Final Report
On RMO VICKERS KEY COMPARISON
COOMET M.H-K1

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Abstract

This report describes a COOMET key comparison on Vickers hardness scales of five National Metrology Institutes – PTB (Germany), BELGIM (Byelorussia), NSC IM (Ukraine), KAZINMETR (Kazakhstan) and VNIIFTRI (Russia). The pilot laboratory was VNIIFTRI. PTB was the linking institute with KCRV CCM.H-K1b and CCM.H-K1c for the Vickers hardness scales HV1 and HV30 accordingly. Comparison were also conducted for the HV5 Vickers hardness scale, since this scale is most frequently used in practice in Russia and CIS countries that work according to GOST standards. In the key comparison two sets of hardness reference blocks for the Vickers hardness scales HV1, HV5 and HV30 consisting each of three hardness reference blocks with the hardness levels of 450 HV and 750 HV are used.The measurement results and uncertainty assessments for HV1 and HV30 hardness scales, announced by BELGIM, NSC IM, KAZINMETR and VNIIFTRI are in good coordination with the key comparisons reference values of CCM.H-K1b and CCM.H-K1c. The comparison results for HV5 hardness scale are viewed as additional information, since up to today CCM key comparisons on this scale haven't been carried out.

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Content

1 Introduction

The present key comparisons of Vickers hardness scales were organized by the Regional Metrology Organization COOMET and registered in CIPM under the cipher COOMET.M.H- K1. This regional comparison between hardness laboratories of national metrological institutes of Germany, Ukraine, Byelorussia, Kazakhstan and Russia is connected with the main comparison CCM.H-K1b and CCM.H-K1c.

2 Organization

In March 2005 during TC 1.6 COOMET meeting (Vilnius, Lithuania) it was decided to entrust the organization of the comparisons on Vickers 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. Physikalisch - Technische Bundesanstalt (PTB, Germany) was assigned the linking institute to the main comparisons CCM.H-K1b and CCM.H-K1c.

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 March 2009.

2.1 Participants

The list of participants is given in Table 1.

Table 1: Participants of comparisons

Abbreviation	Institute	Contact person	Contacts
BELGIM, Byelorussia	Byelorussian 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	kf_kazinmetr@mail.ru Tel: +32 8321 244-22-63 Fax: +32 8321 244-22-63
PTB , Germany	Physikalisch-Technische Bundesanstalt	Febo Menelao, Konrad Herrmann	Febo.Menelao@ptb.de Konrad.Herrmann@ptb.de Tel: +49 531 592 5140 Fax: +49 531 592 5105
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	aslanyan@vniiftri.ru Tel: :+7 495 526-6318 Fax: +7 495 526-6341

2.2 Time 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
PTB	12.2008
VNIIFTRI	03.2009

3 Standards

3.1 Description

In the key comparison two sets of hardness reference blocks for the Vickers hardness scales HV1, HV5 and HV30 consisting each of three hardness reference blocks with the hardness levels of 450 HV and 750 HV (that is altogether six blocks) are used. The dimensions are as follows: length 60 mm, width 40 mm, thickness 10 mm. The upper side of the blocks which is the measurement surface is finished. The blocks are manufactured as commercial products by Centre «MET» LLC, Russia. For the comparison on the hardness reference blocks a grid with 5 x 8 = 40 fields was engraved on the measurement surface. In order to define coordinates of the fields, at the left and the upper edge of the blocks there is an engraving of numbers from 1 to 5 correspondingly and from 1 to 8. The direction along the upper edge of the blocks defines the X-direction (lines), the direction along the left edge of the blocks defines the Y-direction (rows) (see Fig. 1).

	1	2	3	4	5	6	7	8
1								
2								
3								
4								
5								

Fig. 1: Layout of the grid on the measurement surface of the hardness blocks

3.2 Handling

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

4 Measurand

The measurands used in this comparison were of two kinds. First, the mean value of each of six hardness measurements on a hardness reference block had to be determined. The hardness measurements were made on hardness scales HV1, HV5 and HV30 each for the nominal hardness levels of 450 HV and 750 HV. The procedure of the hardness measurement is defined in ISO 6507-1 and -3. Secondly, the mean diagonal length of six reference indents had to be determined according to ISO 6507-1 and -3. The reference indents represent indents for the hardness levels of 450 HV and 750 HV, each for Vickers scales HV1, HV5 and HV30.

5 Methods of measurement

The methods of measurement and the measuring devices used 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, HV	Result at the begin. (1), HV	Result at the end (2) , HV	Diff. Δ_{2-1}, HV	Meas. Unc. U, HV	$\lvert\Delta_{2-1}\rvert$/ U, HV
450 HV1	485,1	484,8	-0,3	13,6	0,02
750 HV1	735,0	732,6	-2,4	17,6	0,14
450 HV5	480,5	479,3	-1,2	8,7	0,14
750 HV5	726,9	732,5	+5,6	16,4	0,34
450 HV30	474,1	475,1	+1,0	6,1	0,16
750 HV30	717,6	720,6	+3,0	11,3	0,27

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 $\lvert\Delta_{2-1}\rvert/U > 1$, 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 the value equals $\lvert\Delta_{2-1}\rvert/U <1$, the drift of the test blocks does 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.

7 Measurement results

In the following tables 4 and 5 the results for the hardness reference blocks with hardness levels of 450 HV and 750 HV 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 4: Results of the measurements for the hardness reference blocks with hardness level 450 HV

	HV1		HV5		HV30	
Institute	**Mean value**	**Std.dev .**	**Mean value**	**Std. dev.**	**Mean value .**	**Std. dev.**
VNIIFTRI	484,8	0,6	479,3	0,9	475,1	1,2
PTB	486,0	2,5	477,7	1,1	476,1	2,9
KAZINMETR	486,8	1,3	476,4	0,9	479,8	1,1
BELGIM	-	-	478,9	2,7	472,0	1,1

NSC IM	-	-	484,4	1,6	476,8	2,2
Mean value	485,7		479,3		476,0	
Std.dev	1,0		3,1		2,8	

Table 5: Results of the measurements for the hardness reference blocks with hardness level 750 HV

	HV1		HV5		HV30	
Institute	**Mean value**	**Std.dev .**	**Mean value**	**Std. dev.**	**Mean value .**	**Std. dev.**
VNIIFTRI	732,56	2,0	732,14	1,3	720,5	2,6
PTB	741,5	2,7	736,0	3,1	719,5	2,7
KAZINMETR	727,7	1,3	729,4	3,6	732,9	2,2
BELGIM	-	-	718,7	2,0	717,1	2,7
NSC IM	-	-	718,68	5,2	728,0	3,5
Mean value	733,9		727,0		723,6	
Std. dev	7,0		7,9		6,6	

8 Uncertainty budgets

8.1 Calculation scheme

The calculation of uncertainty for all the participants was carried out according to a unified procedure suggested in the main comparisons CCM.H-K1b and CCM.H-K1c [3] and which was already used in RMO comparison COOMET.M.H- K1b and COOMET.M.H- K1c [4].

. The calculation scheme can be seen from the example in Table 6.

