 6*
BELGIM	1, 4	2, 2	3, 1	4, 3	5, 3
NSC IM	1, 2	2, 4	3, 2	4, 4	5, 2

Table 6. - Assigned measurement cells on hardness block №14.

Participants	Location of indentation			
	1	2	3	4
VNIIFTRI	1, 1	1, 5	4, 1	4, 5
KAZINMETR	1, 3	2, 2	2, 5	3, 4
BELGIM	1, 4	2, 1	2, 3	2, 2
NSC IM	1, 2	2, 4	3, 1	3, 5

According to the protocol, measurement of each indentation diameter was required to be repeated three times. The average of three measurements for x and y – directions was adopted as the indentation diameter. Brinell hardness of the block was calculated as the average value of five (or in one case four) Brinell hardness indentations.

6. Methods of measurement

The methods of measurement and the measuring devices used by the participants are described in Appendix A.

7. 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 7.

Table 7 **-** Measurement results at the beginning and at the end of the comparison by the pilot laboratory

Measurand, HBW	Result at the begin. (1), HBW	Result at the end (2) , HBW	Diff. Δ_{2-1}, HBW	Meas. Unc. U, HBW	$\|\Delta_{2-1}\|$/ U
100 HBW 5/250/15	98,4	98,6	0,2	0,7	0,3
200 HBW 5/750/15	221,2	220,7	-0,5	1,6	0,3
400 HBW 5/750/15	422,7	422	-0,7	2,7	0,3
100 HBW 10/1000/15	99,9	100,1	0,2	0,7	0,3
200 HBW 10/3000/15	217,3	217,8	0,5	1,6	0,3
400 HBW 10/3000/15	427,3	426,8	-0,5	1,7	0,3

In the last row the difference between the first and the second measurement Δ_{2-1} is compared to the measurement uncertainty. If the difference is $|\Delta_{2-1}|/U > 1$, it means that the difference Δ_{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 $|\Delta_{2-1}|/U < 1$, for each of the reference blocks, the drift of the test blocks did not influence significantly 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.

8. Measurement results

In the following tables 8, 9, 10 the results for the hardness reference blocks with hardness levels of 100 HBW, 200 HBW, 400 HBW are summarised. The results are expressed by mean values, the standard deviations s_5 of each of 5 repetition measurements and the standard deviations between the institutes s_{Inst}.

Table 8 - Results of the measurements for the hardness reference blocks with hardness level 100 HBW

	HBW 5/250/15		HBW 10/1000/15	
Institute	Mean value	Std.dev. (s_5)	Mean value	Std. dev. (s_5)
VNIIFTRI	98,5	0,16	100,1	0,22
KAZINMETR	98,7	0,21	100,1	0,44
BELGIM	-	-	99,4	0,26
NSC IM	98,6	0,65	100,5	0,07
Mean value	97,9		100,0	
Std.dev (s_{inst})	1,24		0,46	

Table 9 - Results of the measurements for the hardness reference blocks with hardness level 200 HBW

	HBW 5/750/15		HBW 10/3000/15	
Institute	Mean value	Std.dev. (s_5)	Mean value	Std. dev. (s_5)
VNIIFTRI	220,7	0,23	217,8	0,64
KAZINMETR	218,6	0,26	218,0	0,25
BELGIM	-	-	219,2	0,09
NSC IM	219,5	0,3	220,2	0,42
Mean value	219,7		218,7	
Std.dev (s_{inst})	1,27		1,25	

Table 10 - Results of the measurements for the hardness reference blocks with hardness level 400 HBW

	HBW 5/750/15		HBW 10/3000/15	
Institute	Mean value	Std.dev. (s_5)	Mean value	Std. dev. (s_5)
VNIIFTRI	422,0	2,24	426,8	2,13
KAZINMETR	423,9	2,62	428,2	9,98
BELGIM	-	-	426,3	0,00
NSC IM	422,9	1,58	430,5	3,2
Mean value	422,9		427,1	
Std.dev (s_{inst})	0,95		2,49	

9. Uncertainty budgets

9.1 Calculation scheme

The calculation of uncertainty for all the participants was carried out according to a unified procedure suggested by the Pilot laboratory. The calculation scheme can be seen from the example in Table 11.

Table 11 - Calculation scheme for the unified estimation of the measurement uncertainty

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	**F**	N	**2451,60**	0,137	6,3E-03	0,0402	1,0E-05	10	1,0E-11
Indentation diameter length	**d**	mm	**1,7682**	0,005	8,3E-06	-115,3	1,1E-01	30	4,1E-04
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-115,3	4,4E-03	30	6,5E-07
Diameter of indenter	*D*	mm	5	0,00021	1,5E-08	1,362	2,7E-08	9	8,3E-17
Force applying time	*ta*	s	5	0,5	8,3E-02	0,0863	6,2E-04	9	4,3E-08
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1411	1,7E-03	9	3,1E-07
Total							1,2E-01		4,1E-04
Combined standard uncertainty *u (H)*							3,4E-01	ν_{eff}	33
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**0,7**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,7**	**%**	
Hardness	**98,5**	**HBW**							

From the influencing quantities X_i measurement deviations Δx_i and uncertainties in the form of standard deviation s_i (type A) and a_i (type B) are considered.

Standard uncertainty:

$$u^2(x_i) = \frac{\Delta x_i^2}{3}$$

Sensitivity coefficients:

$$c_1 = \frac{\partial HBW}{\partial F} = \frac{HBW}{F}$$

$$c_2 = \frac{\partial HBW}{\partial d} = \frac{-HBW(D+\sqrt{D^2-d^2})}{d(\sqrt{D^2-d^2})}$$

$$c_3 = \frac{\partial HBW}{\partial D} = \frac{HBW(D-\sqrt{D^2-d^2})}{D(\sqrt{D^2-d^2})}$$

$$c_4 = 0{,}06487 + 0{,}0002173HBW$$

$$c_5 = -0{,}1554 + 0{,}0001454HBW$$

Variances:

$$u^2(y_i) = c_i^2 u^2(x_i)$$

Combined standard uncertainty:

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

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

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

Coverage factor:

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

Expanded standard uncertainty:

$$U(H) = k \cdot u(H)$$

Relative expanded standard uncertainty:

$$U_{rel}(H) = \frac{U(H)}{H} \cdot 100, \%$$

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

9.2 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 Brinell measuring method was recommended [2].

The reference values of the supplementary comparisons and the expanded uncertainties of the reference values with a coverage factor of 2 are calculated according to [3]

$$X_{ref} = \frac{\sum \frac{x_i}{u^2(x_i)}}{\sum \frac{1}{u^2(x_i)}}$$

$$u(X_{ref}) = \sqrt{\frac{1}{\sum \frac{1}{u^2(x_i)}}}$$

$$U(X_{ref}) = 2u(X_{ref})$$

The uncertainty budgets of the participants based on a unified procedure as presented in cl. 8.1 appear in Appendix B. Table 12 shows mean values of hardness measurements and expanded uncertainties of the measurement results for hardness level 100 HBW. The table also shows the reference values of the comparisons and the expanded uncertainties of the reference values of the comparisons.

Table 12 – Mean hardness values and expanded uncertainties.

	HBW 5/250/15		HBW 10/1000/15	
Institutes	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)
VNIIFTRI	98,5	0,7	100,1	0,7
KAZINMETR	98,7	0,5	100,1	0,5
BELGIM	-	-	99,4	0,7
NSC IM	98,6	1,5	100,5	0,7
Reference value	98,6	0,4	100,0	0,3

Table 13 shows mean values of hardness measurements and expanded uncertainties of the measurement results for hardness level 200 HBW. The table also shows the reference values of the comparisons and the expanded uncertainties of the reference values of the comparisons.

Table 13 – Mean hardness values and expanded uncertainties.

	HBW 5/750/15		HBW 10/3000/15	
Institutes	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)
VNIIFTRI	220,7	1,6	217,8	1,6
KAZINMETR	218,6	1,5	218	0,7
BELGIM	-	-	219,2	1,9
NSC IM	219,5	3,2	220,2	1,6
Reference value	219,6	1,0	218,4	0,6

Table 14 shows mean values of hardness measurements and expanded uncertainties of the measurement results for hardness level 400 HBW. The table also shows the reference values of the comparisons and the expanded uncertainties of the reference values of the comparisons.

Table 14 – Mean hardness values and expanded uncertainties.