Table 6: Calculation scheme for the unified estimation of the measurement uncertainty

Influencing quantity X_i	**Symbol**	**Unit**	**Value**	**Δx_i**	**s_i**	**a_i**	**$u^2(x_i)$**	**c_i**	**ΔH**	**$u^2(y_i)$**	**ν_i**	**$u_i^4(y)/\nu_i$**
Test force F	***F***	N	**1,96**	0,000		9,80E-03	3,2E-05	1,3E+02	0,0E+00	5,1E-01	8	3,3E-02
Indentation diagonal length	***d***	mm	**0,039**	0		0,0004	5,3E-08	-1,3E+04	0,0E+00	8,7E+00	9	8,5E+00
Plane angle α	α	°	136	-8,7E-04		0,00175	1,0E-06	5,0E+01	-4,4E-02	2,5E-03	10	6,4E-07
Tip radius Δr	*r*	mm		3,0E-04		1,0E-04	3,3E-09	-7,1E+03	-2,1E+00	1,7E-01	10	2,8E-03
Length of line of junction Δc	*c*	mm		4,0E-04		1,0E-04	3,3E-09	9,0E+03	3,6E+00	2,7E-01	10	7,1E-03
Total									**1,41**	9,7E+00		8,5E+00
Combined standard uncertainty *u (H)*										3,1E+00	ν_{eff}	11
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**6,8**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**8,3**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**3,3**	**%**	
Hardness	**247,5**	**HV**										

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:

$$u^2(x_i) = s_i^2 \vee \frac{a_i^2}{3} \qquad (1)$$

Sensitivity coefficients:

$$c_1 = \frac{\partial HV}{\partial F} = \frac{0{,}204 \cdot \sin\alpha/2}{d^2}$$
$$c_2 = \frac{\partial HV}{\partial d} = \frac{-0{,}408 \cdot F \cdot \sin\alpha/2}{d^3}$$
$$c_3 = \frac{\partial HV}{\partial \alpha} = \frac{0{,}102 \cdot F \cdot \cos\alpha/2}{d^2} \qquad (2)$$
$$c_4 = \frac{\partial HV}{\partial r} = \frac{-0{,}204 \cdot F \cdot \sin\alpha/2}{d^3} \cdot (1{,}099 + 1{,}1515 \cdot \frac{r}{d})$$
$$c_5 = \frac{\partial HV}{\partial c} = \frac{0{,}2856 \cdot F \cdot \sin\alpha/2}{d^3}$$

Single hardness deviation:

$$\Delta H_i = c_i \cdot \Delta x_i \qquad (3)$$

Variances:

$$u^2(y_i) = c_i^2 u^2(x_i) \qquad (4)$$

Combined standard uncertainty:

$$u(H) = \sqrt{\sum_{i=1}^{n} u^2(y_i)} \qquad (5)$$

Sum of hardness deviations:

$$\Delta H = \sum_{i=1}^{n} \Delta H_i \qquad (6)$$

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

$$\nu_{eff} = \frac{u^4(y)}{\sum_{i=1}^{\nu} \frac{u_i^4(y)}{\nu_i}} \qquad (7)$$

Coverage factor:

$$k = f(\nu_{eff}, P) \qquad (8)$$

Expanded standard uncertainty:

$$U(H) = k \cdot u(H) + |\Delta H| \qquad (9)$$

Relative expanded standard uncertainty:

$$U_{rel}(H) = \frac{U(H)}{H} \cdot 100, \% \qquad (10)$$

According to this unified procedure for the estimation of measurement uncertainty, the following measurement uncertainties for the participants were received. If the participants had omitted the indenter tip radius because they did not have the facility to measure it, a value of r = 0,5 µm with an uncertainty of 0,2 µm would be set in.

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 Brinell and the Vickers measuring method was recommended [2].

The uncertainty budgets of the participants based on a unified procedure as presented in ch. 8.1 appear in Appendix B. Table 7 shows mean values of hardness measurements and expanded uncertainties of the measurement results for hardness level 450 HV.

Table 7: Mean hardness values and expanded uncertainties.

	HV1		HV5		HV30	
Institutes	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)
VNIIFTRI	484,8	13,6	479,3	8,7	475,1	6,1
PTB	486,0	10,0	477,7	7,0	476,1	4,3
KAZINMETR	486,8	6,9	476,4	5,9	479,8	4,1
BELGIM	-	-	478,9	4,8	472,0	5,3
NSC IM	-	-	484,4	2,6	476,8	2,2

Table 8 shows mean values of hardness measurements and expanded uncertainties of the measurement results for hardness level 750 HV.

Table 8: Mean hardness values and expanded uncertainties.

	HV1		HV5		HV30	
Institutes	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)	Mean value	Expanded uncertainty (U)
VNIIFTRI	732,56	17,6	732,14	16,4	720,5	11,3
PTB	741,5	15,2	736,0	13,5	719,5	8,0
KAZINMETR	727,7	12,4	729,4	10,9	732,9	7,7
BELGIM	-	-	718,7	7,9	717,1	8,1
NSC IM	-	-	718,68	4,6	728,0	4,0

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. A black horizontal line shows hardness mean value for the participants. Fig. 2 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 450 HV1.

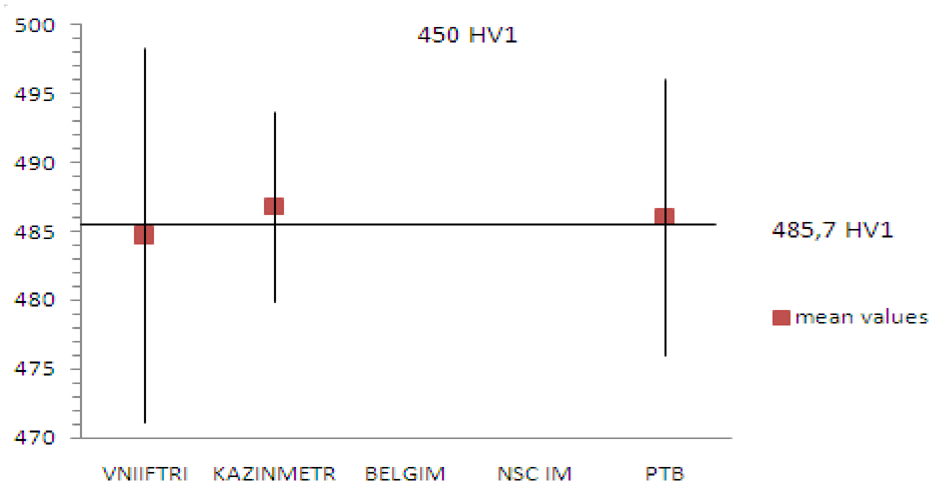

Fig. 2 Comparisons results for hardness level 450 HV1

Fig. 3 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 450 HV5.

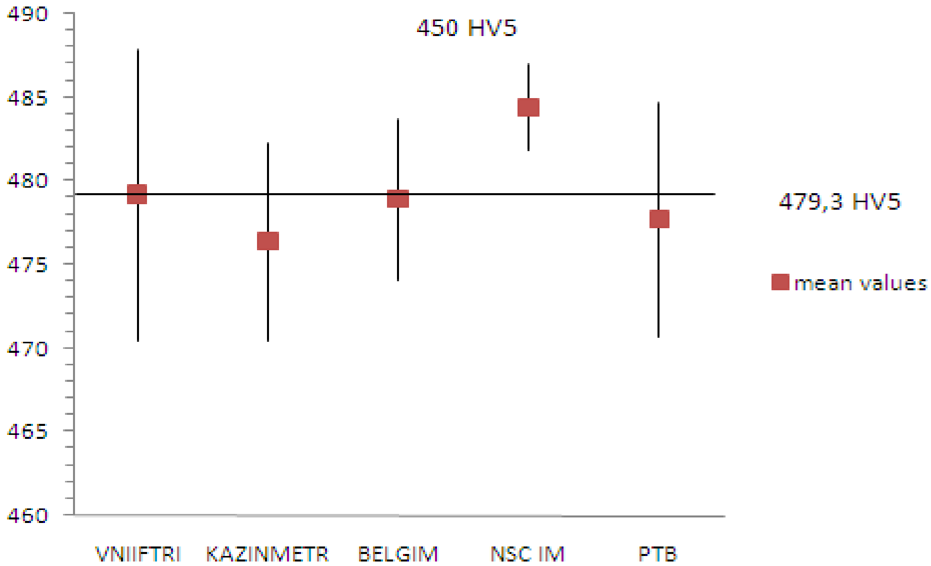

Fig. 3 Comparisons results for hardness level 450 HV5

Fig. 4 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 450 HV30.