	HBW 5/750/15		HBW 10/3000/15	
Institutes	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)
VNIIFTRI	422,0	2,8	426,8	3,1
KAZINMETR	423,9	2,4	428,2	1,7
BELGIM	-	-	426,3	3,5
NSC IM	422,9	2,8	430,5	2,5
Reference value	423,0	1,5	428,3	1,2

In fig.2-7 mean values of the measurements are shown by a red square highlighter. Expanded uncertainties are shown by black vertical lines. The length of lines equals 2U. The red horizontal line shows the reference value of comparisons. The blue dashed line shows the expanded uncertainty of reference value.

Fig. 2 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 100 HBW 5/250/15.

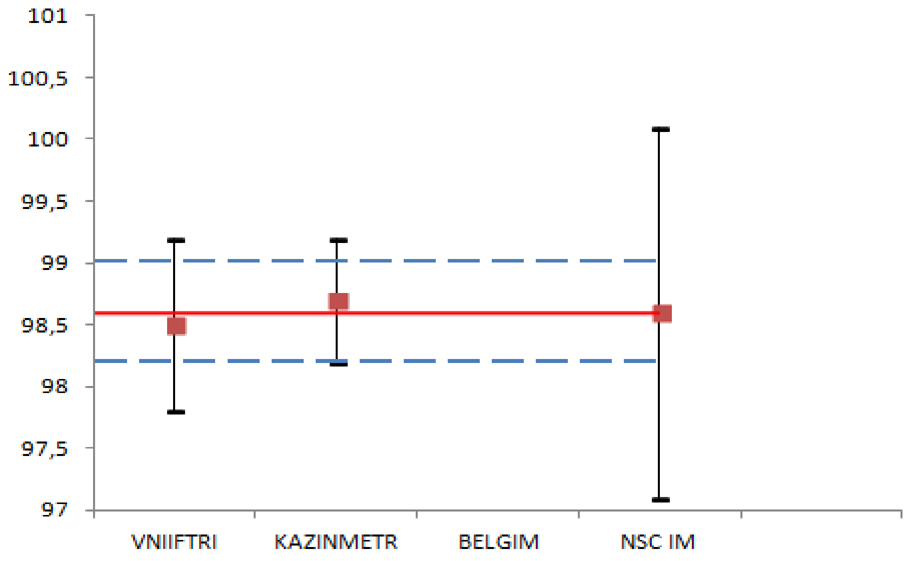

Fig. 2 Comparisons results for hardness level 100 HBW 5/250/15

Fig. 3 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 200 HBW 5/750/15.

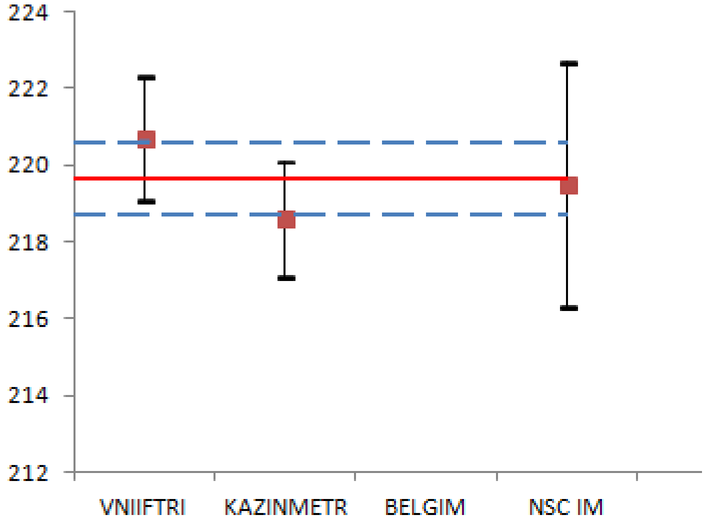

Fig. 3 Comparisons results for hardness level 200 HBW 5/750/15

Fig. 4 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 400 HBW 5/750/15.