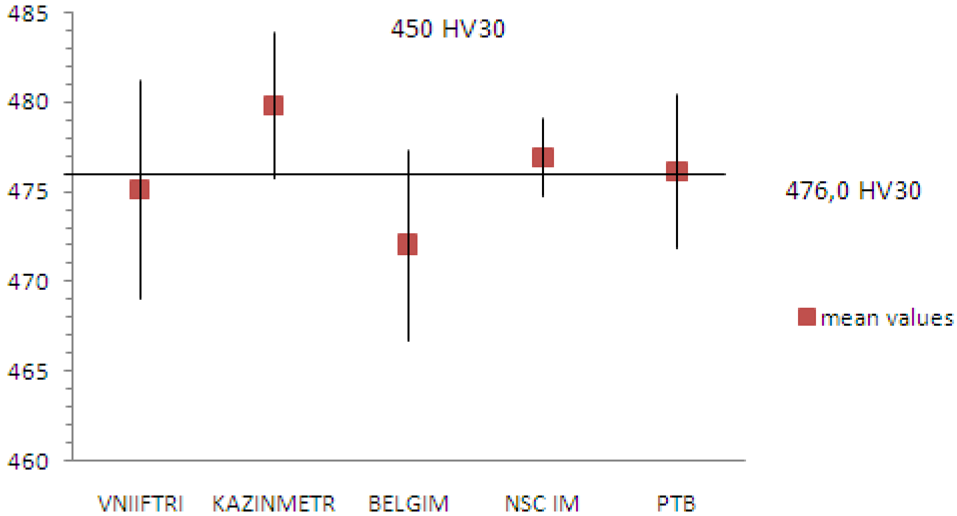

Fig. 4 Comparisons results for hardness level 450 HV30

Fig. 5 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 750 HV5.

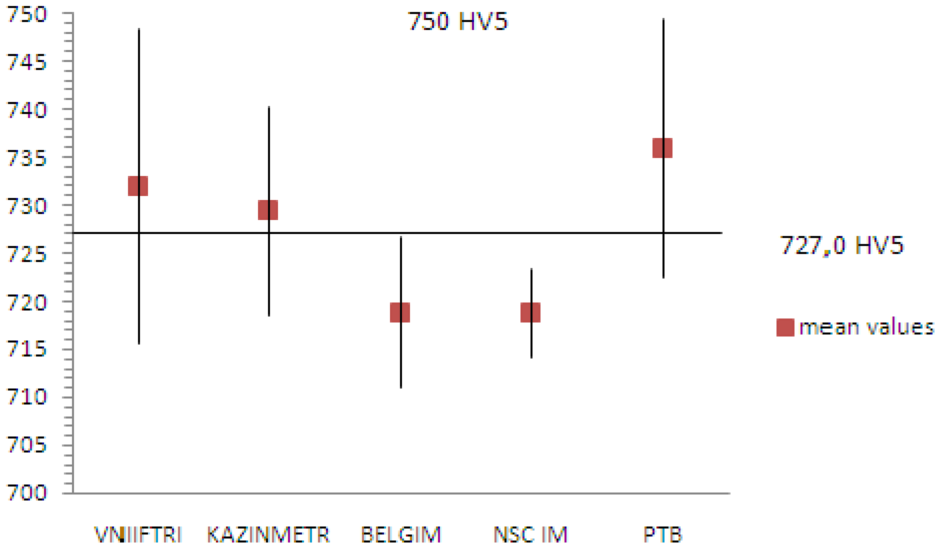

Fig. 5 Comparisons results for hardness level 750 HV5

Fig. 6 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 750 HV1.

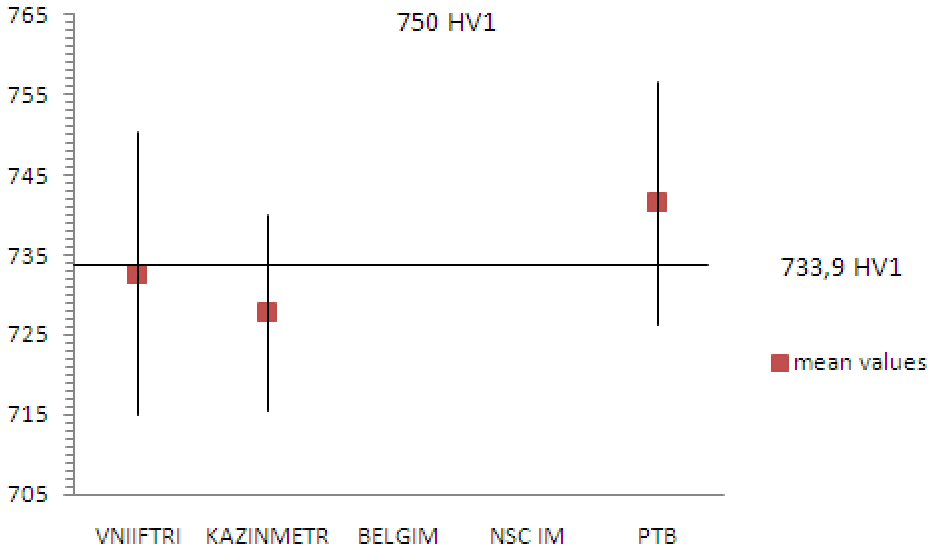

Fig.6 Comparisons results for hardness level 750 HV1

Fig. 7 shows mean values and expanded uncertainties of hardness measurement results by national laboratories for level 750 HV30.

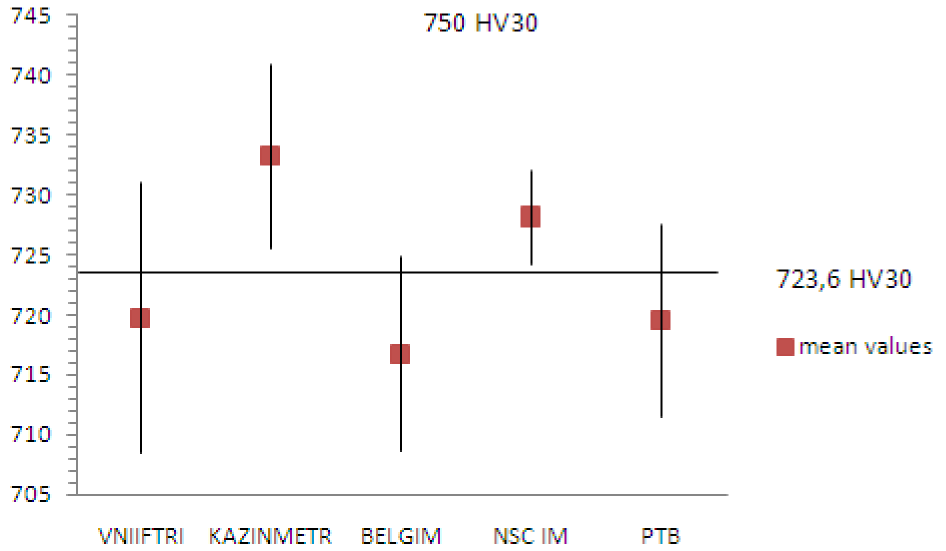

Fig. 7 Comparisons results for hardness level 750 HV30

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

9 Degree of equivalence of the participants relatively to CCM.H-K1b and CCM.H-K1c Vickers key comparisons

Table 9 shows the degree of equivalence results for Vickers VNIIFTRI, NSC IM, BELGIM, KAZINMETR primary machines in relation to the calculation of equivalence degree performed at [5].

A detailed calculation of equivalence levels and uncertainties of these degrees is described in Appendix C.

Table 9: Degrees of equivalence of primary machines of the countries participating in comparisons to the results of CCM.H-K1b and CCM.H-K1c key comparisons and uncertainties of calculating equivalence degrees.

Hardness test block	Institutes							
	VNIIFTRI		KAZINMETR		BELGIM		NSC IM	
	d	U_d	d	U_d	d	U_d	d	U_d
450 HV1	2,2	8,8	4,2	7,3	-	-	-	-
750 HV1	-4,5	18,3	-9,4	17,7	-	-	-	-
450 HV30	-3,6	5,4	1,0	5,0	-6,9	5,2	-1,9	4,8
750 HV30	-0,5	11,9	11,9	11,3	-3,9	11,4	7,0	11,0

Here d – degree of equivalence of hardness measurement results on Vickers scales by national primary machines to the reference value of key comparisons (KCRV) of CCM Vickers KC 2003 (CCM.H-K1b and CCM.H-K1c) [3], U_d – uncertainties of these degrees of equivalences.

If $|d| < 2U_d$, then uncertainty estimates stated by metrological institutes correlate with the comparisons data. Table 9 illustrates that the stated measurement uncertainties of all the participants correlate with the comparisons data.

Appendix C shows the calculation of equivalence degrees and uncertainties of these degrees, as well as pairwise equivalence degrees and their uncertainties.

10 Conclusions

The COOMET.M.H- K1 comparison can be considered as a successful metrological exercise.

The current comparisons for HV1 and HV30 scales contain KCRV from CCM.H-K1b and CCM.H–K1c accordingly.

The measurement results and uncertainty assessments for HV1 and HV30 hardness scales, announced by BELGIM, NSC IM, KAZINMETR and VNIIFTRI are in good coordination with the key comparisons reference values of CCM.H-K1b and CCM.H-K1c.

The comparison results for HV5 hardness scale are viewed as additional information, since up to today CCM key comparisons on this scale haven't been carried out.

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

11 Acknowledgments

The authors express their gratitude to all members of WGH CCM/CIPM for their helpful advice while working on the comparisons.

12 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] K. Herrmann “Final report on CCM Vickers key comparison.” Metrologia, 2006, 43, Tech. Suppl., 07010.

[4] E. Aslanyan, K. Herrmann “Final Report on COOMET Vickers PTB/VNIIFTRI Key Comparison. Metrologia, 2013, 50, Tech. Suppl., 07008.

[5] Guidelines for data evaluation of COOMET key comparison. COOMET R/GM/14, 2006.

Appendix A.

Description of the instruments by the participants

VNIIFTRI

Instrument

Device type	Indenter for measurements on HV scale
national primary hardness standard machine TPO-2 manufacturer «Etalon», St. Petersburg	Diamond pyramid № Tip 1170

Device type	Indenter for measurements on HV scale
national primary hardness standard machine TBO 2154 manufacturer «Tochpribor», Ivanovo	Diamond pyramid № Tip 1170

Instruments used to measure the indentations:
Microscope with a nominal division of the scale equal to 0,8 µ with the numerical aperture of the objective 0,17;
Microscope with a nominal division of the scale equal to 0,2 µ with the numerical aperture of the objective 0,65;

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements				
	a_F(N)	a_l (mm)	α (°)	c (µm)	r (µm)
HV1	0,015	0,0004-0,0006	135,98	0,5	0,5
HV5	0,017	0,0009	135,98	0,5	0,5
HV30	0,1	0,0016	135,98	0,5	0,5

PTB

Device type	Indenter for measurements on HV scale
Hardness standard machine VB 187,5 manufacturer PGH Kraftmessgeräte Halle/Saale”	Diamond pyramid

Device type	Indenter for measurements on HV scale
Hardness standard machine HMV 2000 (used for the scale HV 1) manufacturer Shimadzu Co	Diamond pyramid

Instruments used to measure the indentations:

Scale	Device	Magnification	Numerical aperture
240 HV1	HMV2000	500	0,75
540 HV1	HMV2000	500	0,75
840 HV1	HMV2000	500	0,75
240 HV30	Libra200 (Leitz)	100	0,20
540 HV30	Libra200 (Leitz)	100	0,20
840 HV30	Libra200 (Leitz)	100	0,20

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements				
	a_F (N)	a_l, (mm)	α (^{o})	c (μm)	r(μm)
HV1	0,0098	0,0003 - 0,0004	135,95^0	0,3	0,4
HV5	0,0255	0,0007	135,95^0	0,3	0,4
HV30	0,15	0,0011	135,95^0	0,3	0,4

NSC IM

Device type	Indenter for measurements on HV scale
The primary Vickers hardness machine DETU 02-03-99 manufacturer NSC "Institute of Metrology"	Diamond pyramid

Instruments used to measure the indentations:
A hardness tester microscope PMT-3 is used for the measurement of the diagonal length. Epi objective with F = 23,2 mm, numerical aperture 0,17. Epi objective with F = 6,2 mm, numerical aperture 0,65.

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements				
	S_F (N)	a_l, (mm)	α (^{o})	c (μm)	r(μm)
HV5	1×10^{-3}	0,00021	135,9	0,5	0,5
HV30	6×10^{-3}	0,00053	135,9	0,5	0,5

KAZINMETR

Device type	Indenter for measurements on HV scale
Vickers hardness tester 5030 TKV (2003), manufacturer Indentec Ltd, England	Diamond pyramid

Instruments used to measure the indentations:
Built-in integrated microscope with adjustable lighting:
objective magnification of 10x;
eyeglass magnification of 10x;
numerical aperture of 0,2;
resolution of 0,0001 mm.

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements				
	S_F(N)	a_l (mm)	α (°)	c (μm)	r (μm)
HV1	0,021	0,00025	136,05	0,5	0,5
HV5	0,045	0,00057	136,05	0,5	0,5
HV30	0,24	0,001	136,05	0,5	0,5

BELGIM

Device type	Indenter for measurements on HV scale
Vickers hardness tester ZHV30 № 063278/2006, manufacturer Indentec Ltd, England	Diamond pyramid № 06149

Instruments used to measure the indentations:
An optical microscope with the magnification and objective numerical aperture of 10×40

Scale	Results of measuring the main values influencing the uncertainty of hardness measurements				
	S_F (N)	a_l (mm)	α (^{o})	c (μm)	r (μm)
HV5	0,148	0,0003	136,08	0,5	0,5
HV30	1,28	0,0004	136,08	0,5	0,5

Appendix B.

Uncertainty budgets of the participants based on a unified procedure

VNIIFTRI; hardness level 450 HV1

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force F	**F**	N	**9,81**	0,000		1,50E-02	7,5E-05	4,9E+01	0,0E+00	1,8E-01	8	4,2E-03
Indentation diagonal length	**d**	mm	**0,062**	0		0,0006	1,2E-07	-1,6E+04	0,0E+00	2,9E+01	9	9,7E+01
Plane angle α	α	°	136	-5,8E-04		0,01	3,3E-05	9,8E+01	-5,7E-02	3,2E-01	10	1,0E-02
Tip radius Δr	r	mm		5,0E-04		1,0E-04	3,3E-09	-8,7E+03	-4,3E+00	2,5E-01	10	6,3E-03
Length of line of junction Δc	c	mm		5,0E-04		1,0E-04	3,3E-09	1,1E+04	5,5E+00	4,0E-01	10	1,6E-02
Total									**1,09**	3,1E+01		9,7E+01
Combined standard uncertainty $u(H)$										5,5E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty $U(H)$										**12,5**	**HV**	
Expanded standard uncertainty $U(H)+\|\Delta H\|$										**13,6**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**2,8**	**%**	
Hardness	**484,7**	**HV**										

KAZINMETR; hardness level 450 HV1

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force F	**F**	N	**9,81**	0,000	2,1E-02		4,4E-04	5,0E+01	0,0E+00	1,1E+00	8	1,5E-01
Indentation diagonal length	**d**	mm	**0,062**	0		0,00025	2,1E-08	-1,6E+04	0,0E+00	5,2E+00	9	3,0E+00
Plane angle α	α	°	136	8,7E-04	5,0E-03		2,5E-05	9,8E+01	8,6E-02	2,4E-01	10	5,9E-03
Tip radius Δr	r	mm		5,0E-04		1,0E-04	3,3E-09	-8,7E+03	-4,4E+00	2,5E-01	10	6,5E-03
Length of line of junction Δc	c	mm		5,0E-04		1,0E-04	3,3E-09	1,1E+04	5,5E+00	4,1E-01	10	1,7E-02
Total									**1,24**	7,2E+00		3,2E+00
Combined standard uncertainty $u(H)$										2,7E+00	ν_{eff}	16
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty $U(H)$										**5,7**	**HV**	
Expanded standard uncertainty $U(H)+\|\Delta H\|$										**6,9**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,4**	**%**	
Hardness	**486,8**	**HV**										