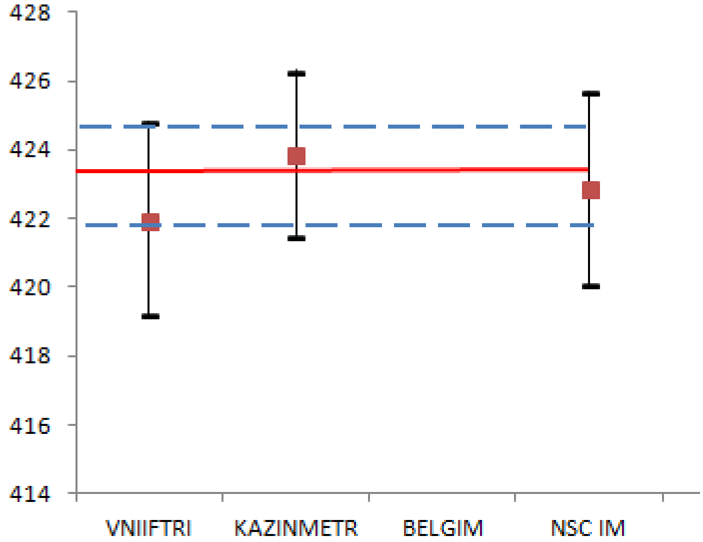

Fig. 4 Comparisons results for hardness level 400 HBW 5/750/15

Fig. 5 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 100 HBW 10/1000/15.

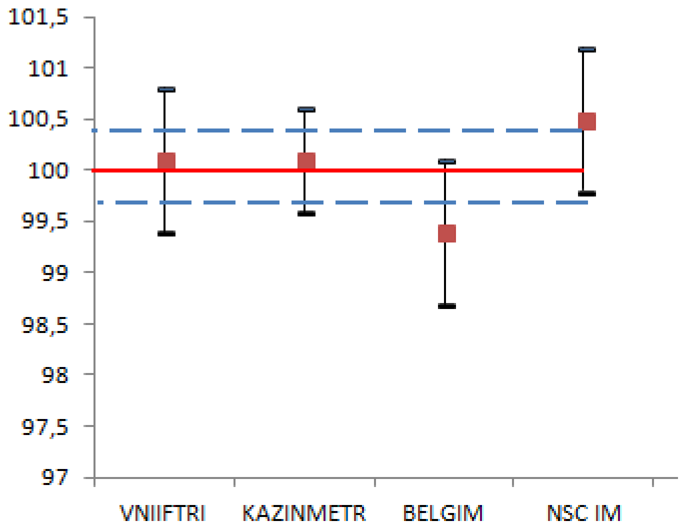

Fig. 5 Comparisons results for hardness level 100 HBW 10/1000/15

Fig. 6 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 200 HBW 10/3000/15.

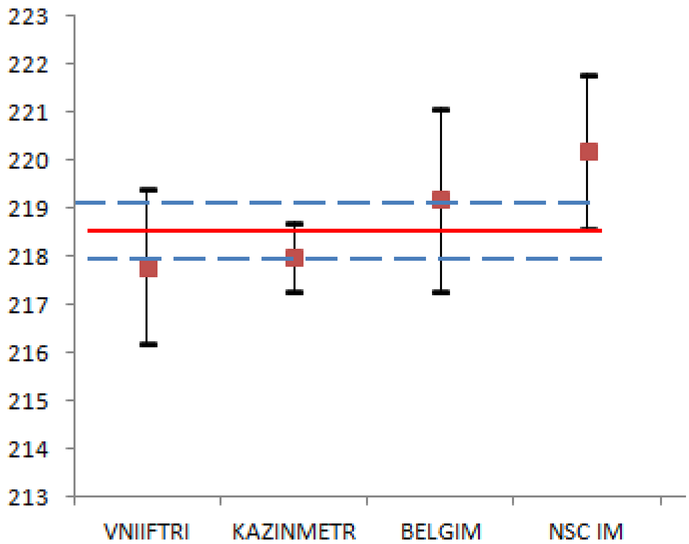

Fig.6 Comparisons results for hardness level 200 HBW 10/3000/15

Fig. 7 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 400 HBW 10/3000/15.