PTB; hardness level 450 HV1

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force F	**F**	N	**9,81**	0,000		0,0098	3,2E-05	5,0E+01	0,0E+00	7,9E-02	8	7,7E-04
Indentation diagonal length	**d**	mm	**0,062**	0		0,0004	5,3E-08	-1,6E+04	0,0E+00	1,3E+01	9	1,9E+01
Plane angle α	α	°	136	-8,7E-04		0,00175	1,0E-06	9,8E+01	-8,6E-02	9,8E-03	10	9,6E-06
Tip radius Δr	r	mm		3,0E-04		1,0E-04	3,3E-09	-8,7E+03	-2,6E+00	2,5E-01	10	6,3E-03
Length of line of junction Δc	c	mm		4,0E-04		1,0E-04	3,3E-09	1,1E+04	4,4E+00	4,0E-01	10	1,6E-02
Total									**1,71**	1,4E+01		1,9E+01
Combined standard uncertainty $u(H)$										3,7E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty $U(H)$										**8,3**	**HV**	
Expanded standard uncertainty $U(H)+\|\Delta H\|$										**10,0**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**2,1**	**%**	
Hardness	**486,0**	**HV**										

VNIIFTRI; hardness level 450 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000		0,017	9,6E-05	9,8E+00	0,0E+00	9,2E-03	8	1,1E-05
Indentation diagonal length	***d***	mm	**0,139**	0		0,0009	2,7E-07	-6,9E+03	0,0E+00	1,3E+01	9	1,8E+01
Plane angle α	α	°	136	-5,8E-04		0,01	3,3E-05	9,7E+01	-5,6E-02	3,1E-01	10	9,8E-03
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-3,8E+03	-1,9E+00	4,8E-02	10	2,3E-04
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	4,8E+03	2,4E+00	7,8E-02	10	6,0E-04
Total									**0,46**	1,3E+01		1,8E+01
Combined standard uncertainty *u (H)*										3,6E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**8,2**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**8,7**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,8**	**%**	
Hardness	**479,2**	**HV**										

KAZINMETR; hardness level 450 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000	4,5E-02		2,0E-03	9,7E+00	0,0E+00	1,9E-01	8	4,6E-03
Indentation diagonal length	***d***	mm	**0,140**	0		0,00057	1,1E-07	-6,8E+03	0,0E+00	5,1E+00	9	2,8E+00
Plane angle α	α	°	136	8,7E-04	4,9E-03		2,4E-05	9,6E+01	8,4E-02	2,2E-01	10	5,0E-03
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-3,8E+03	-1,9E+00	4,7E-02	10	2,2E-04
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	4,8E+03	2,4E+00	7,6E-02	10	5,8E-04
Total									**0,59**	5,6E+00		2,8E+00
Combined standard uncertainty *u (H)*										2,4E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**5,3**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**5,9**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,2**	**%**	
Hardness	**476,4**	**HV**										

BELGIM; hardness level 450 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000	1,5E-01		2,2E-02	9,8E+00	0,0E+00	2,1E+00	8	5,5E-01
Indentation diagonal length	***d***	mm	**0,139**	0		0,0003	3,0E-08	-6,9E+03	0,0E+00	1,4E+00	9	2,2E-01
Plane angle α	α	°	136	1,5E-03	5,0E-03		2,5E-05	9,7E+01	1,4E-01	2,3E-01	10	5,5E-03
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-3,8E+03	-1,9E+00	4,8E-02	10	2,3E-04
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	4,8E+03	2,4E+00	7,7E-02	10	6,0E-04
Total									**0,65**	3,9E+00		7,8E-01
Combined standard uncertainty *u (H)*										2,0E+00	ν_{eff}	19
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty *U (H)*										**4,1**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**4,8**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,0**	**%**	
Hardness	**478,9**	**HV**										

NSC IM; hardness level 450 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000	1,0E-03		1,0E-06	9,9E+00	0,0E+00	9,8E-05	8	1,2E-09
Indentation diagonal length	***d***	mm	**0,138**	0		0,00021	1,5E-08	-7,0E+03	0,0E+00	7,2E-01	9	5,8E-02
Plane angle α	α	°	136	-1,7E-03	5,1E-03		2,6E-05	9,8E+01	-1,7E-01	2,5E-01	10	6,2E-03
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-3,9E+03	-1,9E+00	5,0E-02	10	2,5E-04
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	4,9E+03	2,5E+00	8,0E-02	10	6,4E-04
Total									**0,35**	1,1E+00		6,5E-02
Combined standard uncertainty *u (H)*										1,0E+00	ν_{eff}	18
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty *U (H)*										**2,2**	**HV**	
Expanded standard uncertainty *U(H)+IΔHI*										**2,6**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**0,5**	**%**	
Hardness	**484,4**	**HV**										

PTB; hardness level 450 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000		0,0255	2,2E-04	9,7E+00	0,0E+00	2,1E-02	8	5,3E-05
Indentation diagonal length	***d***	mm	**0,139**	0		0,0007	1,6E-07	-6,9E+03	0,0E+00	7,7E+00	9	6,5E+00
Plane angle α	α	°	136	-8,7E-04		0,00175	1,0E-06	9,7E+01	-8,4E-02	9,5E-03	10	8,9E-06
Tip radius Δr	*r*	mm		3,0E-04		1,0E-04	3,3E-09	-3,8E+03	-1,1E+00	4,8E-02	10	2,3E-04
Length of line of junction Δc	*c*	mm		4,0E-04		1,0E-04	3,3E-09	4,8E+03	1,9E+00	7,7E-02	10	5,9E-04
Total									**0,70**	7,8E+00		6,5E+00
Combined standard uncertainty *u (H)*										2,8E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**6,3**	**HV**	
Expanded standard uncertainty *U(H)+IΔHI*										**7,0**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,5**	**%**	
Hardness	**477,6**	**HV**										

VNIIFTRI; hardness level 450 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**294,20**	0,000		0,1	3,3E-03	1,6E+00	0,0E+00	8,7E-03	8	9,4E-06
Indentation diagonal length	***d***	mm	**0,342**	0		0,0016	8,5E-07	-2,8E+03	0,0E+00	6,6E+00	9	4,8E+00
Plane angle α	α	°	136	-5,8E-04		0,01	3,3E-05	9,6E+01	-5,6E-02	3,1E-01	10	9,4E-03
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-1,5E+03	-7,6E-01	7,8E-03	10	6,1E-06
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	1,9E+03	9,7E-01	1,3E-02	10	1,6E-05
Total									**0,15**	6,9E+00		4,8E+00
Combined standard uncertainty *u (H)*										2,6E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**5,9**	**HV**	
Expanded standard uncertainty *U(H)+IΔHI*										**6,1**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,3**	**%**	
Hardness	**475,1**	**HV**										

KAZINMETR; hardness level 450 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force F	F	N	**294,20**	0,000	2,4E-01		5,8E-02	1,6E+00	0,0E+00	1,5E-01	8	2,9E-03
Indentation diagonal length	d	mm	**0,341**	0		0,001	3,3E-07	-2,8E+03	0,0E+00	2,6E+00	9	7,8E-01
Plane angle α	α	°	136	8,7E-04	4,9E-03		2,4E-05	9,7E+01	8,5E-02	2,3E-01	10	5,1E-03
Tip radius Δr	r	mm		5,0E-04		1,0E-04	3,3E-09	-1,6E+03	-7,8E-01	8,0E-03	10	6,4E-06
Length of line of junction Δc	c	mm		5,0E-04		1,0E-04	3,3E-09	2,0E+03	9,9E-01	1,3E-02	10	1,7E-05
Total									**0,30**	3,0E+00		7,9E-01
Combined standard uncertainty $u(H)$										1,7E+00	ν_{eff}	11
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty $U(H)$										**3,8**	**HV**	
Expanded standard uncertainty $U(H)+\|\Delta H\|$										**4,1**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**0,9**	**%**	
Hardness	**479,8**	**HV**										