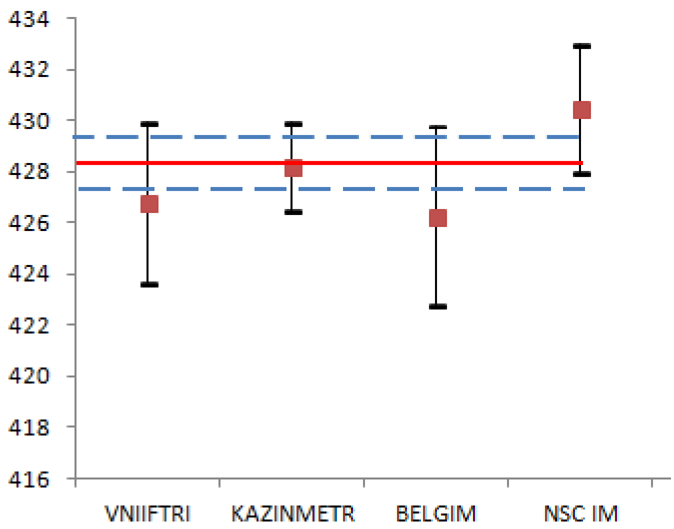

Fig. 7 Comparisons results for hardness level 400 HBW 10/3000/15

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

To check the correlation of the results of comparisons for each level of hardness and each scale, a coefficient was determined χ

$$\chi = \sqrt{\sum_{i=1}^{n} \frac{(x_i - X_{ref})^2}{u^2(x_i)}}$$

The results of the comparisons are considered correlated if the coefficient value χ lower then critical value χ, calculated for n-1 degree of freedom and a confidence level of 0.95. The En criterion is calculated by the formula:

$$E_n = \frac{|x_i - X_{ref}|}{2\sqrt{u^2(x_i) - u^2(X_{ref})}}$$

If En <1 and the results of comparisons of the i-th participant are included in the set of agreed, then the minimum standard uncertainty that can be stated in the CMC lines is equal to the standard uncertainty of measurements of the i-th participant in comparisons. If En >1 and the results of comparisons of the i-th participant are included in the set of agreed, then the minimum standard uncertainty of measurements, which can be stated in the CMC lines, is calculated by the following formula [3]:

$$u_{CMC} = \sqrt{\frac{(x_i - X_{ref})^2}{4} + u^2(X_{ref})}$$

Tables 15-18 present the En criteria and the minimum extended uncertainties that can be declared in the CMC rows by the participants of the comparisons for each hardness level and each scale.

Table 15 – Results of measurements for VNIIFTRI

Reference value	Scale	Correlation criterion (χ^2)	Critical criterion for n-1 degrees of freedom and confidence level 0,95 (χ^2_{n-1})	Criterion E_n	The minimum expanded uncertainty for CMC lines HBW
98,6	HBW 5/250/15	0,22	5,99	0,22	0,7
220	HBW 5/750/15	3,67	5,99	0,92	1,6
423	HBW 5/750/15	1,08	5,99	0,44	2,8
100	HBW 10/1000/15	5,16	7,81	0,1	0,7
218	HBW 10/3000/15	7,62	7,81	0,37	1,6
428	HBW 10/3000/15	5,35	7,81	0,52	3,1

Table 16 – Results of measurements for KAZINMETR

Reference value	Scale	Correlation criterion (χ^2)	Critical criterion for n-1 degrees of freedom and confidence level 0,95 (χ^2_{n-1})	Criterion E_n	The minimum expanded uncertainty for CMC lines HBW
98,6	HBW 5/250/15	0,22	5,99	0,23	0,5
220	HBW 5/750/15	3,67	5,99	0,9	1,5
423	HBW 5/750/15	1,12	5,99	0,47	2,4
100	HBW 10/1000/15	5,16	7,81	0,16	0,5
218	HBW 10/3000/15	7,62	7,81	0,88	0,7
428	HBW 10/3000/15	5,35	7,81	0,08	1,7

Table 17 – Results of measurements for BELGIM

Reference value	Scale	Correlation criterion (χ^2)	Critical criterion for n-1 degrees of freedom and confidence level 0,95 (χ^2_{n-1})	Criterion E_n	The minimum expanded uncertainty for CMC lines HBW
98,6	HBW 5/250/15	-	-	-	-
220	HBW 5/750/15	-	-	-	-
423	HBW 5/750/15	-	-	-	-
100	HBW 10/1000/15	5,16	7,81	1,02	0,7
218	HBW 10/3000/15	7,62	7,81	0,46	1,9
428	HBW 10/3000/15	5,35	7,81	0,61	3,5

Table 18 – Results of measurements for NSC IM

Reference value	Scale	Correlation criterion (χ^2)	Critical criterion for n-1 degrees of freedom and confidence level 0,95 (χ^2_{n-1})	Criterion E_n	The minimum expanded uncertainty for CMC lines HBW
98,6	HBW 5/250/15	0,22	5,99	0,02	0,7
220	HBW 5/750/15	3,67	5,99	0,02	1,6
423	HBW 5/750/15	1,12	5,99	0,06	2,7
100	HBW 10/1000/15	5,16	7,81	0,74	0,7
218	HBW 10/3000/15	7,62	7,81	1,23	1,9
428	HBW 10/3000/15	5,35	7,81	1,005	2,5

10. Discussions, conclusions and remarks

The COOMET.M.H- S4. comparison can be considered as a successful metrological exercise. At present Brinell hardness reference blocks with high time-dependent stability and high local homogeneity, including high surface quality are available.

The results of the hardness measurements according to Brinell in different institutions correlated with each other. There are three cases where $E_n > 1$ (one case is for BELGIM measurements, two cases are for NSC IM measurements), but, nevertheless, results of measurements are correlated with each other, because $\chi^2 < \chi^2_{n-1}$ (for confidence level 0,95). The minimum standard uncertainties of measurements for CMC lines calculated by formula:

$$u_{CMC} = \sqrt{\frac{\left(x_i - X_{ref}\right)^2}{4} + u^2(X_{ref})}$$

only for cases with $E_n > 1$, and in other cases the minimum standard uncertainties of measurements for CMC lines calculated by formulas from cl. 9.1 of this Report.

Comparisons of national primary hardness standards on Brinell scales were carried out successfully and at a high level. Based on the results of the comparisons, the CMC values for the laboratories participating in the comparisons should be approved. The minimum expanded uncertainty of measurements for CMC lines were given in tables 15 – 18.

11. References

[1] T. J. Quinn, Guidelines for key comparisons carried out by Consultative Committees, BIPM, Paris.

[2] EA Working group Hardness; Draft: Guideline to the estimation of the uncertainty of the Brinell and the Vickers measuring method, July 2002.

[3] COOMET R/GM/19:2016

Description of the instruments by the participants

VNIIFTRI

Instrument

Device type	Deadweight Brinell hardness machine National primary hardness standard machine manufacturer «Etalon», St. Petersburg
Indenter	Tungsten ball with diameter 5 mm and 10 mm

Instruments used to measure the indentations:
Microscope with a nominal division of the scale equal to 0,1 μm with the numerical aperture of the objective 0,2; total magnification 30x – 50x

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements		
	Δx_F(N)	Δx_l (mm)	D (mm)
HBW 5/250/15	0,137	0,001	5
HBW 5/750/15	0,196	0,001	5
HBW 10/1000/15	0,235	0,001	10
HBW 10/3000/15	0,892	0,001	10

KAZINMETR

Instrument

Device type	Calibration machine manufacturer Foundrax Engineering Products Ltd, UK
Indenter	Tungsten ball with diameter 5 mm and 10 mm

Instruments used to measure the indentations:
Microscope with a nominal division of the scale equal to 0,1 μm with the numerical aperture of the objective 0,25, total magnification 100x;

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements		
	Δx_F(N)	Δx_l (mm)	D (mm)
HBW 5/250/15	2,948	0,002	5
HBW 5/750/15	8,736	0,002 - 0,004	5
HBW 10/1000/15	11,366	0,003	10
HBW 10/3000/15	33,557	0,004	10

BELGIM

Device type	Brinell hardness tester NB3010 Manufactured by Indentec Ltd, UK
Indenter	Tungsten ball with diameter 10 mm

Instruments used to measure the indentations:
Microscope with a nominal division of the scale equal to 10 µm with the numerical aperture of the objective 0,6, total magnification 50x;

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements		
	Δx_F(N)	Δx_l (mm)	D (mm)
HBW 10/1000/15	19,613	0,01	10
HBW 10/3000/15	58,839	0,01	10

NSC IM

Instrument

Device type	National primary hardness standard machine for Brinell scales «DETU 02-03-99» manufacturer NSC IM, Ukraine
Indenter	Tungsten ball with diameter 5 mm and 10 mm

Instruments used to measure the indentations:
Microscope with a nominal division of the scale equal to 1 µm with the numerical aperture of the objective 4,2; total magnification 50x

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements		
	Δx_F(N)	Δx_l (mm)	D (mm)
HBW 5/250/15	1,962	0,001	5
HBW 5/750/15	7,357	0,001	5
HBW 10/1000/15	8,829	0,001	10
HBW 10/3000/15	11,772	0,001	10