BELGIM; hardness level 450 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force F	F	N	**294,20**	0,000	1,3E+00		1,6E+00	1,6E+00	0,0E+00	4,2E+00	8	2,2E+00
Indentation diagonal length	d	mm	**0,343**	0		0,0004	5,3E-08	-2,7E+03	0,0E+00	4,0E-01	9	1,8E-02
Plane angle α	α	°	136	1,5E-03	5,0E-03		2,5E-05	9,5E+01	1,4E-01	2,3E-01	10	5,2E-03
Tip radius Δr	r	mm		5,0E-04		1,0E-04	3,3E-09	-1,5E+03	-7,6E-01	7,6E-03	10	5,8E-06
Length of line of junction Δc	c	mm		5,0E-04		1,0E-04	3,3E-09	1,9E+03	9,6E-01	1,2E-02	10	1,5E-05
Total									**0,34**	4,9E+00		2,2E+00
Combined standard uncertainty $u(H)$										2,2E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty $U(H)$										**4,9**	**HV**	
Expanded standard uncertainty $U(H)+\|\Delta H\|$										**5,3**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,1**	**%**	
Hardness	**472,0**	**HV**										

NSC IM; hardness level 450 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force F	F	N	**294,20**	0,000	6,0E-03		3,6E-05	1,6E+00	0,0E+00	9,5E-05	8	1,1E-09
Indentation diagonal length	d	mm	**0,342**	0		0,00053	9,4E-08	-2,8E+03	0,0E+00	7,3E-01	9	5,9E-02
Plane angle α	α	°	136	-1,7E-03	5,1E-03		2,6E-05	9,6E+01	-1,7E-01	2,4E-01	10	5,8E-03
Tip radius Δr	r	mm		5,0E-04		1,0E-04	3,3E-09	-1,5E+03	-7,7E-01	7,9E-03	10	6,2E-06
Length of line of junction Δc	c	mm		5,0E-04		1,0E-04	3,3E-09	2,0E+03	9,8E-01	1,3E-02	10	1,6E-05
Total									**0,04**	9,9E-01		6,5E-02
Combined standard uncertainty $u(H)$										1,0E+00	ν_{eff}	15
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty $U(H)$										**2,1**	**HV**	
Expanded standard uncertainty $U(H)+\|\Delta H\|$										**2,2**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**0,5**	**%**	
Hardness	**476,9**	**HV**										

PTB; hardness level 450 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**294,20**	0,000		0,1500	7,5E-03	1,6E+00	0,0E+00	2,0E-02	8	4,8E-05
Indentation diagonal length	***d***	mm	**0,342**	0		0,0011	4,0E-07	-2,8E+03	0,0E+00	3,1E+00	9	1,1E+00
Plane angle α	α	°	136	-8,7E-04		0,00175	1,0E-06	9,6E+01	-8,4E-02	9,4E-03	10	8,8E-06
Tip radius Δr	*r*	mm		3,0E-04		1,0E-04	3,3E-09	-1,5E+03	-4,6E-01	7,8E-03	10	6,1E-06
Length of line of junction Δc	*c*	mm		4,0E-04		1,0E-04	3,3E-09	2,0E+03	7,8E-01	1,3E-02	10	1,6E-05
Total									**0,24**	3,2E+00		1,1E+00
Combined standard uncertainty *u (H)*										1,8E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**4,0**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**4,3**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**0,9**	**%**	
Hardness	**476,1**	**HV**										

VNIIFTRI; hardness level 750 HV1

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**9,81**	0,000		1,50E-02	7,5E-05	7,5E+01	0,0E+00	4,2E-01	8	2,2E-02
Indentation diagonal length	***d***	mm	**0,050**	0		0,0004	5,3E-08	-2,9E+04	0,0E+00	4,5E+01	9	2,3E+02
Plane angle α	α	°	136	-5,8E-04		0,01	3,3E-05	1,5E+02	-8,6E-02	7,3E-01	10	5,3E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-1,6E+04	-8,1E+00	8,7E-01	10	7,6E-02
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	2,0E+04	1,0E+01	1,4E+00	10	1,9E-01
Total									**2,02**	4,9E+01		2,3E+02
Combined standard uncertainty *u (H)*										7,0E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**15,5**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**17,6**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**2,4**	**%**	
Hardness	**732,6**	**HV**										

KAZINMETR; hardness level 750 HV1

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**9,81**	0,000	2,1E-02		4,4E-04	7,4E+01	0,0E+00	2,4E+00	8	7,4E-01
Indentation diagonal length	***d***	mm	**0,050**	0		0,00025	2,1E-08	-2,9E+04	0,0E+00	1,7E+01	9	3,3E+01
Plane angle α	α	°	136	8,7E-04	5,0E-03		2,5E-05	1,5E+02	1,3E-01	5,4E-01	10	2,9E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-1,6E+04	-8,0E+00	8,5E-01	10	7,3E-02
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	2,0E+04	1,0E+01	1,4E+00	10	1,8E-01
Total									**2,22**	2,2E+01		3,4E+01
Combined standard uncertainty *u (H)*										4,7E+00	ν_{eff}	14
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty *U (H)*										**10,2**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**12,4**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,7**	**%**	
Hardness	**727,7**	**HV**										

PTB; hardness level 750 HV1

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**9,81**	0,000		0,0098	3,2E-05	7,6E+01	0,0E+00	1,8E-01	8	4,2E-03
Indentation diagonal length	***d***	mm	**0,050**	0		0,0003	3,0E-08	-3,0E+04	0,0E+00	2,6E+01	9	7,7E+01
Plane angle α	α	°	136	-8,7E-04		0,00175	1,0E-06	1,5E+02	-1,3E-01	2,3E-02	10	5,2E-05
Tip radius Δr	*r*	mm		3,0E-04		1,0E-04	3,3E-09	-1,6E+04	-4,9E+00	9,0E-01	10	8,0E-02
Length of line of junction Δc	*c*	mm		4,0E-04		1,0E-04	3,3E-09	2,1E+04	8,3E+00	1,4E+00	10	2,1E-01
Total									**3,25**	2,9E+01		7,8E+01
Combined standard uncertainty *u (H)*										5,4E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**12,0**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**15,2**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**2,1**	**%**	
Hardness	**741,5**	**HV**										

VNIIFTRI; hardness level 750 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000		1,70E-02	9,6E-05	1,5E+01	0,0E+00	2,1E-02	8	5,8E-05
Indentation diagonal length	***d***	mm	**0,113**	0		0,0009	2,7E-07	-1,3E+04	0,0E+00	4,6E+01	9	2,3E+02
Plane angle α	α	°	136	-5,8E-04		0,01	3,3E-05	1,5E+02	-8,6E-02	7,3E-01	10	5,3E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-7,2E+03	-3,6E+00	1,7E-01	10	3,0E-03
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	9,1E+03	4,6E+00	2,8E-01	10	7,6E-03
Total									**0,88**	4,7E+01		2,3E+02
Combined standard uncertainty *u (H)*										6,8E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**15,5**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**16,4**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**2,2**	**%**	
Hardness	**732,0**	**HV**										

KAZINMETR; hardness level 750 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000	4,5E-02		2,0E-03	1,5E+01	0,0E+00	4,5E-01	8	2,5E-02
Indentation diagonal length	***d***	mm	**0,113**	0		0,00057	1,1E-07	-1,3E+04	0,0E+00	1,8E+01	9	3,7E+01
Plane angle α	α	°	136	8,7E-04	4,9E-03		2,4E-05	1,5E+02	1,3E-01	5,2E-01	10	2,7E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-7,1E+03	-3,6E+00	1,7E-01	10	2,9E-03
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	9,1E+03	4,5E+00	2,7E-01	10	7,5E-03
Total									**1,09**	2,0E+01		3,7E+01
Combined standard uncertainty *u (H)*										4,4E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**9,9**	**HV**	
Expanded standard uncertainty *U(H)+I ΔHI*										**10,9**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,5**	**%**	
Hardness	**729,4**	**HV**										

BELGIM; hardness level 750 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000	1,5E-01		2,2E-02	1,5E+01	0,0E+00	4,7E+00	8	2,8E+00
Indentation diagonal length	***d***	mm	**0,114**	0		0,0003	3,0E-08	-1,3E+04	0,0E+00	4,8E+00	9	2,6E+00
Plane angle α	α	°	136	1,5E-03	5,0E-03		2,5E-05	1,5E+02	2,1E-01	5,3E-01	10	2,8E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-7,0E+03	-3,5E+00	1,6E-01	10	2,7E-03
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	8,9E+03	4,4E+00	2,6E-01	10	6,9E-03
Total									**1,15**	1,0E+01		5,4E+00
Combined standard uncertainty *u (H)*										3,2E+00	ν_{eff}	20
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty *U (H)*										**6,7**	**HV**	
Expanded standard uncertainty *U(H)+IΔHI*										**7,9**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,1**	**%**	
Hardness	**718,8**	**HV**										

NSC IM; hardness level 750 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000	1,0E-03		1,0E-06	1,5E+01	0,0E+00	2,1E-04	8	5,8E-09
Indentation diagonal length	***d***	mm	**0,114**	0		0,00021	1,5E-08	-1,3E+04	0,0E+00	2,4E+00	9	6,2E-01
Plane angle α	α	°	136	-1,7E-03	5,1E-03		2,6E-05	1,5E+02	-2,5E-01	5,5E-01	10	3,0E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-7,0E+03	-3,5E+00	1,6E-01	10	2,7E-03
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	8,9E+03	4,4E+00	2,6E-01	10	6,9E-03
Total									**0,68**	3,3E+00		6,6E-01
Combined standard uncertainty *u (H)*										1,8E+00	ν_{eff}	16
Confidence level										95%		
Coverage factor										2,1		
Expanded standard uncertainty *U (H)*										**3,9**	**HV**	
Expanded standard uncertainty *U(H)+IΔHI*										**4,6**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**0,6**	**%**	
Hardness	**718,8**	**HV**										

PTB; hardness level 750 HV5

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**49,03**	0,000		0,0255	2,2E-04	1,5E+01	0,0E+00	4,9E-02	8	3,0E-04
Indentation diagonal length	***d***	mm	**0,112**	0		0,0007	1,6E-07	-1,3E+04	0,0E+00	2,8E+01	9	8,8E+01
Plane angle α	α	°	136	-8,7E-04		0,00175	1,0E-06	1,5E+02	-1,3E-01	2,2E-02	10	5,0E-05
Tip radius Δr	*r*	mm		3,0E-04		1,0E-04	3,3E-09	-7,2E+03	-2,2E+00	1,7E-01	10	3,0E-03
Length of line of junction Δc	*c*	mm		4,0E-04		1,0E-04	3,3E-09	9,2E+03	3,7E+00	2,8E-01	10	7,9E-03
Total									**1,37**	2,9E+01		8,8E+01
Combined standard uncertainty *u (H)*										5,3E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**12,1**	**HV**	
Expanded standard uncertainty *U(H)+IΔHI*										**13,5**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,8**	**%**	
Hardness	**735,9**	**HV**										

VNIIFTRI; hardness level 750 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**294,20**	0,000		1,00E-01	3,3E-03	2,4E+00	0,0E+00	2,0E-02	8	5,0E-05
Indentation diagonal length	***d***	mm	**0,278**	0		0,0016	8,5E-07	-5,2E+03	0,0E+00	2,3E+01	9	5,8E+01
Plane angle α	α	°	136	-5,8E-04		0,01	3,3E-05	1,5E+02	-8,5E-02	7,1E-01	10	5,0E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-2,9E+03	-1,4E+00	2,7E-02	10	7,3E-05
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	3,6E+03	1,8E+00	4,4E-02	10	1,9E-04
Total									**0,30**	2,4E+01		5,8E+01
Combined standard uncertainty *u (H)*										4,9E+00	ν_{eff}	9
Confidence level										95%		
Coverage factor										2,3		
Expanded standard uncertainty *U (H)*										**11,0**	**HV**	
Expanded standard uncertainty *U(H)+I Δ HI*										**11,3**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,6**	**%**	
Hardness	**719,7**	**HV**										

KAZINMETR; hardness level 750 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**294,20**	0,000	2,4E-01		5,8E-02	2,5E+00	0,0E+00	3,6E-01	8	1,6E-02
Indentation diagonal length	***d***	mm	**0,275**	0		0,001	3,3E-07	-5,3E+03	0,0E+00	9,4E+00	9	9,9E+00
Plane angle α	α	°	136	8,7E-04	4,9E-03		2,4E-05	1,5E+02	1,3E-01	5,3E-01	10	2,8E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-2,9E+03	-1,5E+00	2,9E-02	10	8,2E-05
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	3,7E+03	1,9E+00	4,6E-02	10	2,1E-04
Total									**0,53**	1,0E+01		1,0E+01
Combined standard uncertainty *u (H)*										3,2E+00	ν_{eff}	10
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**7,2**	**HV**	
Expanded standard uncertainty *U(H)+I Δ HI*										**7,7**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,1**	**%**	
Hardness	**733,2**	**HV**										

BELGIM; hardness level 750 HV30

Influencing quantity X_i	Symbol	Unit	Value	Δx_i	s_i	a_i	$u^2(x_i)$	c_i	ΔH	$u^2(y_i)$	ν_i	$u_i^4(y)/\nu_i$
Test force *F*	***F***	N	**294,20**	0,000	1,3E+00		1,6E+00	2,4E+00	0,0E+00	9,7E+00	8	1,2E+01
Indentation diagonal length	***d***	mm	**0,279**	0		0,0004	5,3E-08	-5,1E+03	0,0E+00	1,4E+00	9	2,2E-01
Plane angle α	α	°	136	1,5E-03	5,0E-03		2,5E-05	1,4E+02	2,1E-01	5,2E-01	10	2,7E-02
Tip radius Δr	*r*	mm		5,0E-04		1,0E-04	3,3E-09	-2,8E+03	-1,4E+00	2,7E-02	10	7,2E-05
Length of line of junction Δc	*c*	mm		5,0E-04		1,0E-04	3,3E-09	3,6E+03	1,8E+00	4,3E-02	10	1,9E-04
Total									**0,60**	1,2E+01		1,2E+01
Combined standard uncertainty *u (H)*										3,4E+00	ν_{eff}	11
Confidence level										95%		
Coverage factor										2,2		
Expanded standard uncertainty *U (H)*										**7,5**	**HV**	
Expanded standard uncertainty *U(H)+I Δ HI*										**8,1**	**HV**	
Relative Expanded standard uncertainty $U_{rel}(H)$										**1,1**	**%**	
Hardness	**716,7**	**HV**										

Appendix C.

Calculation of degrees of equivalence

The procedure of calculating equivalence degrees and uncertainties of calculating equivalence degrees is described in the Guidelines for data evaluation of COOMET key comparison. COOMET R/GM/14, 2006 document.

PTB laboratory was the linking laboratory in the comparisons.

The equivalence degree (d_i) for the i-th institute was calculated according to the formula:

$$d_i = x_i + \Delta - x_{ref} \qquad (1)$$

Where x_i - result of hardness measurement in regional comparisons (COOMET.M.H-K1) by the i-th laboratory, x_{ref} – KCRV CCM Vickers KC 2003, Δ - additive correction determined from the formula:

$$\Delta = x_i^{**} - x_i^{*} \qquad (2)$$

Where x_i^{**} - hardness value obtained by the linking laboratory in CCM Vickers KC 2003, x_i^{*} - hardness value obtained by the linking laboratory in COOMET.M.H-K1 comparisons. Tables 1, 2 show the calculation of equivalence degrees.