Uncertainty budgets of the participants based on a unified procedure

VNIIFTRI; hardness level 100 HBW 5/250/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**2451,60**	0,137	6,3E-03	0,0402	1,0E-05	10	1,0E-11
Indentation diameter length	***d***	mm	**1,7682**	0,005	8,3E-06	-115,3	1,1E-01	30	4,1E-04
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-115,3	4,4E-03	30	6,5E-07
Diameter of indenter	*D*	mm	5	0,00021	1,5E-08	1,362	2,7E-08	9	8,3E-17
Force applying time	*ta*	s	5	0,5	8,3E-02	0,0863	6,2E-04	9	4,3E-08
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1411	1,7E-03	9	3,1E-07
Total							1,2E-01		4,1E-04
Combined standard uncertainty *u (H)*							3,4E-01	ν_{eff}	33
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**0,7**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,7**	**%**	
Hardness	**98,5**	**HBW**							

KAZINMETR; hardness level 100 HBW 5/250/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**2451,60**	2,948	2,9E+00	0,0403	4,7E-03	10	2,2E-06
Indentation diameter length	***d***	mm	**1,7669**	0,0021	1,5E-06	-115,6	2,0E-02	30	1,3E-05
Diameter measuring system	*Rms*	mm		0,002	2,0E-06	-115,6	2,6E-02	30	2,3E-05
Diameter of indenter	*D*	mm	5	0,00200	1,3E-06	1,361	2,5E-06	9	6,8E-13
Force applying time	*ta*	s	5	0,5	8,3E-02	0,0863	6,2E-04	9	4,3E-08
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1410	1,7E-03	9	3,1E-07
Total							5,3E-02		3,8E-05
Combined standard uncertainty *u (H)*							2,3E-01	ν_{eff}	72
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**0,5**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,5**	**%**	
Hardness	**98,7**	**HBW**							

NSC IM; hardness level 100 HBW 5/250/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**2451,60**	1,962	1,3E+00	0,0402	2,1E-03	10	4,3E-07
Indentation diameter length	***d***	mm	**1,7675**	0,011	4,0E-05	-115,5	5,4E-01	30	9,6E-03
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-115,5	4,4E-03	30	6,6E-07
Diameter of indenter	*D*	mm	5	0,00500	8,3E-06	1,361	1,5E-05	9	2,7E-11
Force applying time	*ta*	s	5	0,5	8,3E-02	0,0863	6,2E-04	9	4,3E-08
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1411	1,7E-03	9	3,1E-07
Total							5,5E-01		9,6E-03
Combined standard uncertainty *u (H)*							7,4E-01	ν_{eff}	30
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**1,5**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**1,5**	**%**	
Hardness	**98,6**	**HBW**							

VNIIFTRI; hardness level 200 HBW 5/750/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**7355,30**	0,196	1,3E-02	0,0300	1,2E-05	10	1,3E-11
Indentation diameter length	***d***	mm	**2,0347**	0,006	1,2E-05	-227,3	6,2E-01	30	1,3E-02
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-227,3	1,7E-02	30	9,9E-06
Diameter of indenter	*D*	mm	5	0,00021	1,5E-08	4,183	2,6E-07	9	7,4E-15
Force applying time	*ta*	s	5	0,5	8,3E-02	0,1128	1,1E-03	9	1,3E-07
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1233	1,3E-03	9	1,8E-07
Total							6,4E-01		1,3E-02
Combined standard uncertainty *u (H)*							8,0E-01	ν_{eff}	31
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**1,6**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,7**	**%**	
Hardness	**220,7**	**HBW**							

KAZINMETR; hardness level 200 HBW 5/750/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**7355,30**	8,736	2,5E+01	0,0297	2,2E-02	10	5,1E-05
Indentation diameter length	***d***	mm	**2,0440**	0,0037	4,6E-06	-224,2	2,3E-01	30	1,8E-03
Diameter measuring system	*Rms*	mm		0,004	5,8E-06	-224,2	2,9E-01	30	2,8E-03
Diameter of indenter	*D*	mm	5	0,00200	1,3E-06	4,187	2,3E-05	9	6,1E-11
Force applying time	*ta*	s	5	0,5	8,3E-02	0,1124	1,1E-03	9	1,2E-07
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1236	1,3E-03	9	1,8E-07
Total							5,5E-01		4,6E-03
Combined standard uncertainty *u (H)*							7,4E-01	ν_{eff}	64
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**1,5**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,7**	**%**	
Hardness	**218,6**	**HBW**							

NSC IM; hardness level 200 HBW 5/750/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**7355,30**	7,357	1,8E+01	0,0298	1,6E-02	10	2,6E-05
Indentation diameter length	***d***	mm	**2,0401**	0,012	4,8E-05	-225,5	2,4E+00	30	2,0E-01
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-225,5	1,7E-02	30	9,6E-06
Diameter of indenter	*D*	mm	5	0,00500	8,3E-06	4,185	1,5E-04	9	2,4E-09
Force applying time	*ta*	s	5	0,5	8,3E-02	0,1126	1,1E-03	9	1,2E-07
Force duration time	*td*	s	15	0,5	8,3E-02	-0,1235	1,3E-03	9	1,8E-07
Total							2,5E+00		2,0E-01
Combined standard uncertainty *u (H)*							1,6E+00	ν_{eff}	30
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**3,2**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**1,5**	**%**	
Hardness	**219,5**	**HBW**							

VNIIFTRI; hardness level 400 HBW 5/750/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**7355,30**	0,196	1,3E-02	0,0574	4,2E-05	10	1,8E-10
Indentation diameter length	***d***	mm	**1,4874**	0,004	5,3E-06	-580,9	1,8E+00	30	1,1E-01
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-580,9	1,1E-01	30	4,2E-04
Diameter of indenter	*D*	mm	5	0,00021	1,5E-08	4,002	2,4E-07	9	6,2E-15
Force applying time	*ta*	s	5	0,5	8,3E-02	0,1566	2,0E-03	9	4,6E-07
Force duration time	*td*	s	15	0,5	8,3E-02	-0,0940	7,4E-04	9	6,0E-08
Total							1,9E+00		1,1E-01
Combined standard uncertainty *u (H)*							1,4E+00	ν_{eff}	33
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**2,8**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,7**	**%**	
Hardness	**422,0**	**HBW**							

KAZINMETR; hardness level 400 HBW 5/750/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**7355,30**	8,736	2,5E+01	0,0576	8,5E-02	10	7,1E-04
Indentation diameter length	***d***	mm	**1,4841**	0,0026	2,3E-06	-584,8	7,7E-01	30	2,0E-02
Diameter measuring system	*Rms*	mm		0,002	1,8E-06	-584,8	6,2E-01	30	1,3E-02
Diameter of indenter	*D*	mm	5	0,00200	1,3E-06	4,001	2,1E-05	9	5,1E-11
Force applying time	*ta*	s	5	0,5	8,3E-02	0,1570	2,1E-03	9	4,7E-07
Force duration time	*td*	s	15	0,5	8,3E-02	-0,0938	7,3E-04	9	6,0E-08
Total							1,5E+00		3,3E-02
Combined standard uncertainty *u (H)*							1,2E+00	ν_{eff}	65
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**2,4**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,6**	**%**	
Hardness	**423,9**	**HBW**							

NSC IM; hardness level 400 HBW 5/750/15

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	$u^2(x_i)$	c_i	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**7355,30**	7,357	1,8E+01	0,0575	6,0E-02	10	3,6E-04
Indentation diameter length	***d***	mm	**1,4858**	0,004	5,1E-06	-582,8	1,7E+00	30	9,9E-02
Diameter measuring system	*Rms*	mm		0,001	3,3E-07	-582,8	1,1E-01	30	4,3E-04
Diameter of indenter	*D*	mm	5	0,00500	8,3E-06	4,002	1,3E-04	9	2,0E-09
Force applying time	*ta*	s	5	0,5	8,3E-02	0,1568	2,0E-03	9	4,7E-07
Force duration time	*td*	s	15	0,5	8,3E-02	-0,0939	7,3E-04	9	6,0E-08
Total							1,9E+00		1,0E-01
Combined standard uncertainty *u (H)*							1,4E+00	ν_{eff}	36
Confidence level							95%		
Coverage factor							2,0		
Expanded standard uncertainty *U (H)*							**2,8**	**HBW**	
Relative Expanded standard uncertainty $U_{rel}(H)$							**0,7**	**%**	
Hardness	**422,9**	**HBW**							