Table 1 – calculation of equivalence degrees for 450 HV hardness level

Institute	x_i, HV		Δ, HV		x_{ref}, HV		d_i, HV	
	HV1	HV30	HV1	HV30	HV1	HV30	HV1	HV30
VNIIFTRI	484,8	475,1	51,8	46,8	534,4	525,5	2,2	-3,6
KAZINMETR	486,8	479,7					4,2	1,0
BELGIM	-	471,8					-	-6,9
NSC IM	-	476,8					-	-1,9

Table 2 –calculation of equivalence degrees for 750 HV hardness level

Institute	x_i, HV		Δ, HV		x_{ref}, HV		d_i, HV	
	HV1	HV30	HV1	HV30	HV1	HV30	HV1	HV30
VNIIFTRI	732,6	720,5	94,3	98,4	831,4	819,4	-4,5	-0,5
KAZINMETR	727,7	732,9					-9,4	11,9
BELGIM	-	717,1					-	-3,9
NSC IM	-	728,0					-	7,0

The uncertainty of calculating equivalence degrees (U_d) is determined by the formula:

$$U_d^2 = u_x^2 + u_{ref}^2 + u_\Delta^2 \times \left(1 - \frac{u_{ref}^2}{u_{x_C^{**}}^2}\right) \qquad (3)$$

Where u_x – standard uncertainty of hardness measurement result in laboratory, u_{ref} - uncertainties of CCM Vickers KC, u_Δ - uncertainties of additive adjustment of connecting NIM (PTB)., $u_{x_C^{**}}$ - uncertainties of PTB in CCM Vickers KC.

Tables 3, 4 show the uncertainties of calculating equivalence degrees.

Table 3 – calculation of uncertainty of calculating equivalence degrees for 450 HV hardness level

Institute	u_x , HV		u_{ref}, HV		u_{Δ} , HV		$u_{x_c^{**}}$,HV		U_d, HV	
	HV1	HV30	HV1	HV30	HV1	HV30	HV1	HV30	HV1	HV30
VNIIFTRI	5,6	2,6	6,1	5,0	3,5	4,1	11,0	4,6	8,8	5,4
KAZINMETR	2,7	1,7							7,3	5,0
BELGIM	-	2,2							-	5,2
NSC IM	-	1,0							-	4,8

Table 4 – calculation of uncertainty of calculating equivalence degrees for 700 HV hardness level

Institute	u_x , HV		u_{ref}, HV		u_{Δ} , HV		$u_{x_c^{**}}$,HV		U_d, HV	
	HV1	HV30	HV1	HV30	HV1	HV30	HV1	HV30	HV1	HV30
VNIIFTRI	7,0	4,9	16,8	11,3	3,8	3,8	18,2	8.8	18,3	11,9
KAZINMETR	4,7	3,2							17,5	11,3
BELGIM	-	3,4							-	11,4
NSC IM	-	1,8							-	11,0

Table 5 – degrees of equivalence and uncertainty

Hardness test block	institutes							
	VNIIFTRI		KAZINMETR		BELGIM		NSC IM	
	d	U_d	d	U_d	d	U_d	d	U_d
450 HV1	2,2	8,8	4,2	7,3	-	-	-	-
750 HV1	-4,5	18,3	-9,4	17,5	-	-	-	-
450 HV30	-3,6	5,4	1,0	5,0	-6,9	5,2	-1,9	4,8
750 HV30	-0,5	11,9	11,9	11,3	-3,9	11,4	7	11,0

Inequation $|d| < 2U_d$ is held by all laboratories for all scales. The stated measurement uncertainties of all participants correlate with the comparisons data.

Pairwise equivalence degrees (d_{ij}) are determined by the formula:

$$d_{ij} = x_i - x_j \quad (4)$$

The uncertainty of the pairwise equivalence ($U_{d_{ij}}$) is determined by the formula:

$$U^2{}_{d_{ij}} = u_{x_i}^2 + u_{x_j}^2 - 2cov(X_i, X_j) \quad (5)$$

Where u_{x_i}, u_{x_j} - standard uncertainties in the i-th and j-th laboratories, X_i, X_j – arrays of hardness values in the i-th and j-th laboratories.

Table 6 Pairwise equivalence degrees for 450 HV1 hardness level

	VNIIFTRI	KAZINMETR
VNIIFTRI		-2
KAZINMETR	2	

Table 7 Uncertainties of calculating pairwise equivalence degrees for 450 HV1 hardness level

	VNIIFTRI	KAZINMETR
VNIIFTRI		6,1
KAZINMETR	6,1	

Table 8 Pairwise equivalence degrees for 750 HV1 hardness level

	VNIIFTRI	KAZINMETR
VNIIFTRI		4,9
KAZINMETR	-4,9	

Table 9 Uncertainties of calculating pairwise equivalence degrees for 750 HV1 hardness level

	VNIIFTRI	KAZINMETR
VNIIFTRI		8,6
KAZINMETR	8,6	

Table 10 Pairwise equivalence degrees for 450 HV30 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM
VNIIFTRI		-4,6	3,3	-1,7
KAZINMETR	4,6		7,9	2,9
BELGIM	-3,3	-7,9		-5
NSC IM	1,7	-2,9	5	

Table 11 Uncertainties of calculating pairwise equivalence degrees for 450 HV30 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM
VNIIFTRI		3,1	3,5	3,3
KAZINMETR	3,1		2,6	2,0
BELGIM	3,5	2,6		2,5
NSC IM	3,3	2,0	2,5	

Table 12 Pairwise equivalence degrees for 750 HV30 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM
VNIIFTRI		-12,4	3,4	-7,5
KAZINMETR	12,4		15,8	4,9
BELGIM	-3,4	-15,8		-10,9
NSC IM	7,5	-4,9	10,9	

Table 13 Uncertainties of calculating pairwise equivalence degrees for 750 HV30 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM
VNIIFTRI		6,3	6,5	6,1
KAZINMETR	6,3		4,5	2,5
BELGIM	6,5	4,5		3,8
NSC IM	6,1	2,5	3,8	

Table 14 Pairwise equivalence degrees for 450 HV5 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM	PTB
VNIIFTRI		2,8	0,3	-5,2	1,60
KAZINMETR	-2,8		-2,5	-8	-1,2
BELGIM	-0,3	2,5		-5,5	1,3
NSC IM	5,2	8	5,5		6,8
PTB	-1,60	1,2	-1,3	-6,8	

Table 15 Uncertainties of calculating pairwise equivalence degrees for 450 HV5 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM	PTB
VNIIFTRI		4,4	3,7	3,5	4,7
KAZINMETR	4,4		3,3	2,9	3,5
BELGIM	3,7	3,3		2,0	3,9
NSC IM	3,5	2,9	2,0		3,3
PTB	4,7	3,5	3,9	3,3	

Table 16 Pairwise equivalence degrees for 750 HV5 hardness level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM	PTB
VNIIFTRI		2,6	13,2	13,2	-3,9
KAZINMETR	-2,6		10,6	10,6	-6,5
BELGIM	-13,2	-10,6		0	-17,1
NSC IM	-13,2	-10,6	0		-17,1
PTB	3,90	6,5	17,1	17,1	

Table 17 Uncertainties of calculating pairwise equivalence degrees for 750 HV5 level

	VNIIFTRI	KAZINMETR	BELGIM	NSC IM	PTB
VNIIFTRI		8,5	7,6	6,9	9,0
KAZINMETR	8,5		5,6	6,7	5,9
BELGIM	7,6	5,6		2,3	6,2
NSC IM	6,9	6,7	2,3		6,9
PTB	9,0	5,9	6,2	6,9	